International Competition in the Bicycle Industry

Keeping Pace with Technological Change

December 1991
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The World Bank Industry and Energy Department, OSP
INTERNATIONAL COMPETITION IN THE BICYCLE INDUSTRY: KEEPING PACE WITH TECHNOLOGICAL CHANGE

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December, 1991

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PREFACE

Competition in a period of rapid technological change is the subject of this and three other companion reports. Four relatively mature industries of considerable interest to less developed countries were chosen to investigate whether organizational and technological innovations are of any relevance to them. The answer is a resounding yes. Organizational changes, automation, and use of new materials to change the production process and to transform the product itself were found to be of tremendous importance in each sector. These changes quite overwhelm simple differences in factor costs.

This research was financed by the World Bank’s Research Committee to which we are all very grateful. Numerous colleagues have supported this work and we would like to specially thank Nancy Barry, Carl Dahlman, Sandra Salmans, and Masami Shimizu. Our greatest debt is to managers and engineers in dozens of companies in six countries who spent their valuable time with us.

International Competition in Printed Circuit Board Assembly.  
International Competition in the Footwear Industry.
1. INTRODUCTION

1.1 Overview

Diffusion of innovation proceeds at varying rates in different countries, creating differences in the productivity with which resources are used, and hence affecting the competitive position of nations. At this moment, there is a special ferment in the world of manufacturing as organizational innovations, automation, and new materials are transforming not only the manufacturing process but also, in many cases, the product itself. The speed at which these innovations are absorbed is likely to have a significant impact on a country's ability to compete. Developing countries face a special challenge as they determine how best to keep pace with the changes.

In this study, we project the effect of innovative manufacturing technologies on the long-term productivity of firms and countries. We believe that, through such analysis, we are enriching the debate on differences in international productivity, and suggesting new policy directions to improve productivity in developing countries.

Manufacturing processes worldwide are being transformed by complementary developments. The first, and perhaps the most important, relates to organizational changes within the firm. Pioneered by the Japanese and associated with various names, such as total quality control, kaizen and just-in-time, it has set new standards for scrap management, machine reliability, inventory control, and worker training and participation. Firms successfully adopting these practices have uniformly reported large gains in productivity.

Another major influence on manufacturing has come from microelectronics-based technologies. These technologies are permitting increased automation of a wide range of operations in many industries. Ultimately, it is expected that, in specific sectors, electronics controls could transform discrete (or batch) production into a continuous process requiring limited human intervention.

A third influence, of particular relevance to the bicycle industry, is the development of new materials. In general, the bicycle assembly has been less affected by advances in microelectronics than the other industries studied in companion reports. New materials have been used, so far, principally for exotic, high-priced bicycles, but they are diffusing steadily to lower-end bicycles, implying profound changes in design, production and marketing.

What implications do these influences have for the bicycle industry? Will the advent of new technologies pose a threat to bicycle manufacturing in developing countries? If so, what options are available to companies in these countries, and how can these options be best exploited?

In this report (as in companion reports), our central task is to account for differences in costs of production across countries and to predict how the level and structure of costs will evolve as organizational changes, automation and materials technologies diffuse more widely. The evolution in
costs will influence production and trade patterns. We relate our findings on technology trends to trends in international trade. The systemic nature of the technological change is emphasized. Hence the need for better information on long-term international relationships with producers and buyers, improved worker training and incentives, and the key role of infrastructure are discussed.

1.2 Location of Production

The most accessible mode of transportation in less developed countries, the bicycle has increasingly become a leisure product. The market for leisure bicycles for adults has grown from virtually nothing to about $3 billion in annual sales, almost entirely in developed countries. Paradoxically, as the market for bicycles grew, developed countries seemed to lose competitiveness in producing bicycles. Thus, Japan was displaced by Taiwan as the world's largest exporter of bicycles. Now Taiwan is being threatened by China and Thailand. The developed countries, which in 1967 accounted for half of global bicycle production, produced less than 25 percent of the world's bicycles in 1987. (Cycle Press International, Oct. 1988, p.7, 11)

In recent years, some revival has occurred in the fortunes of developed country bicycle producers, and the seemingly inevitable movement of production to countries with cheap labor and large populations may have been stemmed. In this study, we shall describe the market and technological trends that have influenced recent shifts in world market shares.

World production of bicycles reached an estimated 100 million units in 1988 (Table 1.1). China has consistently topped the production list, followed by Taiwan, Japan, India, and the United States. Swings in Chinese production dominate trends in world bicycle production. After reaching a peak of 44 million bicycles in 1988 (about 40 percent of the world total), Chinese production fell sharply, to 30 million in 1990. The extraordinary levels of production in 1987 and 1988 created a large inventory of bicycles for domestic use, forcing cutbacks.

World trade has been very dynamic. The value of bicycles traded internationally grew almost two and a half times between 1984 and 1989 (Table 1.2). Trade has been increasingly dominated by a select group of countries. Table 1.2 shows that the top ten exporters accounted for 85 percent of world trade in recent years. Of these, Taiwan has been the most outstanding.

In 1987, Taiwan produced more than 10 million bicycles and accounted for almost half of the bicycles traded internationally. In 1988, Taiwan took a sharp fall in production and exports. Volumes of production and trade have since stabilized. Currently, Taiwan produces about 7.5 million bicycles a year, and exports 6.5 million. However, the unit values of Taiwanese products have risen, restoring significantly its market share. Sales in Europe have increased sharply. Beset by a strong currency, and rising labor costs, Taiwan has held onto its competitive advantage through radical change, moving its sights to a more upscale bicycle market (See Box 1.1).
China - which, until recently, had concentrated almost exclusively on its vast domestic market - has emerged as a serious exporter to developed countries. Exports doubled between 1987 and 1988, and have since plateaued at 2.5 million. Chinese exports have increased their share from 3 percent of the value of world trade in 1981 to 8 percent in 1989 (See Table 1.2). Exports have grown particularly to the United States, the world's largest importer of bicycles. In 1990, China accounted for 10 percent of the foreign-made bicycles shipped to the U.S., thus displacing Korea as the second largest source of imports (Table 1.3). See also Appendix on China.

For the most part, China supplies the low end of the market. But both the trade statistics and descriptions of new factories in China indicate that this is changing rapidly. In the category "other" bicycles, Chinese exports to the United States are priced only marginally lower than Taiwanese exports (Table 1.3). This import category, which is dominated by products such as mountain bikes, has been the most dynamic segment of U.S. imports, rising from nothing in 1981 to half of U.S. imports in 1990.

Table 1.1: BICYCLE PRODUCTION

<table>
<thead>
<tr>
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<th></th>
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<tbody>
<tr>
<td>World</td>
<td>64.8</td>
<td>79.3</td>
<td>83.6</td>
<td>92.2</td>
<td>100.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>U.S.</td>
<td>6.8</td>
<td>5.8</td>
<td>5.3</td>
<td>5.2</td>
<td>4.5</td>
<td>5.3</td>
<td>5.9</td>
</tr>
<tr>
<td>Japan</td>
<td>6.6</td>
<td>6.8</td>
<td>6.6</td>
<td>7.4</td>
<td>7.5</td>
<td>7.9</td>
<td>8.1</td>
</tr>
<tr>
<td>Germany</td>
<td>3.4</td>
<td>2.9</td>
<td>3.2</td>
<td>2.9</td>
<td>3.0</td>
<td>3.4</td>
<td>3.8</td>
</tr>
<tr>
<td>Taiwan</td>
<td>3.5</td>
<td>6.5</td>
<td>7.7</td>
<td>10.2</td>
<td>7.3</td>
<td>7.2</td>
<td>7.3</td>
</tr>
<tr>
<td>Korea</td>
<td>0.8</td>
<td>0.9</td>
<td>1.2</td>
<td>2.4</td>
<td>2.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>China</td>
<td>17.5</td>
<td>32.2</td>
<td>35.7</td>
<td>41.1</td>
<td>44.4</td>
<td>36.5</td>
<td>30.0</td>
</tr>
<tr>
<td>Thailand</td>
<td>-</td>
<td>2.7</td>
<td>3.4</td>
<td>5.2</td>
<td>9.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>India</td>
<td>5.0</td>
<td>5.6</td>
<td>5.9</td>
<td>6.5</td>
<td>6.7</td>
<td>7.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>


