
Paul Swamidass, Auburn University

Available at: https://works.bepress.com/paulswamidass/7/
Modeling the adoption rates of manufacturing technology innovations by small US manufacturers: a longitudinal investigation

Paul M. Swamidass

Thomas Walter Center for Technology Management, Auburn University, Tiger Drive, Room 314, Auburn, AL 36849-5358, USA

Received 31 August 2000; received in revised form 1 December 2001; accepted 1 December 2001

Abstract

This study provides conclusive evidence to support the view that small plants are slower than larger plants to adopt manufacturing innovations. This empirical study based on over 1000 US manufacturing plants engaged in producing discrete products, studies the adoption of manufacturing technologies in small plants relative to large plants between 1993 and 1997.

Under the assumption that small manufacturers are disadvantaged, several federal and state programs have been created to assist small manufacturers in acquiring and adopting manufacturing innovations. Through quantification of technology adoption in small manufacturing firms, this study’s findings reveal which manufacturing innovations are in greater need of governmental assistance programs. While small plants are making progress over time in catching up with larger plants in computerized technology use, they are not making similar progress in adopting manufacturing technology innovations in soft technologies. Several propositions for future research and recommendations for public policy are offered.

© 2002 Elsevier Science B.V. All rights reserved.

Keywords: Computerized technologies; Innovations in manufacturing; Large and small plants; Manufacturing technology adoption; Small plant manufacturing technology adoption ratio (SPMTAR); Soft technologies

1. Introduction

Small manufacturing firms are vital to the US economy. For example, over 70% of all manufacturing plants in the industries conforming to Standardized Industrial Classifications (SICs) 34–38 (a description of these industries in the Standardized Industrial Classification of the US Department of Commerce appears later) are small plants with less than 100 employees; there are over 30,000 such small plants in these industries (Bureau of Census, 1993). Yet, small manufacturing firms, which are in a majority in this country, are at a disadvantage. Consider this:

Most of the literature on competitive strategy—from the fields of business strategy, marketing and industrial organization economics—has focused on the advantage of large firms and high market share. . . (Fiegenbaum and Kirnani, 1991; p. 101).

Swamidass (2000a) found that more than 67% of US manufacturers report manufacturing cycle time reduction, manufacturing cost reduction, product line increase and ROI increase as a result of manufacturing technology use. Literature records that larger plants
use more manufacturing technologies than small plants (Swamidass and Kotha, 1998; p. 31). The focus of this study is to estimate how much small plants lag behind larger plants in manufacturing technology use.

2. Research background

Since advanced manufacturing technology adoption is one form of innovative activity of the firm, let us consider the literature on the subject. The study of firm size upon innovative activity in the form of innovative effort and innovative success has a long history and has a classical tone to it (Schumpeter, 1934). One debate central to this issue surrounds the question, “Which is more innovative—the small firm or the larger one in regards to the use of new manufacturing technologies?” Let us consider the evidence in regards to manufacturing technology use.

First, in a study of JIT use (JIT is one of the soft technologies investigated in this study) among small as well as larger plants in the US, White et al. (1999) covered manufacturers, who are members of the Association for Manufacturing Excellence (AME). They compared small manufacturers (employment <250) to larger manufacturers (employment >1000). Using a sizable sample of 454 responses, they concluded that “JIT implementations are more common and more advanced in large US manufacturers than in small;...” (p. 1).

Second, Swamidass and Kotha (1998) studied the relationship between manufacturing technology use and size using survey and secondary data from 160 firms from industries covered by SIC 34–38 listed in the Compustat database (produced and marketed by the Standard and Poor’s Corporation, Englewood, CO). They studied the use of four groups of technologies and found that the use of the following three groups of technologies “increases with size” (p. 32).

1. Seven information exchange and planning technologies, which include LAN, computers used for factory control, computers for production planning, EDI, MRP and MRP II, and inter-company networks.
2. Five automation technologies for high-volume production, which include computer-aided quality control, computer-aided inspection, robots, and manufacturing-automation protocol.
3. Four flexible automation technologies for low-volume production, which include NC/CNC machines, programmable controllers, CAD/CAM, and FMC/FMS.

Swamidass and Kotha (1998) report that compared to other groups in the list above, flexible automation technology in low-volume production “grows faster... with increase in firm size. This may be due to the generally capital intensive nature of items such as FMS...” (p. 32). To date, Swamidass and Kotha (1998) provide the most robust findings concerning the increased use of a variety of technologies (16 in all) with size. Their study provides fairly strong evidence that larger manufacturers use more technologies and with greater sophistication.

Third, Acs and Audretsch (1990) found that the “relatively high cost of NC machines explains both their slow rate of diffusion as well as the bias in diffusion rates towards large firms” (p. 109).

Fourth, using Canadian firms, Globerman (1975) confirmed the findings of Mansfield et al. (1971) that the probability of adopting NC machines was positively related to firm size.

Finally, using samples of over 1000 plants, Swamidass (1996, 2000a) studied the use of 15 technologies (1996) and 17 technologies (2000a) and found that small plants used fewer manufacturing technologies in both instances. His explanation for this phenomenon is as follows.

- Small plants may need assistance to understand the use and benefits of new technologies.
- The training expense may hold back small plants from investing in manufacturing technologies.
- Funds for investment may be more difficult to obtain.