Table 1.2: TRADE IN BICYCLE PRODUCTS

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Value of World Trade (USS billion)</td>
<td>0.04</td>
<td>0.69</td>
<td>0.67</td>
<td>1.14</td>
<td>1.24</td>
<td>1.54</td>
</tr>
<tr>
<td>Japan</td>
<td>5.33</td>
<td>17.53</td>
<td>15.15</td>
<td>6.79</td>
<td>6.37</td>
<td>3.56</td>
</tr>
<tr>
<td>Italy</td>
<td>7.15</td>
<td>8.36</td>
<td>7.98</td>
<td>7.28</td>
<td>9.52</td>
<td>8.53</td>
</tr>
<tr>
<td>Germany</td>
<td>15.83</td>
<td>7.97</td>
<td>7.44</td>
<td>6.54</td>
<td>6.66</td>
<td>5.91</td>
</tr>
<tr>
<td>France</td>
<td>10.22</td>
<td>11.16</td>
<td>7.52</td>
<td>6.02</td>
<td>6.42</td>
<td>5.27</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>9.09</td>
<td>3.19</td>
<td>2.93</td>
<td>1.76</td>
<td>1.99</td>
<td>1.52</td>
</tr>
<tr>
<td>Taiwan</td>
<td>3.08</td>
<td>20.09</td>
<td>38.94</td>
<td>47.58</td>
<td>40.55</td>
<td>46.29</td>
</tr>
<tr>
<td>Korea</td>
<td>2.15</td>
<td>1.64</td>
<td>2.26</td>
<td>6.14</td>
<td>6.69</td>
<td>4.61</td>
</tr>
<tr>
<td>China</td>
<td>1.94</td>
<td>3.24</td>
<td>2.19</td>
<td>3.70</td>
<td>5.50</td>
<td>8.02</td>
</tr>
<tr>
<td>Thailand</td>
<td>0.00</td>
<td>0.01</td>
<td>0.04</td>
<td>0.30</td>
<td>0.35</td>
<td>1.25</td>
</tr>
<tr>
<td>India</td>
<td>0.13</td>
<td>0.48</td>
<td>0.41</td>
<td>0.36</td>
<td>0.16</td>
<td>0.04</td>
</tr>
<tr>
<td>TOTAL of above 10 exporters</td>
<td>54.96</td>
<td>74.36</td>
<td>85.53</td>
<td>87.61</td>
<td>85.36</td>
<td>86.55</td>
</tr>
</tbody>
</table>

Source: UN Comtrade Database, Geneva.
Table 1.3: MAJOR SUPPLIERS TO THE U.S. MARKET, 1990

<table>
<thead>
<tr>
<th>Bicycle Imports (%)</th>
<th>Unit Value of Imports</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20&quot;</td>
</tr>
<tr>
<td>Japan</td>
<td>1.9</td>
</tr>
<tr>
<td>Taiwan</td>
<td>73.8</td>
</tr>
<tr>
<td>Korea</td>
<td>8.6</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>1.5</td>
</tr>
<tr>
<td>China</td>
<td>10.0</td>
</tr>
<tr>
<td>Thailand</td>
<td>2.8</td>
</tr>
<tr>
<td>All others</td>
<td>1.4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: Bicycle Manufacturers Association, Washington, D.C.

Thailand is emerging as another low-wage production base. Rising from a negligible share of international markets in the early 1980s, in 1989, Thailand accounted for 1.3 percent of world trade in bicycles (Table 1.2) and 2.6 percent of the U.S.'s imported bicycles (Table 1.3).

Like China, India has historically focused on meeting domestic demand, which amounts to some 9 million bicycles annually. (The world's largest bicycle maker, with 3.2 million in 1990, is India's Hero Cycles.) Quality has been poor, and the small volume of overseas sales have been mainly to the Middle East, Africa and the Soviet Union. Now, however, Indian companies have embarked on joint ventures aimed at raising quality and exports to DCs.

Recently, however, developed countries have been reasserting themselves as bicycle manufacturers. Currently, about 26 million bicycles are produced every year in the European Community (12 million), Japan (8 million) and the United States (6 million). After falling in the late 1970s (particularly sharply in the U.S.), production stabilized and has risen in recent years. U.S. production rose in 1990 to 6 million bicycles, its highest level since 1983 (though lower than peaks attained in the early 1970s). Production in Japan reached new highs in 1989 and 1990, and West German production in 1989 regained levels reached in the early 1980s (Table 1.1).

The United States imported 7.4 million bicycles in 1987; by 1990 the level had dropped to 4.8 million, and the U.S. Department of Commerce forecasts a continued fall in 1991. While the initial drop in imports in 1988 was due to a sharp decline in domestic demand, the domestic market has partially recovered and imports have not. In fact, U.S. exports have expanded recently, after years of decline.

Japanese trends are very similar. As Japanese production has risen to record levels, imports have fallen steadily for four consecutive years, and exports rose in 1990 for the first time in five years (Cycle Press International, January 1991, p. 7).

Not to be overlooked, amidst these statistics on bicycle assemblers, is the role of the manufacturer of bicycle components--brakes, hubs, derailleurs (a type of gear found on about 25 percent of all bikes) and
chains. While components are manufactured everywhere that bicycles are made, Japan's Shimono Industrial, a $1 billion-a-year company that is the world's largest component manufacturer, dominates the industry to a remarkable degree. Although Shimano exports about two-thirds of its production, to NIEs as well as DCs, there is a continuing shortage of high-quality components. The company recently increased its operation in Malaysia, and plans to open its first Indonesian factory this year.

1.3 Market Trends

Design, more than production technology, has been responsible for the major recent changes in bicycle manufacture. In the late 1970s, enthusiasts began redesigning their road bikes to ride them on hillside trails. Their efforts had an impact on the industry that was nothing short of revolutionary: the creation of a several million dollar-a-year market in MTBs, or mountain bikes.

In 1987, mountain bikes (MTBs) were 12 percent of the U.S. market. Currently, MTBs (and their many variants) comprise about half of the bicycles sold in the U.S.

The trend is the same worldwide. Mountain bikes also account for half the bicycles sold in Europe. In Japan, this surge in demand has proved particularly beneficial to developed country producers, whose design, engineering and marketing skills have become more critical than before. Small specialty producers have been at the innovative forefront, experimenting with new design concepts and materials. However, volume producers in DCs have also gained. Mountain bikes have been a major source of revenue and profit for Huffy, one of the three largest U.S. producers. Japanese production of mountain bikes in 1990 rose three and a half times over the previous year to 325,000 and is expected to grow at a vigorous pace in the near future.

These bicycles have wider tires and higher handlebars than the once popular "lightweights." Mountain bikes, and their many variants, emphasize comfort and smooth ride over speed. However, the speed disability of mountain bikes is being gradually whittled down as lighter frames (using new materials) are reducing their weight.

any of the design changes have been introduced via CAD, which has completely supplanted mechanical drawing in the bicycle industry. At Schwinn Bicycle Co., for example, the mini-supercomputer runs a sophisticated CAD software - an animated, on-screen drafting program - and performs finite element analysis, juggling up to 12,000 numerical variables for 8 hours or

1/ The Bicycle Manufacturers Association, Washington D.C., does not actually publish the number of MTBs sold and produced. The category of bicycles described as "all other bicycles" is widely used as a measure of the more innovative new bicycles; and this category is dominated by MTB-type bicycles. For a similar interpretation see U.S. Industrial Outlook 1990, U.S. Department of Commerce, Washington D.C.
more. This is used to weigh the many possible combinations of tube diameters and wall thicknesses for bicycle prototypes. The computer can even perform stress analysis, putting a frame through its paces on screen and highlighting critical areas as the frame bows and bends. This reduces development costs by reducing or eliminating trial and error (Bicycling, April 1990).

New materials technologies have also been responsible for transforming the industry, at least at the upper end. While most bicycles are still built from steel, in the interest of low weight and high performance, manufacturers have experimented with aluminum, titanium and innovative steel frames. Now composites, already used in aircraft, boats, automobiles and many mainstream consumer goods, are attracting interest. Some experts predict that, by 1995, carbon-fiber frames will have a major - and perhaps dominant - piece of the market (Bicycling, April 1990). There are continuing efforts to improve the racing bicycle’s aerodynamics through design changes. A British firm has developed a very large pressure diecasting machine that can produce one-piece frames - made of magnesium - at a rate of one a minute (Engineering Materials and Design, March 1988).

The impact of microelectronics on bicycle production has been more limited. However, a Japanese company, National Bicycle Industrial, has brought flexible manufacturing to bear on the production of bicycles. Humans, robots and computers together "build" bicycles to customers' specifications. Buyers can choose from 18 types of bicycles in 199 colors with a variety of pedals and tires, for a total of 11,231,862 variations. The bicycles, delivered within two weeks, are priced only 10 percent higher than comparable ready-made models.
BOX 1.1: TAIWAN RECOVERS

The bicycle manufacturing industry of Taiwan is on track again after a short slump. Although its road to recovery has been bumpy, its revival makes for an instructive contrast with Korea's bicycle industry, which is losing market not only overseas but at home.

In 1990, Taiwan's bicycle exports increased 5.5 percent from the previous year, to 6.3 million units. More significantly, the average unit price rose by 24 percent, to US$113. The growth came after three years of a phenomenal downturn. Between 1987, when Taiwan exported more than 9 million bicycles, and 1989, exports fell by 50 percent.

Taiwan's bicycle manufacturers began to foresee trouble in the mid-1980s, as the country's economic boom resulted in a strong currency, high commodity prices, rising labor costs and manpower shortages. Faced with serious erosion of the all-important U.S. market, which began importing cheaper bicycles from China and Thailand, Taiwanese manufacturers began a concerted effort to seek new geographic markets and shift to higher-priced models. Some also consolidated to achieve economies of scale.

Moving upmarket called for fundamental changes in the ways factories approached production. Taiwan companies, which had been making low-end, low-quality bicycles for 20 years, had to upgrade their management, their organizational methods and their worker training. Firms also began offering unprecedented fringe benefits to retain good workers.

Special government programs help companies improve manufacturing techniques and materials technology. The Industrial Development Bureau of the Ministry of Economic Affairs supports the Industrial Research Institute that provides consultancy advice to companies on technology strategy. One recent user of that service was the Fritz Jou Company, which set up a modern, highly automated factory based on advice received. Taiwan's largest bicycle company, Giant Bicycle Company, has been working closely with the government-sponsored Material Research Institute to develop carbon-fiber composites for its new generation of bicycles (Free China Review, September 1989).

In 1990, these efforts bore fruit. While North America remained the single most important market, it accounted for only 46.5 percent of Taiwan's exported bicycles. By contrast, Europe bought one-third of Taiwan's bicycles, a 163 percent increase over the previous year. Furthermore, Europe absorbed a much larger percentage of high-end models, including the popular mountain bikes.

Not every manufacturer has been able to shift to higher-quality production. At least five companies, including the medium-sized assembler, Roadtech, have gone into bankruptcy. Other small and medium-sized manufacturers are expected to follow suit.

Source: TK
The immense variety arises from the company's capability to closely tailor bicycle dimensions to the buyer's physique. This phenomenon is being referred to as "mass-produced customization." Aggregate production volumes are high, which is not the case with craft production. However, modifications in components and operations can be achieved quickly and at low cost.

These changes are not encouraging for low-wage developing country producers that had been waiting in the wings for developed and newly industrializing economy producers to become uncompetitive because of high and rising wages. While China has made a major breakthrough into international markets, sales seem to have stabilized at a relatively modest level. Among other low-wage countries, only Thailand has made limited progress; Indonesia is only just beginning to export and Indian exports have shown no dynamism. Meanwhile, Taiwan is recovering its export strength. With developed country firms increasing their exports for the first time in many years, the so-called "productcycle," which is presumed to move production inevitably to low wage countries, appears to have reversed direction.

To be sure, the new materials and customizing are relevant mainly to the upper end of the market. The larger volume, lower-end production will continue to move to the lowest-cost producer. However, as the innovations in materials and assembly technology cause the low-end to be economically superceded by higher performance bicycles sold at only slightly higher prices, even low-wage countries are being forced to move upscale. A good example of this is China, where the new factories being established by firms from Taiwan, the U.S. and elsewhere are targeting the medium-priced bicycle market.

Similarly, Taiwan's upscale move clearly accounts for the industry's health in that country, while Korea is suffering from its slowness to retool. Samchully, Korea's largest bicycle producer, has been hurt by its dependence on low-end bicycles, including children's bicycles.

1.4 Scope of the Study

Being internationally competitive takes a lot of doing: materials must be procured efficiently from domestic and overseas sources, production must be organized efficiently and staff motivated appropriately, links with buyers must be maintained to obtain timely information on trends in demand, and so on. We are in no position to analyze the entire chain of activities. Our focus is on the manufacturing process (See Figure 1.1).
Figure 1.1
There can be little doubt that efficiency in manufacturing will be a key ingredient of success at least for the less developed and newly industrializing countries. It is our conjecture, moreover, that certain underlying principles of manufacturing (efficient management and good flow of information) hold equally for other components of the value chain.

A related boundary on the quantitative exercise is our focus on production costs. We have emphasized above that competition is multi-faceted and depends on the firm's ability to respond flexibly to customer needs, implying that low costs are not the only factor determining competitive ability. We have been able to quantify costs in very great detail, as will become evident in the following chapters. However, quantifying the benefits of flexibility and superior product characteristics is much more difficult. This is unfortunate since many of the more innovative processes we study lead primarily to gains in flexibility and product enhancement. Our approach has been to discuss quality and flexibility with ordinal measures and, more importantly, to discuss the trade-offs between product characteristics, flexibility, and cost. For example, when a process leads to an obvious improvement in product characteristics but limited increase in production cost, then it is relatively safe to conclude that the process is likely to diffuse widely.

1.5 Country Stylizations

It is a long-held principle among economists that systematic differences in operational efficiency across countries cannot persist over long periods of time. Any such differences, according to the conventional wisdom, would soon be wiped out by economics' invisible hand. Leamer 1984, for example, says that unless there exist "biological differences" between the nationals of different countries, or "effective counterintelligence agents," all economies should be equally efficient in the tasks they perform.

Like other researchers, however, we have observed empirically that this mind set does not correspond to reality. In this sector and others, we find that some of the newly-industrializing economies operate at a consistently higher level of efficiency than other country types. They invest more effectively, learn faster, and stabilize their production at higher levels of efficiency.

It would be pointless to dismiss such differences as illusory. Indeed, we strongly believe that, by examining their causes, we can enrich the debate on international productivity differences.

In this and companion studies, the firm has emerged as a dynamic organization, even in those industries previously thought to be mature. The successful firm is in a constant state of flux as it introduces and absorbs technical and, above all, organizational innovation: automation in design and manufacture, design for manufacture, quality control and inventory management.

For the firm, then, the learning curve is extremely steep - but so is the reward. In fact, it is probably safe to say that the firm's position on the learning curve is more critical to its success than other, exogenous factors. Firms - notably LDC manufacturers - that are only at the beginning
of the curve are substantially less efficient than those at the end, and not even cheap labor - as in the case of LDCs - can make up the differences.

Accordingly, we set ourselves the task of accounting for efficiency differences in terms of operational characteristics, and then discussing how performance, as defined by those characteristics, could be improved. We do not trace the learning curve, or limit our analysis to the beginning and end. Rather, we observe the process at several points in time - almost like snapshots - and discuss, in a qualitative way, how to advance from one to the next.

In our quantitative exercises, therefore, we introduce important stylizations regarding the level of efficiency attained. Of the three groups of countries we study, we assume the newly-industrializing economies (NIEs) to be the most efficient. These were represented in our study by South Korea and Singapore. Although our interviews in Japan provided us with substantial information on the frontiers of production technology, the benchmark cost estimates for developed countries (DCs) are based on conditions in the United States. Less-developed countries (LDCs) are represented by Mexico and Indonesia. After demonstrating the impact of inefficiencies, we examine cost differentials across groups if they all operated at the NIE level of efficiency. That comparison allows us to study the effect of factor costs - the costs of labor, land and capital - and technology choices.

1.6 Plan of the Study

Product and manufacturing strategies of a sampling of firms visited for this project are described in the next chapter. On the basis of these visits, the manufacturing literature, and our engineering knowledge and experience, we created benchmark factory cost models defined at a fine level of specification (Chapter 3). These benchmark models are intended to replicate production costs of "representative" factories in the countries visited. A series of cost scenarios based on the adoption of modern management practices and new hardware technologies are examined in Chapters 4 and 5. Throughout, the lessons from our cost models are illustrated with concrete case studies based on our field visits or on the industry literature. The concluding chapter comments on the shifts occurring in the competitive abilities of different country types.
2. THREE MANUFACTURERS: A STUDY IN CONTRASTS

2.1 Background

In the following chapters, we will simulate changes in unit costs when alternative techniques are adopted by stylized, country-specific benchmark factories. The discussion here provides some of the basis for stylizations discussed later in the report. We summarize first the basic pattern of technology adoption by companies visited for this project and then discuss in some detail three companies, each representing one of the three country types. The objective is to relate the choice of production technique to the company's economic environment, product strategy, and human resource strategy.

Eleven bicycle assemblers in six countries were studied in considerable depth, usually over a day with some follow-up questions and visits. In addition, similar interviews were conducted with 31 other firms (in the electronics assembly, shoe, and steel industries), and the stylizations that emerge for bicycle production conform with the overall project results.