In summary, the foregoing illustrates the consistency of evidence that small plants do not use manufacturing technologies as much as larger plants, and do not use them with the same level of sophistication. Below is a tabulated summary of very recent studies comparing technology use in small and larger plants.
A summary of recent studies of technology use in small versus larger firms

<table>
<thead>
<tr>
<th>Study</th>
<th>Technologies studied</th>
<th>Sample size</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swamidass (1996)</td>
<td>15 Technologies</td>
<td>1041</td>
<td>Small plants use fewer technologies</td>
</tr>
<tr>
<td>Swamidass and Kotha (1998)</td>
<td>19 Technologies</td>
<td>160</td>
<td>Technology use increases with size</td>
</tr>
<tr>
<td>White et al. (1999)</td>
<td>JIT use only</td>
<td>454</td>
<td>JIT implementation is more common in larger plants</td>
</tr>
<tr>
<td>Swamidass (2000a)</td>
<td>17 Technologies</td>
<td>1025</td>
<td>Small plants use fewer technologies</td>
</tr>
</tbody>
</table>

2.1. Purpose of the study

This study’s focus is not merely to confirm if small plants use less technology or lag larger plants in the use of technologies but to venture into something never investigated before.

1. Estimate and quantify the extent of the lag in technology use with regard to 14 different computerized and soft technologies.
2. Determine the effect of time on the lag in technology adoption by small plants vis-à-vis larger plants, that is to determine if small plants are closing the gap faster in certain technologies as opposed to others.

2.2. The significance of this study

Technology use has contributed to the competitiveness of US manufacturers (Swamidass, 2000c, 2002). Therefore, it is important to understand why and by how much small manufacturers lag their larger counterparts. Further, unlike previous studies (Bureau of Census, 1991, 1993), this study makes a distinction between “computerized” and “soft technologies” (Swamidass, 1994, 1996, 2000a; also see definition of the various technologies in the glossary in Appendix A).

Computerized technologies are hardware and software intensive, while soft technologies are techniques, procedures, and know-how, which may or may not need computer hardware and software. MRP and MRP II (or ERP in current terminology) are essentially planning/scheduling techniques or information technologies, which are also dependent on computer hardware and software. Examples of soft technologies included in this study are JIT and SPC.

2.3. Public policy issues

Small manufacturing plants frequently receive attention from policy makers who channel funds for enhancing their technology base through state and federally funded technology centers. NIST, through its Manufacturing Extension Partnership, funds and oversees manufacturing extension centers in more than 40 states and Puerto Rico to serve small and mid-sized manufacturers; more centers are being planned (Federal Technology Report, 1996).

Franks and Meehan (1994–1995), bi-partisan co-chairs of the Manufacturing Task Force, a project of the Northeast-Midwest Congressional Coalition express the interest of policy makers on this subject: “Unfortunately, many small and mid-sized manufacturers cannot obtain the capital they need to modernize equipment or expand their production.” “Established large manufacturers have an advantage in the capital markets because they can turn to the bond and commercial paper arenas. In practice, these avenues are closed to small and new manufacturers” (p. 50).

2.4. An index of small plant technology adoption

In this study, in order to quantitatively estimate the lag in technology use in small plants relative to larger plants, the following ratio is used as an index:

Small plant manufacturing technology adoption ratio (SPMTAR) = \frac{\text{percent of small plants using a technology}}{\text{percent of large plants using the same technology}}

SPMTAR is a ratio that can be computed for each individual technology such as CAD, JIT, etc. In theory,
when a technology is used by larger plants, the ratio could take on any value greater than zero. When SPMTAR = 0, it indicates small plants do not use the said technology. When SPMTAR = 1, the percent of small plants using a technology is identical to the percent of large plants using the technology. When SPMTAR > 1, the percent of small plants using a technology exceeds the percent of large plants using the same. However, in reality, it is less than 1.0. There is not even anecdotal evidence of the ratio exceeding 1.0. An SPMTAR value of 0.86 means that when 100% of large plants use a certain technology, only 86% of small plants use the same technology; currently, there exists no equivalent index to compare small plants’ use of technology with large plants across different technologies.

Thus, when SPMTAR for a number of technologies are compared, a researcher or policy maker could easily see the technologies whose adoption rates in small plants are worse than the adoption rate for other technologies. For example, an SPMTAR value of 0.9 for technology A, and an SMPTAR value of 0.3 for technology B would indicate that the small plants are lagging severely behind large plants, in the case of technology B.

3. Methods

3.1. Technologies studied

We classify manufacturing technologies into two groups, computerized and soft technologies (Appendix A). Today, computerized technologies are a complex bundle of equipment, computer hardware and software (Swamidass, 1996, 2000a). For example, CNC, CAD, CAM, CIM, LAN, MRP, MRPII, AI, robots, AGV and FMS are computerized technologies included in this study (see glossary for a description of manufacturing technology terms and abbreviations). In contrast, soft technologies are manufacturing techniques and know-how such as JIT, TQM, MC, and SQC—equipment and computers are not essential to their successful use, but may enhance their effectiveness. The technologies investigated in this study cover most of the computerized technologies covered by the US Bureau of Census (BOC) study (1991, 1993) plus some not covered by the BOC study. Further, all soft technologies investigated here are not covered by the BOC study.