The manufacturers we visited were chosen for their representativeness of one of the three country types. Extensive consultation with industry and country experts, review of the industry literature, and our industrial consulting experience was the basis for choosing particular firms. The visits were not intended to generate primary data on the basic manufacturing process; that was derived from our experience and expertise. The visits were intended, instead, to enhance our grasp of the range of manufacturing competence. Within a country type, factories in the four industries resembled each other more closely in terms of key operational characteristics than did factories in the same industry across country types. Thus, the relatively modest number of visits to manufacturers in each sector was effectively amplified by visits to manufacturers in other sectors.

2.2 Technology Usage Summary

Before examining in detail three bicycle companies, one in each country type, consider first the summary of technologies in use at the factories visited (Table 2.1). In terms of automation, the most advanced factories were in the developed countries. The only two plants using Computer-Aided Design (CAD), for example, were in DCs. The NIEs had typically instituted low-cost automation, pneumatic and hydraulic aids to production.

In other respects that may be more critical to final unit cost, however, the DCs lagged the NIE manufacturers. Total Quality Control (TQC), for instance, had been adopted by all three NIE companies, but by neither the DC (in this case, the U.S.) nor the LDC manufacturers.

By the same token, only the NIEs had instituted just-in-time (JIT) techniques as a means of controlling their inventory. Two of the three DCs had implemented Materials Requirement Planning (MRP), a materials ordering and job scheduling system. However, MRP has been less effective than JIT in reducing work-in-process (WIP) levels.
As we shall discuss below, consciousness of product quality assurance programs has risen greatly in the United States, and formal procedures are being instituted widely in bicycle and other industries. However, our observation is consistent with that of others who also find NIEs to have taken the lead over some DCs in shop-floor planning and reduction of waste (see Womack and associates 1991).

JIT is not merely an inventory reduction method but is also an institutionalization of continuous learning through incremental changes. Unlike MRP, which serves as a high-level database and provides overall materials management function, JIT emphasizes focus on shop-floor practices. JIT is a tool for the systematic elimination of waste in all aspects of manufacturing. It is clear both through the factory visits and through our consulting experience that the NIE firms have progressed beyond U.S. firms in this regard. This is reflected, as will be discussed in the next chapter, in indicators such as lower scrap, shorter cycle times, greater machine reliability at the NIE factories when compared with the U.S. factories.

<table>
<thead>
<tr>
<th>Table 2.1: TECHNOLOGY USAGE SUMMARY</th>
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<tr>
<td>FIRM</td>
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<tr>
<td>TECHNOLOGY</td>
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<tr>
<td>Production Volume</td>
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<tr>
<td>Use of CAD</td>
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<tr>
<td>Automatic Equipment</td>
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<td>Total Quality Control</td>
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<tr>
<td>Use of New Materials</td>
</tr>
<tr>
<td>Partial Assembly</td>
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<tr>
<td>Inventory Control</td>
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</tbody>
</table>

Production Volume
Very Low: Fewer than 10,000 bicycles per year; Low: 10,000 to 50,000; Medium: 50,000 to 50,000; High: more than 500,000.

Automation
LCA-Low cost Automation (pneumatic and hydraulic controls); Hard-Hard Automatic Equipment (i.e. Non-flexible, Non-programmable)

Inventory Control
MRP-Materials Requirements Planning; JIT-Just in Time

2.3 Developed Country Firm: Company I

Company I is a U.S. manufacturer of low-end bicycles and other mechanical products. Bicycles have been its principle product for more than 50 years, and 95 percent of the bikes it makes are sold under its own name.
It offers a complete line, including light weights (racing and touring), which account for 30 percent of sales; mountain bicycles (MTBs), the biggest sellers, with 35 percent of sales; cruisers; bicycles for teenagers (BMX) and children's 12- to 16-inch bicycles.

Company I is an integrated manufacturer of bicycles, producing most components in-house. It buys its derailleurs, or gear-shifting devices, however, from Japan, Taiwan and France. As noted in the introduction, the Japanese firm Shimano is dominant in advanced products such as derailleurs: high quality, plus a firmly established brand identity, make its components almost mandatory for higher performance bicycles such as MTBs.

In terms of machinery installed, Company I is one of the most advanced manufacturers we visited. Because it competes with countries with far lower wages, it has been forced to use as much automatic and semi-automatic equipment as the process allows. The process flow resembles those in other companies, the biggest difference being production cycle times.

Company I produces its own tubing in 18-foot-long tubes, which are then cut to the desired length to form the frame. Its cutting machines are "hard" automated (i.e., they cannot easily be reset to accommodate variations in input and output requirements) and their process time is about one second. Tubes are then sent to presses, where they are shaped for ease of assembly and better fit. Although this task is performed manually, process times are low.

Tubes next are shaped into frames at automatic welding stations; the stations are loaded manually, with one worker for every two stations. Each bicycle must go through three or four such stations. The process time in each station is about 10 to 15 seconds. The welded frames are then sent to the painting line, which uses rotating fixtures. Decals are applied manually, and the finished frame is sent to the assembly line for partial assembly.

The partial assembly line produces eight bicycles per minute. Final assembly - the most labor-intensive area in bicycle-making - is left to the customer. In partial assembly, only the most complicated or delicate components and parts are assembled in the factory. This practice, common among DC bicycle manufacturers, makes a product somewhat less attractive than a similar one fully assembled - especially if the latter has a nearly identical price tag. 1/

Company I has undertaken many measures that would improve its competitive advantage. Probably its most significant advanced technology investment is in a state-of-the-art CAD system, which was introduced first for

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1/ An option being considered by DC bicycle manufacturers is to redesign bicycles for ease of assembly. A technique known as DFA (Design for Assembly, Boothroyd 1982) is used in other industries to simplify and speed up the assembly process. Also, since the ease of assembly derives principally from a reduction in the number of parts, costs can also decline if the design is cleverly done. In a companion report on assembly of printed circuit boards we have explored these possibilities in more detail.
its other products but is now being used for bicycles. While management agrees they could not have justified CAD solely for bicycles, they do feel that CAD will help them react faster to market changes. Computers are also widely used throughout the firm for accounting and other managerial tasks.

Quality control was not practiced systematically at Company I. Outgoing quality levels were satisfactory, thanks to inspection of the finished frame before it went to the assembly line, but scrap and rework pervaded the manufacturing process. The Company could cut costs significantly if it implemented an effective TQC program and built quality into the entire process rather than checking for it at the end of the line.

Like most bicycle firms, Company I keeps large inventories to meet seasonal demand from consumers and the somewhat unpredictable demand from major retailers. Because it makes a wide variety of bicycles, it has a huge stock. At year-end, when it makes the transition from one model year to the next, Company I warehouses up to 300 different models. At any point in the year, the warehouse might store an average of 200,000 finished bicycles, and up to 50,000 bicycles of just one model. This includes not only the bicycles made in-house, but also those bought overseas. Work-in-progress (WIP), equal to about five days' worth of production, also adds to total costs.

Currently the Company uses an MRP system to monitor inventory and WIP, but it has been unable to reduce levels. It is studying the possibility of implementing a JIT-style system. This would not only help reduce inventory problems, but would also help the Company react faster to changes in the marketplace since production lead times would be reduced. To cope with seasonality, the Company could cross-train all employees and, during peak season, hire low-skilled workers to perform the least complicated tasks while shifting trained workers to higher-skill areas.

A more futuristic possibility is the production of one-piece frames made of composites (carbon fiber), cast metals or plastic. This would eliminate the need for welding, which is labor-intensive. However, composite frames are currently expensive ($900 and up) and do not seem to be a viable alternative for low-end manufacturers. If an inexpensive plastic or composite frame could be manufactured, it could improve the competitive advantage of DC companies such as Company I. (See also our discussion of this issue in Chapter 6.)

2.4 Newly Industrializing Economy Firm: Company G

Company G is a long-established and sizable bicycle manufacturer, producing about 1.2 million units annually. It exports 70 percent of production, of which 90 percent goes to the U.S. and the rest to Japan. It manufactures some 200 different models that fall into the following categories: children's bicycles, about 35 percent of production; youth bicycles (BMX, small racers, etc.), 30 percent; English bicycles; 12-speed racers; 10-speed racers; beach cruisers; mountain bicycles; and 3-speed models.

Company G manufactures its own steel tubing automatically, from sheets. It cuts the tubing into 6-meter lengths for easier handling, using lathe-like cutting machines imported years ago from Japan. (These machines
are now available locally.) It then aligns the tubing, using supports, before welding or brazing. The company has a German-made automatic frame brazer. After they are painted in a Japanese-made automatic painting machine, the frames and forks are transported by carousel. Decals are placed manually.

The company also manufactures rims, either with a semi-automatic French machine or manually, with pneumatic feeding. The rims are given the required tension with a computerized balancing machine. Tires are mounted manually.