3.2. Sample

This study investigated technology use in discrete products manufacturing industries covered by SIC 34–38 (see the following sections for a description of these industries). These industries are often grouped together in manufacturing technology studies because the processes they use are similar while their products may be very different (Bureau of Census, 1991, 1993). While the BOC studies included SIC 39 (miscellaneous manufacturing), the present study did not include SIC 39 because it covered relatively fewer plants and the products of this industry had less in common with the manufacturing processes of the other industries included.

SIC 34–38 produce discrete products as opposed to commodity products such as gasoline, sugar, chemicals, and the like. The industries covered by the study represent over 40% of US employment and value added in the entire US manufacturing sector (Bureau of Census, 1993). The industries covered in this classification are as follows.

- SIC 34: Manufactures metal, except machinery.
- SIC 35: Industrial and commercial machinery, computer equipment.
- SIC 36: Electrical, other electrical equipment.
- SIC 37: Transportation equipment.
- SIC 38: Measurement instruments, photo goods, watches.

3.3. Data and questionnaire

Data were collected from manufacturing plants (as opposed to firms) by using similar survey questionnaires in 1993 and 1997 (Swamidass, 1994, 1998). The questionnaire was first developed and improved after a pilot study conducted in 1990 in which 385 manufacturers participated. The part of the questionnaire used to collect data on technology use in 1997 is in Appendix B. In the 1997 questionnaire, the respondents were asked to rate their plant’s skill level in the use of 21 different technologies (with each survey administration, the questionnaire is updated to reflect new technologies in use. Thus, data were collected
in 1993 on only 14 of the technologies and in 1997, questionnaire in Appendix B, therefore, the longitudinal investigation covers the use of 14 technologies over time.

For this study, a plant was considered a “user” of a technology if the plant indicated the use of the technology at any of the three skill levels indicated in the questionnaire (Appendix B). A plant that indicates “do not use” against a technology is considered a non-user of the technology. This approach to measuring technology use is similar to at least two reported in the literature.

The first is by White et al. (1999). They asked their respondents when the implementation of 10 components of JIT was started in their plant. The options given to respondents were: not implemented; 0–1; 1–3; 3–5; and >5 years. They converted these responses to either “implemented” or “not implemented” for the said JIT techniques. The results of White, Pearson and Wilson are used to validate some of the findings of this study later in this paper. Second, in the study of technology use and performance by Garsombke and Garsombke (1989), they presented 30 different technologies to respondents, who were asked to check the technologies they use.

The survey questionnaire on manufacturing technology use was first mailed in summer/fall of 1993 to all 4453 members of National Association of Manufacturers (NAM), who belong to the SIC classifications 34–38. Since technology use within the various plants of a single firm may vary substantially between plants due to the nature of products produced, the age of the plant, etc. the questionnaire requested multi-plant manufacturers to provide data from any one of their plants.

3.3.1. Non-response bias—1993 data

To examine non-response bias, if any, a split sample was developed. The first sample consisted of 556 responses and the second 565 responses for a total of 1121 responses; the response rate being 25.8% including 25 unusable responses and 3 that arrived after the cut-off date. Among the respondents, 53.2% were from small plants (employment < 100). The BOC estimates small plants with less than 100 employees to be about 71% of all plants in these industries (Swamidass, 1996). The comparison of the split samples showed no particularly strong bias in the data.

Of the 1121 responses, 79 that did not belong to SIC 34–38 were excluded from further analyses, resulting in a sample of 1042 plants. Responses were from the top management of plants; 86% of the respondents reported their titles to be vice-president or higher including owner, chief executive officer, president, etc.

3.4. 1997 Data

A similar questionnaire was mailed out to NAM members in the summer/fall of 1997 (Swamidass, 2000a). A total of 1025 responses were usable for a response rate of 21.4% (details in Swamidass, 1998). Small plants with less than 100 employees were 57.1% (53.2% in 1993) of the respondents; in this regard the 1993 and 1997 samples are similar. Once again, the split samples showed no strong bias in the data.

4. Findings

The findings are reported as follows. First, plant characteristics are presented for 1993. Since plant characteristics data for 1997 is similar to 1993, it is not included. Second, technology adoption rates in small plants as captured by the index SPMTAR (the focus of this study) is then reported for 1993 and 1997.

4.1. Plant characteristics (1993 data)

Data from the 1993 survey show that there is an unambiguous, systematic difference between small and large plants in the use of manufacturing innovations. Table 1 permits the comparison of small and large plants on different characteristics. The data in Table 1 is presented in four groups of variables: (1) size parameters; (2) significantly different variables; (3) similar variables; and (4) performance variables. Size parameters include employment and sales. According to the table, large plants are 9.6 times larger than small plants (443 and 46 employees, respectively) in terms of employment and 16.3 (US$ 87.2 millions for large and US$ 5.35 millions for small) times larger in terms of sales.

Table 1 shows that plant size has no impact on inventory turns and the number of product lines. However, size has a significant impact on the investment recovery time, lead time in weeks, production to stock,
Table 1
A comparison of small and larger plant characteristics 1993

<table>
<thead>
<tr>
<th>Item</th>
<th>Small</th>
<th>Large</th>
<th>t-statistic</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Employment—average</td>
<td>46</td>
<td>443</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>(2) Sales (US$ million)—average</td>
<td>5.35</td>
<td>87.2</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Significantly different variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) Investment recovery (months)</td>
<td>32.5 (407)</td>
<td>27.7 (406)</td>
<td>4.40</td>
<td>0.0001</td>
</tr>
<tr>
<td>(4) Average lead time (weeks)</td>
<td>6.19 (514)</td>
<td>7.92 (426)</td>
<td>–2.89</td>
<td>0.0025</td>
</tr>
<tr>
<td>(5) Production to stock (% of total)</td>
<td>18.9 (371)</td>
<td>23.4 (378)</td>
<td>–1.94</td>
<td>0.05</td>
</tr>
<tr>
<td>(6) Models</td>
<td>71.5 (294)</td>
<td>143 (214)</td>
<td>–1.9</td>
<td>0.05</td>
</tr>
<tr>
<td>(7) Number of components for typical product</td>
<td>162 (415)</td>
<td>366.5 (390)</td>
<td>–3.9</td>
<td>0.0004</td>
</tr>
<tr>
<td>Similar variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(8) Inventory turns</td>
<td>8.27 (410)</td>
<td>7.77 (423)</td>
<td>0.72</td>
<td>0.47</td>
</tr>
<tr>
<td>(9) Product lines</td>
<td>23.7 (376)</td>
<td>23.5 (366)</td>
<td>0.03</td>
<td>0.07</td>
</tr>
<tr>
<td>Performance variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(10) Sales/employee (US$ in thousands)</td>
<td>114 (522)</td>
<td>144 (417)</td>
<td>–4.42</td>
<td>0.0001</td>
</tr>
<tr>
<td>(11) Return on investment (%)</td>
<td>11.5 (446)</td>
<td>14.7 (372)</td>
<td>–3.52</td>
<td>0.0004</td>
</tr>
<tr>
<td>(12) Direct labor (% of sales)</td>
<td>21.5 (458)</td>
<td>14.7 (397)</td>
<td>7.04</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

Sample size in parentheses.

number of models produced, and number of components in a typical product. One inference is that larger plants make twice as many models (143 versus 71.5; \( P = 0.05 \)) with many more components, which may explain the longer lead time reported by larger plants (7.92 versus 6.19; \( P = 0.002 \)).

According to Table 1, larger plants produce a greater proportion of their output to stock (23.4% versus 18.9; \( P = 0.05 \)) than small plants. This finding implies less custom production and perhaps more automation in larger plants.

Table 1 reveals that large plants are superior in productivity (sales per employee US$ 144,000 versus US$ 114,000), in return on investment (14.7% versus 11.5%), and direct labor (14.7% versus 21.5% of sales for small plants).

4.2. Investment recovery time is longer for small plants (1993 data)

Large plants report a shorter time for investment recovery than smaller plants (27.7 months versus 32.5 months; \( P = 0.0001 \)). This could mean that larger plants are able to recover the capital invested in equipment sooner than smaller plants; a definite advantage for larger plants when it comes to investing in capital intensive equipment; this confirms the concerns expressed by Franks and Meehan (1994–1995). This means that small plants must allow more time to recover investments in technologies. This provides one explanation for the slower investments in technologies in small plants.

Smaller plants may allow a longer recovery time (about 5 months longer than large plants) perhaps because they are getting a lower return from their investments. If this were true, small manufacturers would be investing more cautiously and more slowly than larger plants. This also confirms the concerns of Franks and Meehan (1994–1995) discussed earlier in the section on public policy issues.

4.3. Significantly higher adoption of manufacturing technologies in larger plants (1993 data)

A comparison of technology use in small and larger plants is displayed in Table 2. According to the table, small plants use 5.4 technologies on an average, while larger plants use 9 technologies (out of a possible 15 technologies). When small and larger plants are compared on the basis of a weighted sum of technologies used (Table 2; skilled use is weighted more), the difference is 10:18.3 in favor of the larger plants. Clearly, larger plants report more use of technologies and more skilled use of technologies. On the average,
Table 2

<table>
<thead>
<tr>
<th>Items of comparison</th>
<th>Small plants (employees &lt; 100)</th>
<th>Larger plants</th>
<th>t-statistic</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of technologies used</td>
<td>5.4</td>
<td>9.0</td>
<td>−18.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Number of technologies used with extreme skill</td>
<td>1.2</td>
<td>2.6</td>
<td>−9.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Number of benefits due to technology use reported</td>
<td>3.7</td>
<td>5.0</td>
<td>−7.97</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Weighted sum of technologies used &lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.0</td>
<td>18.3</td>
<td>−15.7</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

<sup>a</sup> Weights: extremely skilled use = 3; moderately skilled use = 2; uses the technology = 1.

small plants are extremely skilled in the use of 1.2 technologies, while larger plants are extremely skilled in the use of 2.6 technologies ($t = −9.8; P < 0.001$).


4.4.1. Computerized technology adoption rate in small plants

Fig. 1 shows SPMTAR for 1993 and 1997 for computerized technologies. In the figure, the SPMTAR for CAD for 1993 is 0.793, i.e. if we assume 100% of larger plants use CAD, only 79.3% of small plants use CAD. This ratio improves to 0.847 by 1997. This means that small plants are closing the gap in the use of CAD. In the case of robots, in the year 1993, if we assume 100% of larger plants use robots, only 25.4% of small plants do so but it improves to 0.352 by 1997. Relative to CAD, the penetration of robot use in small plants in 1993 is less than one third (79.2–25.4%).