For the low end of the market that it supplies, product quality is very good. Parts receive a random quality check upon arrival and, if defects are found, quality control engineers contact the suppliers directly to discuss the problem. There is a quality control inspector in every manufacturing and assembly line, and the finished product is also inspected.

For its size, Company G keeps its inventories low. About 20,000 bicycles, or one week's production, are in the finished-product warehouse. It keeps one month's worth of components, 80 percent of which are purchased locally, with the rest imported.

Production planning is complicated by the large number of models and the market's seasonality. Company G changes its models four times a year, resulting in temporary drops in productivity. Production is scheduled based on orders. The company gets yearly demand forecasts from customers, and purchasing orders every two months from overseas customers and monthly from local customers.

In an effort to control purchasing, production and stock, as well as delivery time, the Company is starting to use MRP. It hopes to implement JIT eventually, but management feels it first needs to train local suppliers of components. That could take a while. Although the country's bicycle production capacity is 4 million units, the domestic component industry can supply enough for only 2 million units.

In the short term, Company G is most concerned that rising wages and the strong national currency are eroding its cost-competitiveness. Shipments, both domestic and foreign, have fallen sharply recently. In the future, it believes that it needs to automate as much of its operation as possible, including presses, welding, painting, frame and wheel assembly, packing and pelleting. CAD is just starting to be used.

The company also believes it should turn more of its attention to the growing local market. In addition, research aimed at producing high-end bicycles has begun. While the company has the ability and resources to produce such bicycles, local demand is not big enough to provide enough first-hand experience, and the company feels it is not competitive in the international market at this time.
2.5 Less Developed Country Firm: Company A

With an annual production of 250,000, Company A is the largest bicycle manufacturer in its country. It is an integrated manufacturer, buying only the most specialized components, such as freewheels and derailleurs, for its top-of-the-line bicycles. Sometimes these components are imported from Taiwan, Japan and Korea. The factory is in an urban area, so that space constraints restrict the company's warehouse facilities and complicate layout and flow of WIP.

Company A makes a wide range of bicycles, all at the low end of the market. It makes bicycles for children, bicycles for teenagers (small touring and racing bicycles and BMX), English bicycles and full-size touring and racing bicycles. All production is sold in the domestic market.

In general, the bicycles are made with the least expensive materials and components the company can buy. For frames, it uses low carbon steel tubing, which is manually welded or brazed, depending on the application. After the frame is formed, the bicycle can go to a chrome-plating process if chrome is to be visible in the final product; otherwise, the frame is sand-blasted. All bicycles are painted in an electrostatic painting chamber (the chrome-plated areas are covered with cardboard). Decals are applied by hand.

The frame next goes to the final assembly line, where workers assemble the bicycles manually, using pneumatic tools in a flow line. The appropriate parts and components are placed in large bins at each of the stations. Finished bicycles then go to a storage facility where, at any one time, between 20,000 and 150,000 bicycles await shipment.

Although the quality of the finished product was good for its market, there was no consistent quality control at Company A. Costly scrapping or reworking was common in every process. Quality control was performed consistently only at the point where the frame was painted and finished.

Company A would benefit from a TQC program. However, management would need to make a strong commitment to upgrade the process. Deming (1975) points out that 85 percent of quality problems are due to the process itself, and only 15 percent to the workers. This does not mean that training workers in quality control techniques is irrelevant. On the contrary, once the process is upgraded and quality is built into both process and product, the next step is to train workers to monitor quality, detect problems as they arise, and make suggestions for improving the process.

During our visit to Company A, we were struck by the number of parts and components heaped in the hallways and on the floor around workstations. This impedes the movement of people and goods on the shop floor. Because the company lacks an accurate monitoring system, it does not know the exact number of parts and components that are stacked all over the plant. Similarly, it does not know the precise number of parts it needs to produce, or the precise number of components needed in final assembly. This exacerbates scheduling and purchasing problems. During our plant visit, we saw large numbers of partially finished products piled up at the final
assembly line, waiting for components that were unavailable when the bicycle was scheduled for assembly.

JIT would help Company A resolve these problems. By implementing such a system, the company could dramatically reduce the amount of WIP, actual inventory levels would be known and the purchasing department would thus be able to buy appropriate amounts at the proper time. The shop floor would be cleared of piles of in-process materials.

Implementing JIT would not be easy. Aside from the problems commonly incurred in adopting JIT (Imai, 1986), Company A functions in an extremely difficult business environment. Suppliers are not reliable, customers do not pay on time and the market is unstable, due to seasonal fluctuations in bicycle demand. Company A needs reliable suppliers who can deliver the desired quality and quantity on time. Its position would be improved if it reduced the number of suppliers. By improving the quality of its bicycles and delivering them on time, the company could strengthen its bonds with current customers and might find new ones overseas as well as at home.

JIT would also help tackle the seasonality problem that afflicts most of the industry. Because the company sells about two-thirds of its annual production at Christmastime, it needs large finished-product inventories. It also warehouses raw materials, parts and components for two months’ worth of production, since suppliers' delivery lead times fluctuate between one and two months. With JIT, Company A could cut its lead times so that it could meet Christmas demand in a shorter period of time, consequently shortening storage time for finished bicycles.

Company A has 450 year-round workers but, to meet peak demand, it hires 250 seasonal workers for the least skilled tasks. Implementation of TQC/JIT would make it more difficult to use seasonal workers, who are untrained to perform properly within the system. But TQC/JIT also improves productivity, so that such workers might not be needed. In addition, by upgrading the skill level of its workers, Company A could decrease the large number of shop-floor supervisors employed to control production.

The equipment used by Company A consisted entirely of older, non-automated machines that might have been in place 20 years ago. There was no trace of modern machines or automation. With TQC/JIT, Company A would have to improve its equipment so that it produced parts of consistent quality. Any piece of equipment that proved unreliable would have to be upgraded or replaced. At the same time, it is important to note that automatic equipment would not be profitable for Company A at this point. Given the low wage rates, workforce reductions would not pay for automation. While it is true that automation has many intangible benefits, such benefits are likeliest to materialize when the entire production process is already optimized and the company has the technical expertise to handle the new machinery. This is not the case at Company A.

Company A does have a design staff, which uses "reverse engineering" for most of its products, i.e., designers copy local and foreign bicycles and build prototypes that are then tested and improved. Under current
conditions, a CAD system would not be justified. Company A uses computers for accounting and could also use them for clerical work.

Production levels at Company A are below those of companies in DCs and NIEs in the same market niche. Management has stated that, although it could increase production, it does not do so because the domestic bicycle market is saturated. However, Company A could try to sell overseas, especially to the large U.S. market for children's bicycles. While exporting would require quality improvements, the company would benefit from economies of scale.

At the moment, Company A fully assembles its bicycles. Although partial assembly is generally more profitable, it might not be the best practice for Company A, in a saturated market. Delivering a half-assembled product would probably mean a drop in market share, since competition would be delivering similar products completely assembled at only slightly higher prices.
3. BENCHMARK FACTORIES

3.1 Background

To analyze the impact of innovation on the bicycle industry, it is necessary to move from real-world case studies to stylized representations of manufacturing operational parameters (benchmark models) and input costs in each country type. It is only by doing so that we can introduce controls, eliminate extraneous variables and thus analyze the impact of change.

A benchmark factory for a particular product in a given country is intended to represent a prototypical firm manufacturing that type of product in the country. Thus, a benchmark model does not represent any particular firm. The purpose of the benchmark models is twofold: to replicate the relative rankings of LDCs, NIEs and DCs in terms of unit cost, and then to serve as the basis for simulating the effect on firms of the new technologies.

It is useful to clarify the relationship between a "benchmark" factory and "optimal" technique of production. Since input costs vary in the three country types, we would expect that techniques of production most commonly in use reflect those differences. Our benchmarks show that the technique in use does, in general, vary by country type. DC techniques, in particular, are significantly different from techniques in the other country types, with the one exception of shoes, where the benchmark factory even in the DC is assumed to have the same technique as in the other two country types. The difference between LDC and NIE benchmarks is smaller. In one case, printed circuit board assembly, we have two benchmarks for the NIE, one embodying the same technique as in the LDC and the other embodying a more advanced technique.

The benchmark factories in the three country types are assumed here to produce the same product. This is necessary for making international cost comparisons. A means of transport in developing countries and a leisure product in developed countries, bicycles are produced in a wide variety of sizes and shapes, with a vast array of features and at virtually every price (see Box 3.1). Among the features that differentiate bicycles are:

- The number, complexity, and precision of the components;
- The size of the bicycle and its tires;
- The strength and other physical properties of the frame;
- Colors and other cosmetic features.

A bicycle may require as many as 200 different components. Components may comprise up to 70 percent of the bicycle's cost. Bicycles for young children use the least expensive components and have the highest labor cost content as a percentage. A light-weight racing or touring bicycle requires a larger number of components (and hence a higher percentage cost of materials) and more complex assembly operations. Mountain bikes have even more exacting performance requirements and hence more expensive components, requiring greater precision in assembly.

Our cost analysis is based on the children's bicycle with 12-16" wheel diameter. This is the bicycle in which LDCs have the greatest
comparative advantage because it requires simple components, has high labor content, and has a simple process flow.

The choice of children's bicycle has an important limitation. Demand worldwide is shifting towards higher performance bicycles. In particular, the market for mountain bicycles is exploding. Though the fancier versions of such bicycles are very expensive and hence cater to a very small clientele, changes in technology and the high degree of competition are rapidly resulting in lower prices and at the same time creating a mass market for such bicycles. Alternatively stated, the price-performance ratio of the newer bicycles is such that the market for cheaper but simpler bicycles is likely to contract. Our cost analysis of the simpler bicycles should thus be seen as the most favorable scenario for a low-wage economy.

Finally, we assume that firms in all countries can access material inputs at the same price, thus focussing our spotlight on the manufacturing process.

3.2 Manufacturing Processes

In developing countries, bicycle producers are generally fully integrated, and manufacture their own components, possibly including the tubing. In developed countries, component producers and assemblers are quite distinct.

For the purpose of this study, we will consider only frame and bicycle assembly. Almost all the companies we visited had a process flow that was straightforward and essentially identical apart from minor variations. Figure 3.1 shows a general process flow. The first step in the production of a typical bicycle is cutting the tubing to build the frame. The tubing may be steel, aluminum or composite (i.e., carbon fiber). While the more advanced frames are one-piece composite, typical frames require between six and eight cut tubes. Some companies cut their tubes with presses, while others use lathe-like machines or cold saws. This process can be either automatic or manual.

Next, the pre-cut tubes are shaped on the edges so they can easily fit when joined to form the frame or fork. This is done either with a press or by tapering and reaming with a lathe. The fork and frame are then joined. Steel bicycle manufacturers use welding or brazing, depending on the strength and finish that the product requires. Brazing can be done manually, but some more advanced manufacturers use automatic brazers (which can be bought from specialist suppliers or made by the bicycle manufacturer). Aluminum bicycles can be either welded or glued.

Once the frame and fork are completed, some manufacturers clean the frame of brazing or welding excesses with a chemical bath. The frame can then be nicked and chromed. Both of these steps are optional. Next the frame and fork are painted, preferably together so that the quality of paint is consistent for the entire bicycle. Decals can then be applied.

The finished fork and frame then move to the assembly line, along with all the components needed in a complete bicycle, and the bicycle is assembled in a flow line. The finished product may be only partially
assembled, for easier packing and shipping. In that case, the dealer carries out the final assembly.

BOX 3.1: BICYCLES FOR ALL

Bicycles for young children. These bicycles usually have wheels between 10 and 16 inches in diameter. Since they are intended to be toys, used for short periods of time and under favorable conditions, they must be inexpensive and do not need to excel mechanically. They are offered in many shapes and colors.

Bicycles for teenagers. These are usually known as BMX bicycles. They typically have 20-inch wheels and are much stronger than children's bikes because they are used in rougher conditions. These bicycles can be cheap, but certain high-performance models can be fairly expensive.

Light weights. These are the racing and touring bicycles. They have between 5 and 18 different speeds. The frames are usually made of light-weight materials, for better performance. They may have dropped handlebars. Wheels are between 20 and 28 inches in diameter. These bikes are intended for the adult cyclist, although smaller models are available for youngsters. They range from inexpensive, mass-produced bicycles to extremely expensive, handcrafted bicycle with highly sophisticated components.

Conventional bicycles. These are used mainly for inner city commuting, or transporting goods. They are usually known as Roadsters and English or Dutch bicycles. Roadsters generally have a laid-back frame and 28-inch wheels with semi-balloo tires. English/Dutch bicycles typically have a touring frame, up to 3 gears, a chain guard and 27-inch wheels. These bicycles, robustly built, are usually at the lower to medium end of the market.

Mountain bikes. The newest group, these bicycles have 24- to 26-inch semi-balloo tires, upright seating and between five and 18 speeds. They are intended for cross-country use but, because they are easy to handle and comfortable to ride, they are widely used for inner-city commuting. These bicycles, like the light weights, can range from low-price to very expensive models.

Cleaning can be performed at several stages during the manufacturing process, to ensure a fine finish. Some manufacturers even perform a cosmetic operation, to make the joints almost invisible, before painting the bicycle. Typically, it is the high-end manufacturers, for whom appearance is an important feature, that do this.

The diffusion of automated production techniques in the bicycle industry has been relatively slow. Painting is almost universally automated among volume bicycle producers. Even LDC producers find it economical to automate the painting task. Cutting and brazing automation have spread more
slowly. Automation has clearly helped large volume DC bicycle suppliers to survive by, for example, significantly reducing their cycle time. (See Box 3.2). The expectation is that automation will spread more rapidly as demand shifts towards higher performance bicycles which require greater precision in assembly. Even Chinese bicycle producers are acquiring modern automated equipment for producing their higher performance bicycles.

3.3 The Benchmark Factories: Physical Indicators

We have developed stylized representations of manufacturing operational parameters (benchmark factories) and input costs in each country type. These parameters are inputs to the ManuCost, a software package that models manufacturing costs. ManuCost estimates work-in-progress (WIP) and value of scrap to arrive at total costs. Figure 3.2 is a schematic diagram of the cost model.

![Figure 3.2 SCHEMATIC OF THE COST MODEL](image)

The key element of the ManuCost approach is that production is modeled as a dynamic process that occurs over a period of time. This provides the basis for the work-in-process (WIP) cost category, which does not exist in aggregative models that rely only on measures such as capital-output ratio. The physical performance characteristics of machines and labor, along with a specification of how materials move from one stage to another, create the basis for quantifying waste in the system. This model structure also enables us to evaluate savings (or cost increases) that accrue when the process is simplified or a technological change, such as a more highly automated piece of equipment, is introduced into the process. See Appendix B for more details on ManuCost.
We have developed three benchmark factories, one for each country type. Table 3.1 specifies annual production and the input requirements for meeting that production level. All factories are assumed to produce the same number of bicycles: 250,000 a year. The table also specifies operational parameters, such as cycle time (the time taken for a bicycle to be assembled), machine reliability, and process yields (proportion of bicycles not requiring rework). Differences in these operational characteristics determine the differences in the level of efficiency.

The large number of "machines" in an LDC factory represent simple low-cost workstations. Equipment installed becomes faster and more expensive as we move from an LDC to an NIE and then to a DC. The LDC factory uses more labor and less capital (in terms of value) than an NIE factory, as may be expected. However, poorer machine reliability and maintenance forces the LDC factory to have a higher value of equipment than would be the case if maintenance were better. The DC factory uses more valuable equipment and more workers than an NIE factory. Workers work shorter hours and fewer days in a DC factory than in an NIE factory; and there is greater inefficiency in the use of indirect (or supervisory) labor in a DC factory (reflected in the smaller span of control).

In addition to equipment and labor, two resources of importance are materials and work-in-progress (WIP). Several features of Table 3.1 are especially noteworthy in this regard. Slack work methods and inadequate attention to testing in LDCs lead to greater wastage of material (reflected in poor yields). Higher scrap, longer cycle times and larger buffers lead to greater work-in-progress and hence further increase the use of capital, an LDC's most expensive resource. Higher raw material and finished goods inventory in LDCs similarly increase capital use.