Fig. 1 is valuable because it shows an increase in SPMTAR for computerized technology since 1993 in every technology except FMS (SPMTAR dropped 35%) and MRP II (SPMTAR dropped 8.1%). The initial cost of FMS, unfavorable experience with FMS, and unsuitability of the technology for small firms are reasons which may have caused the SPMTAR for FMS to shrink between 1993 and 1997. While
Table 3
Change in computerized technology usage in small plants from 1993 to 1997

<table>
<thead>
<tr>
<th>Technology used</th>
<th>A</th>
<th>B</th>
<th>B − A</th>
<th>(B − A)/A</th>
<th>Change since 1993 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robots (of all kinds)</td>
<td>0.254</td>
<td>0.352</td>
<td>0.098</td>
<td>0.386</td>
<td>38.6</td>
</tr>
<tr>
<td>AI</td>
<td>0.347</td>
<td>0.424</td>
<td>0.077</td>
<td>0.222</td>
<td>22.2</td>
</tr>
<tr>
<td>CIM</td>
<td>0.456</td>
<td>0.448</td>
<td>0.012</td>
<td>0.027</td>
<td>2.7</td>
</tr>
<tr>
<td>FMS</td>
<td>0.446</td>
<td>0.289</td>
<td>−0.157</td>
<td>−0.322</td>
<td>−35.2</td>
</tr>
<tr>
<td>LAN</td>
<td>0.588</td>
<td>0.499</td>
<td>0.089</td>
<td>0.188</td>
<td>18.8</td>
</tr>
<tr>
<td>CAM</td>
<td>0.689</td>
<td>0.713</td>
<td>0.024</td>
<td>0.035</td>
<td>5.5</td>
</tr>
<tr>
<td>CNC</td>
<td>0.767</td>
<td>0.644</td>
<td>0.123</td>
<td>0.194</td>
<td>26.7</td>
</tr>
<tr>
<td>CAD</td>
<td>0.703</td>
<td>0.847</td>
<td>0.144</td>
<td>0.205</td>
<td>28.4</td>
</tr>
<tr>
<td>MRP I</td>
<td>0.467</td>
<td>0.506</td>
<td>0.039</td>
<td>0.068</td>
<td>14.5</td>
</tr>
<tr>
<td>MRP II</td>
<td>0.396</td>
<td>0.339</td>
<td>−0.057</td>
<td>−0.141</td>
<td>−36.4</td>
</tr>
<tr>
<td>Average 1</td>
<td>0.517</td>
<td>0.548</td>
<td>0.031</td>
<td>0.059</td>
<td>11.7</td>
</tr>
<tr>
<td>Average 2</td>
<td>0.524</td>
<td>0.576</td>
<td>0.052</td>
<td>0.100</td>
<td>19.0</td>
</tr>
</tbody>
</table>


The reason is yet to be determined, FMS use in small plants w.r.t. larger plants has declined. The average increase in SPMTAR for computerized technologies is 6.7% (average 1, Table 3); however, without considering FMS, the increase is much greater at 11.4% (average 2, Table 3).

The reasons for the drop in the use of MRP II (or ERP) may have to do with the well-known difficulties associated with the implementation of this technology. In a recent in-depth study, Swamidass (2000b) reported that a midsize company in the US spent multimillion dollars to implement ERP only to drop it after about 2 years—the relationship with the software vendor ended in a legal dispute.

Fig. 1 and Table 3 provide concrete evidence that SPMTAR for computerized technology is improving gradually over time. Evidently, an increasing SPMTAR with time shows that small plants are catching up with large plants in the use of manufacturing technologies. In other words, Fig. 1 and Table 3 provide evidence that there is a time lag between large and small plants in the use of computerized technologies. According to Table 3, SPMTAR for robots (+38.6%), AI (+22.2%) and LAN (+18.8%) show the greatest increase between 1993 and 1997 i.e. small plants are more rapidly closing the gap in these technologies than the other technologies. The average SPMTAR for robots, AI and LAN in 1993 were 0.396, whereas the average SPMTAR for the other technologies in 1993 was 0.676.

In Fig. 1, we see that the greatest increase in SPMTAR occurred between 1993 and 1997 in those technologies which had a much lower SPMTAR in 1993. Thus, once SPMTAR approaches 1 (the percent of small plants using a technology equals large plants), the rate of increase in SPMTAR slows down. It is notable that in Table 3, we do not find a single technology for which SPMTAR = 1; i.e. the adoption of technologies by small plants does not equal large plants in any of the technologies investigated.

4.4.2. Soft technology adoption rates in small plants

Compared to Fig. 1, Fig. 2 presents a very different picture. In Fig. 2, the SPMTAR for soft technology shows minor increases between 1993 and 1997 for MC. However, SPMTAR shows minor decreases for JIT, TQM, and SQC. When all four technologies in Fig. 2 are considered, the average change since 1993 is less than 1% (Table 4). SPMTAR for MC alone showed an increase of 8.3% (Table 4) since 1993. That is, by and large, SPMTAR for soft technologies are not catching up with large plants, while SPMTAR for computerized technologies is showing a trend towards catching up with larger plants.

4.5. Validation

External validity of a study is established when its findings match similar studies from the field. White et al. (1999) studied the use of 10 different JIT
Table 4
Change in SPMTR (soft technology; 1993–1997)

<table>
<thead>
<tr>
<th>Technology used</th>
<th>A</th>
<th>B</th>
<th>B − A</th>
<th>(B − A)/A</th>
<th>Change since 1993 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JIT variations in JIT</td>
<td>0.746</td>
<td>0.738</td>
<td>−0.008</td>
<td>−0.011</td>
<td>−1.1</td>
</tr>
<tr>
<td>TQM</td>
<td>0.662</td>
<td>0.638</td>
<td>−0.024</td>
<td>−0.036</td>
<td>−3.6</td>
</tr>
<tr>
<td>SQC</td>
<td>0.657</td>
<td>0.625</td>
<td>−0.032</td>
<td>−0.048</td>
<td>−4.8</td>
</tr>
<tr>
<td>Manufacturing Cells</td>
<td>0.532</td>
<td>0.525</td>
<td>−0.007</td>
<td>0.013</td>
<td>2.5</td>
</tr>
<tr>
<td>Average</td>
<td>0.649</td>
<td>0.634</td>
<td>−0.015</td>
<td>−0.023</td>
<td>−3.5</td>
</tr>
</tbody>
</table>


techniques in US manufacturing plants; their survey was conducted prior to 1992. They reported that, regardless of size, an average of 70.8% of respondents to their study reported the use of the various JIT techniques (70.8 is the average of the average use of 10 different JIT techniques by small and large plants in Table 2, p. 7; White et al., 1999). The average use by 70.8% is similar to the findings of the 1993 survey reported here, which found that 71% of respondents used JIT, regardless of plant size. A comparison of technology use in small versus small, and large versus large plants between the two studies is not possible because the definitions of small and large plants are different in the two studies. Since the two studies used different measures as well as samples to arrive at similar answers, the studies validate each other.

5. Discussion and conclusions

This study provides conclusive evidence and joins a vast body of prior literature that testifies to the fact
that small plants lag larger plants in manufacturing technology use. In the context of this finding, this discussion section has two major goals. Although being small has its own advantages, we know that small plants lag larger plants in technology use. The following discussion focuses on why small firms might lag larger plants.

5. Why do small plants lag larger plants in technology use?

5.1. Inherent advantage of largeness is insurmountable

Based on field evidence, it appears that the inherent advantages of largeness are insurmountable advantages for larger firms. This may explain why, in every technology considered in this study, small firms lag their larger counterparts. White et al. (1999) offer an insight into one aspect of the problem. They note that small manufacturers may inherently lack the clout to influence their suppliers to meet JIT delivery and quality requirements. On the other hand, the clout of large auto assemblers such as GM, Ford and Volkswagen has required their JIT suppliers to meet not only stringent delivery and quality standards but also required them to reduce costs at the rate of 5 or 10% a year. This is an example of how the successful implementation of soft technologies is dependent on more than economic resources and how small firms are at a disadvantage even though the implementation of certain soft technologies may not call for high initial capital investment.

5.1.2. Large firms have systemic and entrenched advantages

Because small manufacturers lag large ones in the use of all 14 technologies investigated here, it is right to say that small plants do not lag the larger ones because of the contingent inappropriateness of certain innovations. Therefore, it appears that the problem of small manufacturers vis-à-vis larger manufacturers is more systemic and entrenched.

5.1.3. Management styles discount the inherent advantages of smallness

Chell and Haworth (1988) report that small firms have one of three types of management styles, which have profound influence on the company’s investment in new technology. The three styles of management are as follows:

1. Entrepreneurially managed small firms—these firms are the most innovative.
2. Owner-managed small firms—concerned with mere survival and lack of interest in new ideas.
3. Professionally managed small firms—most cautious and unwilling to take risks.

If we use Chell and Haworth’s model, the advantages of small manufacturers in the list presented earlier in this paper may not accrue to all small firms but only to the entrepreneurially managed small firms. According to this line of thinking, owner-managed and professionally managed small firms lag in technology use. Since most small firms are not entrepreneurially managed, it may explain the repeated findings in literature that small plants lag larger plants in technology use. This explanation deserves further investigation in the future.

5.1.4. Small firm use of technology is constrained by the lack of technical specialists and capital

Lee (1991) and Swamidass (2000a) mention that the lack of “specialist technical knowledge” or know-how in small firms takes away a vital stimulus for change in small firms. Further, based on evidence from JIT implementations, White et al. (1999) say that “…US businessmen’s understanding of issues associated with JIT implementations in large manufacturers is more developed than that of small manufacturers” (p. 1). The lack of funds/capital, which limits investments in technology, may also limit the access of small firms to technical specialists to study, evaluate and implement new technologies.

5.2. A summative model to explain the lag in technology use in small plants

The above discussions are summarized in Fig. 3. The figure (not to scale) uses a summative model to explain why the use of technology in small firms lags larger firms. According to the model in the figure, the level of technology use in small firms (Y) can be explained by the level of technology use in larger firms (X), the management style (a—which could be positive or negative), lack of technical know-how (b),...
lack of funds \((c_i)\), other negative factors \((d_i)\) and other positive factors \((e_i)\). Accordingly we get

\[
Y_t = X_t + a_i - b_i - c_i - d_i' + e_i
\]

In Fig. 3, the top line is representative of the effect of the various factors in an entrepreneurially managed small firm. The bottom line represents the effect of various factors in a professionally or owner-managed small firm. The middle line shows that the lag in technology use in small firms reduces with time (while the other two lines represent the conditions at time \(T\), the middle line represents technology use in owner/professionally managed small firms at time \(T + j\)). The three lines in the figure are able to illustrate the effect of key factors which might cause small firms to lag larger firms in technology use; the effect of time in reducing the lag is also represented.