An indicator of organizational slack is the size of each batch of bicycles processed, also referred to as the lot size. We have taken the benchmark lot size in the LDC factory to be about 20 percent larger than in the NIE factory. Large lot sizes are desirable when a factory has expensive machines that take a long time to be set up for a new process. However, in the benchmark LDC factory, set up times are not long; particularly for technologies with limited automation, there is no good reason for large lot sizes. In fact, a virtue of manual processing is the flexibility it affords. Hence an efficient manual process would typically run very small lot sizes. The large lot size in the LDC manual factory reflects the uncoordinated manner in which inputs and subassemblies travel through the factory. As a consequence, many unfinished bicycles are processed at the same time, not because that is desirable but because production planning and scheduling are poor. This leads to the build-up of inventory and often also causes errors in assembly. Inventory control problems are often exacerbated by seasonal fluctuation and protectionist trade policies (See Box 3.3).
Table 3.1: MANUFACTURING PARAMETERS FOR BENCHMARK MODELS

<table>
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<th>Parameter</th>
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<th>NIE</th>
<th>DC</th>
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</tr>
<tr>
<td>No. indirect labor</td>
<td>34</td>
<td>38</td>
<td>46</td>
</tr>
<tr>
<td>Absentee rate</td>
<td>32%</td>
<td>32%</td>
<td>32%</td>
</tr>
<tr>
<td>No. of machines b/</td>
<td>72</td>
<td>22</td>
<td>17</td>
</tr>
<tr>
<td>Equipment value c/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total value (S000)</td>
<td>418.0</td>
<td>1020.0</td>
<td>1910.0</td>
</tr>
<tr>
<td>Annualized (S000)</td>
<td>92.0</td>
<td>204.0</td>
<td>343.8</td>
</tr>
<tr>
<td>Sample reliability d/</td>
<td>90/8</td>
<td>160/4</td>
<td>150/8</td>
</tr>
<tr>
<td>Material Inputs ($)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frame/Fork Accessories</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Tubes</td>
<td>1.75</td>
<td>1.75</td>
<td>1.75</td>
</tr>
<tr>
<td>Groupos g/</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Sample yields</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At tube-cutting</td>
<td>0.85</td>
<td>0.93</td>
<td>0.90</td>
</tr>
<tr>
<td>At paint</td>
<td>0.80</td>
<td>0.90</td>
<td>0.85</td>
</tr>
<tr>
<td>At Final inspection</td>
<td>0.92</td>
<td>0.96</td>
<td>0.94</td>
</tr>
<tr>
<td>Lot size</td>
<td>208</td>
<td>174</td>
<td>208</td>
</tr>
<tr>
<td>Inventory (months) f/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw materials</td>
<td>2.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Finished goods</td>
<td>4.0</td>
<td>1.5</td>
<td>3.0</td>
</tr>
<tr>
<td>In-process buffers</td>
<td>6 (days)</td>
<td>3 (days)</td>
<td>3 (days)</td>
</tr>
<tr>
<td>Facility area (sq. ft.)</td>
<td>30,000</td>
<td>24,000</td>
<td>30,000</td>
</tr>
<tr>
<td>Land &amp; Buildings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Value (S000)</td>
<td>270.0</td>
<td>288.0</td>
<td>350.0</td>
</tr>
<tr>
<td>Annualized (S000)</td>
<td>50.4</td>
<td>48.0</td>
<td>52.8</td>
</tr>
<tr>
<td>Admin. costs (S000/yr)</td>
<td>97.3</td>
<td>99.5</td>
<td>101.3</td>
</tr>
<tr>
<td>Annual Production ('000s)</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
</tbody>
</table>

a/ The number of employees (labor or staff) that report to the next higher level of management.

b/ This is the total for all types of machines. A detailed breakdown by type of machine is available upon request.

c/ This is the total for various equipment items. Different equipment types have different depreciation schedules, depending on their useful life. This, along with the long-term interest rate, determines the annualized rate for each item of equipment.

d/ The first number is the average number of hours between machine failures, and the second is the average time to repair the machine, also in hours.

e/ This includes all other components such as derailleurs, brake levers, brake cables, seat post, seat, gear shift lever, freewheel gear cluster, chainwheel, chain, pedals, hub, etc. The rims, spokes, and wheels are also included in this category.

f/ These are for inventory before and after the shop floor operations. Inventory on the shop floor (i.e., shop floor WIP) is calculated by the model.
As a leading US manufacturer of bicycles aimed at the lower end of the market, the Murray Ohio Manufacturing Co. uses as much automatic or semi-automatic equipment as the labor-intensive industry allows.

The Lawrenceburg, Tenn., factory, which produces more than 2 million bicycles a year, has pared down the time required by each step of the manufacturing process. Automatic machines cut the tubing in about one second, for example. Tubes are shaped manually, but the process time is also low. Brazing is automatic and, while the brazing stations themselves are loaded manually, a bicycle can pass through each station in only 10 to 15 seconds. Bicycles leave the assembly line at the rate of eight per minute, and robots do the final balancing of the wheels.

Murray even uses a state-of-the-art CAD system. However, the system has been acquired for its line of lawn mowers, not for bicycles. It can be expected that as the company experiments with new materials, the CAD systems will become more useful for bicycles (see Chapter 5).

It also has an MRP (Materials Requirements Planning) system to keep track of inventories, and computers for financial and managerial tasks. Even so, the company keeps large inventories to cope with the marketplace's seasonal demand. At any moment, it has an average of 200,000 bicycles, with up to 50,000 bicycles of a particular model. It also stocks spare parts for bicycles up to 10 years old. And in its components warehouse, depending on the part, Murray keeps between seven and 10 days' worth of inventory.

For all its efficiencies, the company believes it would benefit from a JIT (Just in Time) system. JIT, however, can require more fundamental changes than implementing automation.

Finally, LDCs, like DCs, have a smaller span of control (the number of employees that report to the next higher level of management). A larger span of control leads to a "leaner" organization. It is characteristic that in an LDC or a DC, seven persons report to an immediate superior. However, in an NIE, a supervisor has 10 persons working under him.

3.4 Input Costs

The cost of labor, capital, and land and facilities for each country type is specified in Table 3.2. The stylizations accord with generally perceived opportunity costs of these inputs. Interest rates are highest in the LDC and lowest in the DC; the ordering of labor cost is reversed. Wage costs specified for LDCs are closer to those prevailing in Mexico than those in China, or even India and Indonesia. The implications of this assumption are discussed below. The "long-term" interest rate is used to value fixed capital and the "short-term" interest rate is used to value inventory and work-in-progress (WIP). The virtue of our modeling procedure is that sensitivity of total cost estimates to variations in input prices can be easily assessed.
Costs of equipment and land and buildings are the sum of depreciation (using the "straight-line" depreciation method) and interest costs with respect to the current valuation of the asset. Thus if equipment has a value of $V$, a depreciation life of $Y$ years, and the "long-term" interest rate is $i$, the annualized cost will be $V(1/Y + i/100)$. Different types of equipment are assumed to have different depreciation rates and these are not reported here.

Unlike other inputs, which have been specified in physical terms, material inputs have been specified in US$/bicycle. This has been done mainly to avoid clutter, since the list of actual inputs is long. The benchmark assumes that prices of inputs are the same in all country types, and so the equality in the dollar value of inputs across country types also implies that the quantity of inputs is the same. This is not necessarily a realistic assumption. It is likely, for example, that certain inputs (such as bicycle parts) are more expensive in an LDC than in a DC from which they are transported. However, since our main focus is on the manufacturing process, we have chosen to control the material prices at the same level in all countries.

It should be noted though that certain indirect costs of importation (and delays involved in that process) are included in the higher levels of inventory in LDCs. Moreover, the input costs specified here should be interpreted as the minimum required for every finished bicycle. In addition, as discussed below, much material is wasted during the production process. The lower the production "yields", the greater the wastage. We indicate a wide range of yields, the lowest prevailing in the LDC Manual factory. As a consequence, greater scrap raises the effective material input per unit of output.

### Table 3.2: Economic Parameters for Benchmark Models

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LDC</th>
<th>NIE</th>
<th>DC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production labor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wage (S/hr)</td>
<td>1.75</td>
<td>2.75</td>
<td>8.50</td>
</tr>
<tr>
<td>Benefits rate</td>
<td>15%</td>
<td>22%</td>
<td>29%</td>
</tr>
<tr>
<td>Indirect labor a/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salaries (S000/yr.)</td>
<td>5-50</td>
<td>6.5-60</td>
<td>15-75</td>
</tr>
<tr>
<td>Benefits rate</td>
<td>15%</td>
<td>22%</td>
<td>20%</td>
</tr>
<tr>
<td>Long-term interest rate %</td>
<td>12.0</td>
<td>10.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Short-term interest rate %</td>
<td>25.0</td>
<td>20.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Facility cost (S/sq. ft)</td>
<td>9</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

*The figures shown are the ranges of salary for different categories of employees. A detailed breakdown of employee categories and corresponding salaries is available on request.*

### 3.5 Benchmark Costs
The manufacturing parameters (Table 3.1) and the economic parameters (Table 3.2) are the inputs to ManuCost, which estimates the work-in-progress and the value of the scrap, based on the operational characteristics specified, to arrive at final costs of production. ManuCost also tracks the time during which labor and capital equipment are actually being used. On that basis, it is possible to break down the use of labor and equipment into what we term "productive" and "unproductive" use. When machine or workers are not being used, we term them "unproductive." ManuCost is capable of providing costs accumulated at different stages of production. We present only the costs of producing the entire product. In the following chapters, the benefits of working with a finely specified production process will become evident.