5.3. Propositions for future investigations

The findings, conclusions and Fig. 3 (from the earlier sections) are used to offer several propositions for future investigations. Since SPMTAR for
computerized technologies is increasing and SPMTAR for soft technologies is stagnant with time, the following propositions for future investigation are in order.

1) There is a time lag between large and small plants in the adoption of computerized technologies.
2) Small plants tend to narrow the gap with larger plants in the use of computerized technologies.
3) Small plants find it harder to catch up with large plants in the use of most soft technologies.

The following propositions address the reasons for the lag in the use of technologies by small plants.

4) Risk: small plants are less likely to assume the risk of investing in new technologies and, therefore, they prefer to wait until new technologies are proven in larger plants.
5) Complexity: the complexity associated with soft technology adoption hampers their adoption in small plants.
6) Given the complexity of soft technology implementation, small plants may lack the know-how to implement soft technologies.

Fig. 3 may be debatable and needs to be validated by future research. To assist such research, the following additional propositions are being offered.

7) Management style/priorities: In owner-managed and professionally-managed small firms, technology use lags larger plants more than entrepreneurially-managed small firms.

5.4. New directions for research

The needs, priorities and strategies of entrepreneurially-managed firms are different from other small firms. What appeals to entrepreneurially-managed firms may not appeal to firms under a different style of management. Public assistance programs could be better focused if we know how the differences in management styles influence investment in manufacturing technologies. Therefore, investigations are necessary to understand the differences in priorities and strategies of small firms operating under different management styles. Further, studies are necessary to investigate how different management styles influence the investment in manufacturing technologies. Issues to consider are the attitude of the management towards risks, investment, return on investment, change, etc.

6. Implications for public policy

6.1. Under the assumption of market failure

Policy makers have made tangible policies backed by budget appropriations to help smaller manufacturers become more competitive through the use of manufacturing technologies (Federal Technology Report, 1996; Franks and Meehan, 1994–1995). One could argue that these policies are at least partially based on an assumption of market failure. One theme of these programs is to make smaller plants comparable to larger plants in technology adoption in the hope of making small plants more competitive.

Regardless of whether one accepts market failure in this matter or not, this study provides a quantitative estimate (the SPMTAR) of the difference between small and larger plants in their use of specific manufacturing innovations; the quantification enables a better assessment of technology use in small plants for public policy purposes. Given that public assistance programs are already in existence, the following two recommendations may help to increase the effectiveness of these programs.

6.1.1. Emphasize soft technology assistance

Since SPMTAR is stagnant over time for soft technologies, assistance programs meant to help small manufacturers must pay relatively more attention to the adoption of soft technologies such as JIT, TQM, SQC, and MC for improved pay off from the tax dollars spent. Successful adoption of soft technologies require much training, much cross-functional cooperation, planning and control system modifications, process changes, etc., which may call for expertise that small plants may not have.

6.1.2. Address the lack of funds and technical know-how in small firms

The findings of a study by Swamidass (2000b) show that a continuous improvement theme in some plants
provides for an umbrella of funds for capital investment in new manufacturing technologies. The word must get out to small manufactures about the evolving trend towards investing in manufacturing technology for continuous improvement.

Further, Swamidass (2000b) found that some US manufacturers think that it is foolish not to invest in manufacturing technologies because most manufacturers recover their investments in less than 2 years; a payback of less than 2 years implies a return far in excess of prevailing cost of capital. Small manufacturers should be made to realize that it is foolish not to invest in manufacturing technologies because the returns are high. A part of the solution may lie in the education of small firms on the robust return on investment experienced by firms that invest in manufacturing technologies for continuous improvement, or for strategic purposes.

6.2. When market failure is not assumed

One may argue that the lag in the use of certain technologies by small plants cannot be attributed to market failure and therefore no public response is needed. According to this line of thinking, if small firms need know-how, they could use existing knowledge diffusion programs; if they need to change processes, consultants could help; and if they need capital, they could turn to internally generated funds, capital markets or creditors.

6.2.1. A less complex environment in small plants

If the environment in small plants is less complex (or simpler) than larger plants, one may argue that the smaller plants need not equal the larger plants in technology use to be competitive. This alternative explanation for the differential use of technologies in small and larger plants would render intervention through public policy unnecessary. Therefore, an alternative proposition to investigate in the future would be the following.

Alternative proposition: the inherent simplicity of the manufacturing environment in small plants reduces the need for manufacturing technology.

In an in-depth study of technology use in US manufacturing firms, Swamidass (2000b) found that companies in high-growth electronic industries financed their new manufacturing technologies at “lightning” speed using internally generated funds. These firms enjoyed generous cash flow. Further, they had a low or non-existent debt. However, small manufacturers in mature industries are particularly low in internally generated funds for investment in manufacturing technologies. In such environments, investment in new manufacturing technologies slows down, or investments are made with greater caution. That is, market growth dictates which industries would have generous funds for investment in new technologies and which would not. In this situation, it is up to the public policy makers to decide if they want to intervene and provide assistance to small plants in certain mature industries in need of capital for investment in technologies. Although, those who are against market intervention may argue against such help saying that the market should pick the “winners” and “losers” among industries.

Acknowledgements

This study was made possible by two different NSF grants (SBR-9311807; SBR-9619054) and the support of the NAM, Washington, DC. The following graduate assistants at the Thomas Walter Center for Technology Management contributed to this study: Hubert Jerome, Nupura Kolwalker, Bill Shaninger, Courtney Trimble, Priya Vaidyanathan, and Sankar Vyakaran. The author thanks Dr. Dayne Aldridge and anonymous reviewers for their suggestions to improve this paper.

Appendix A. Glossary of manufacturing technology terms

A.1. Computerized technologies

1. Automated guided vehicle (AGV): AGVs are unmanned carriers or platforms that are controlled by a central computer that dispatches, tracks, and governs their movements on guided loops. AGVs are primarily useful for materials handling, or

\[\text{Adapted from (Swamidass, 1994).}\]
between workstations as a replacement for conventional forklifts and transfer lines.

2. Automated inspection (AI): Automated inspection is defined as the automation of one or more steps involved in the inspection procedure.

3. Computer-aided design (CAD): CAD is a computer software and hardware combination used in conjunction with computer graphics to allow engineers and designers to create, draft, manipulate, and change designs on a computer.

4. Computer-aided manufacturing (CAM): CAM incorporates the use of computers to control and monitor several manufacturing elements such as robots, CNC machines, and AGVs.

5. Computer-integrated manufacturing (CIM): CIM involves the total integration of all computer systems in accounting, engineering, production, etc. in a manufacturing facility; the integration may extend beyond one factory into multiple manufacturing facilities in one or more countries and into the facilities of vendors and customers.

6. Computer numerical control (CNC) machines: CNC machines are locally programmable machines with dedicated micro- or mini-computers. CNC provides great flexibility by allowing the machine to be controlled and programmed on the floor.

7. Flexible manufacturing systems (FMS): A flexible manufacturing system is a group of re-programmable machines linked by an automated material-handling system and a central computer. The intent of such a system is to produce a variety of parts that have similar processing requirements with low set-up costs.

8. Local area networks (LAN): Local area networks are the backbone of communication systems that connect various devices in a factory to a central control center. The LAN, through the control center, allows for the various devices connected to the network to communicate with each other.

9. Materials requirements planning (MRP or MRP I): MRP I is primarily a scheduling technique, a method for establishing and maintaining valid due dates or priorities for orders using bills of material, inventory and order data, and master production schedule information as inputs.

10. Manufacturing resource planning (MRP II): Manufacturing resource planning is a direct outgrowth and extension of closed-loop MRP through the integration of business plan, purchase commitment reports, sales objectives, manufacturing capabilities and cash flow constraints.

11. Robots: The Robotics Institute of America defines the industrial robot as: "A programmable, multi-functional manipulator designed to move material, parts, tools or specialized devices through various programmed motions for the performance of a variety of tasks." The basic purpose of the industrial robot is to replace human labor under certain conditions.

A2. Soft technologies

12. Just-in-time (JIT) manufacturing: The concept of just-in-time manufacturing is a philosophy that requires materials and goods to arrive "just in time" to be used in production or by the customer. The philosophy of JIT has imbedded in it a "continuous habit of improving" and the "elimination of wasteful practices".

13. Manufacturing cells (MC): A manufacturing cell is composed of a small group of workers and machines in a production flow layout, frequently a U-shaped configuration, to produce a group of similar items called "part families" in dedicated production areas. Proponents of cellular manufacturing have claimed several benefits for this type of production system, including less inventory, less material handling, improved productivity and quality, improved worker job satisfaction, smoother flow, and improved scheduling and control.

14. Statistical quality/process control (SQC/SPC): SQC/SPC apply the laws of probability and statistical techniques for monitoring and controlling the quality of a process and its output. SQC/SPC can be used to reduce variability in the process and output quality.

15. Total quality management (TQM): TQM is built on the principle of continuous quality improvement in manufacturing, as well as the entire organization. It works well with frequent feedback of performance measures to various system elements empowered to make changes in their operation such that the system moves closer and closer to its stated goals.
Appendix B

### A SURVEY OF MANUFACTURING TECHNOLOGY USE AND TRAINING, 1997

**Note:** If your company has many plants, evaluate any one plant with which you are most familiar.

The following responses apply to the plant at—
1. City ___________________ (2) State ___________________ (3) Zip ________________
4. The year this plant was commissioned ________________

#### A. Rate your plant’s SKILL LEVEL in the use of the following technologies and estimate the percent of the plant’s total operation affected by each technology you use:

<table>
<thead>
<tr>
<th>Technology</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. FMS</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>6. CIM</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>7. CAM</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>8. CAD</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>9. HTD variations of HT</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>10. MRP</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>11. MRP III</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>12. Robots (all kinds)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>13. Manufacturing cells</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>14. SQC/SPC</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>15. Bar codes</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>16. Automated inspection</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>17. LAN (local area networks)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>18. CNC</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>19. TQM</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>20. Simulation and modeling of</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>processes and equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21. Concurrent engineering</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

(Other sections of the questionnaire not shown)

### References


Federal Technology Report, 1996. NIET plans to finish network for manufacturing assistance. 9 May