The NIE factory is the most cost competitive (Table 3.3). Higher unit costs in the DC are explained directly or indirectly by higher labor costs. Even the higher value of scrap in the DC is a reflection of the value added (and hence essentially labor costs) in the material wasted and discarded. The DC firm is also somewhat less efficient than the NIE firm in terms of manufacturing parameters such as cycle times, yields and inventories.

### Table 3.3: Costs Predicted by Benchmark Models

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Cost Per Bicycle (in USS)</th>
<th>Percentage of Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LDC</td>
<td>NIE</td>
</tr>
<tr>
<td>Material</td>
<td>8.75</td>
<td>8.75</td>
</tr>
<tr>
<td>Direct Labor</td>
<td>2.09</td>
<td>2.43</td>
</tr>
<tr>
<td>Direct Equipment</td>
<td>0.91</td>
<td>0.88</td>
</tr>
<tr>
<td>Non-prod. Direct Labor</td>
<td>0.50</td>
<td>0.59</td>
</tr>
<tr>
<td>Non-prod. Direct Equipment</td>
<td>0.28</td>
<td>0.39</td>
</tr>
<tr>
<td>Indirect Labor</td>
<td>2.35</td>
<td>2.45</td>
</tr>
<tr>
<td>Land and Buildings</td>
<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td>Administrative</td>
<td>0.38</td>
<td>0.39</td>
</tr>
<tr>
<td>Inventory and WIP</td>
<td>2.28</td>
<td>0.59</td>
</tr>
<tr>
<td>Valued Scrap</td>
<td>1.24</td>
<td>0.43</td>
</tr>
<tr>
<td>TOTAL</td>
<td>18.94</td>
<td>17.19</td>
</tr>
</tbody>
</table>

1/ "Non-productive direct costs" are computed for both equipment and labor. Examples of non-productive times are equipment waiting for labor, equipment that has failed, and unused capacity of equipment or labor. Higher non-productive costs reflect an imbalance in the production line or production inefficiencies due to machine down time.

2/ During the entire accumulation process, whenever scrap is generated in manufacturing, the full value of the scrapped items is noted. The valuation of scrap includes the cost of raw materials as well as any direct and indirect costs accumulated in that item. For example, labor and capital costs incurred on the production of the item scrapped are included in scrap value. Moreover, if, at an intermediate step, additional raw material is required due to high scrap in the process, this additional cost will not show up in the "material" category but, rather, in the "valued scrap" category.
Space, or the lack of it, is a conspicuous problem at the Mexico City factory of BIMEX, Mexico's largest bicycle manufacturer. Because the factory is in the middle of the city and cannot expand, it lacks subassembly storage facilities. As a result, WIP lines the hallways and is piled on the floors.

Not surprisingly, inventory control is not BIMEX's strength; nobody seems to have a very good idea of the number of components or subassemblies the factory has produced, or how many parts it needs. The assembly line is relatively efficient, using pneumatic tools, but there are large numbers of half-finished products awaiting components that are on order. The factory management explains that the purchasing department had been recently separated from the production department; after a year of working that way, BIMEX is returning to its previous system.

BIMEX's WIP problem is exacerbated by the seasonal difficulties that are endemic to the bicycle industry. The company, whose annual production fluctuates between 255,000 and 300,000 bicycles, starts each year with low levels of sale and about 450 employees. Production is concentrated on English and racing bicycles. By summer, however, BIMEX begins manufacturing large volumes of children's and teenagers' bicycles for the peak-demand Christmas season. During the second half of the year, the company hires about 250 seasonal workers. About two-thirds of the company's annual production is in storage before Christmas.

Another complication for BIMEX's inventory management is that it imports components for its higher-end bicycles, from Taiwan, Japan and Korea (while making most of the components for its cheapest bicycles, which constitute the largest part of its production).

Mexico's former protectionist trade policies may have contributed to these inventory management difficulties. Until recently, the government routinely refused to issue permits to import components or bicycles. That encouraged manufacturers to produce most components themselves. In general, the quality was poor. Since Mexico joined GATT (General Agreement on Trade and Tariffs), such components can be imported, mainly from Japan, Taiwan and Korea. But there are drawbacks; the components are still heavily taxed, and have a lead time of a month or more.

Some Mexican assemblers avert such problems by producing components themselves, but that creates its own problems. Italjet, possibly the healthiest Mexican bicycle assembler, also produces components such as rims, hubs and handlebars, accounting for about 80% of the aluminum rims made in Mexico. It also makes a wide variety of bicycles, from durable tricycles used for transporting goods to children's and teenagers' bicycles and sports and mountain bicycles.

But Italjet's diversification may actually work against the company. According to Italjet's management, it is virtually impossible for the company to compete in the US market against Korean or Taiwanese bicycles, because manufacturers in those countries are so specialized that they can produce large quantities of a component or bicycle model at a very low price. Thus, although Mexican wages are lower, Italjet is undersold by those manufacturers.
That LDC costs are higher, compared with NIE costs, is more directly attributable to inefficiency. The basis for this inefficiency was described above when discussing the manufacturing parameters. Two significant cost disadvantages that result from these inefficiencies are in scrap costs and WIP costs. These more than wipe out any advantage in labor cost.

The LDC factory's strikingly high inventory and WIP (12 percent of total costs) arise from several sources. The bicycle is a highly seasonal product requiring large inventories to be built up before peak selling seasons. In addition, even though it is much simpler than other modes of transport, like them the bicycle is made up of a large number of components which have to be sourced from a variety of suppliers. Particularly when components have to be sourced from abroad, large inventories become necessary to allow for delays in shipment and import control procedures. Many LDC producers, therefore, attempt to produce one or more components themselves; however, this results in loss of specialization and economies of scale. The inventory problem is not necessarily alleviated since coordinating the production of components and assembly of bicycles is not an easy job. In addition, LDC bicycle producers tend to produce a larger range of bicycles than producers in more advanced countries, further sacrificing specialization and increasing inventories. These problems are magnified by the poor work process (low machine reliability, greater wastage).

A feature of these cost estimates that should be noted is the high proportion of material costs. As we shall see in the following chapters, despite the importance of labor costs in DCs, technical change and especially new organizational practices, have been directed significantly towards lowering material costs. Hence, many of the new organizational practices have direct relevance for developing countries.

The relatively low share of labor cost in the total cost of producing bicycles implies that rising wages in an NIE are not likely to be sufficient to make the LDC or DC competitive with an NIE. For example, it would take a 30 percent rise in NIE wages to raise costs to the LDC level. Similarly, if NIE wages remained unchanged, DC wages would have to be reduced by more than half to reach NIE cost levels. It is the case, however, that LDC competitors with the lowest wages (e.g., China, Indonesia, and India) can produce at costs that are between 5 and 10 percent lower than NIE costs, even with the operational inefficiencies specified here. These lowest wage countries constitute a threat to NIEs.

3/ The quantity of WIP predicted in the manufacturing model, and the short-term interest costs, leads to the WIP carrying costs. The calculation is more complex than a simple multiplication for two reasons: i) The WIP carrying cost at the first operation increases the valuation of the WIP for the second operation, and so on, and thus the WIP carrying cost needs to be computed progressively; and ii) The presence of rework leads to "feedback" where the outputs of a downstream operation affect the inputs of an upstream operation. This requires a system of equations to be solved to get the WIP valuation.
That the NIEs are feeling the squeeze is evident. Though Taiwan continues to dominate international sales of bicycles, its share has been declining. The shift of bicycle production to China is clearly under way, although the management and production expertise is being supplied largely by Taiwanese, Japanese, and Western companies; other low wage locales, such as India and Thailand are also gaining (See Appendix A). The NIE under greater pressure is Korea. Despite many other similarities in product sequencing, Korea started producing bicycles much later than Taiwan for historical reasons that are not apparent. As a consequence, the Korean components industry is far less developed than its Taiwanese counterpart, placing Korean bicycles assemblers at a greater disadvantage than Taiwanese assemblers. However, Korean producers are not walking away from the challenge. Through a combination of production enhancements and marketing efforts, they are continuing to fight for international markets and in some cases, their own domestic market (See Box 3.4).

BOX 3.4: TROUBLE IN KOREA

A few years ago, Corex Sports Corporation's (CSC) bicycles were so attractive to US importers that Murray Ohio formed a joint venture with the Korean company to procure them in substantial amounts. No more. The strong Korean currency, rising wages, restrictive labor laws that prohibit the layoff of workers during periods of slack demand, and changing fashions in bicycles - supplanting light weights with all-terrain bikes that require shorter lead times - eliminated CSC's competitive edge. In 1990, Murray dissolved the relationship.

Largely as a result, CSC exports have dropped to 60 percent of total production, compared to 75 percent in 1989. However, output overall is up substantially. Corex is focusing on increasing domestic sales, while seeking new export markets, particularly in Europe.

CSC was better prepared than many companies to deal with adverse market developments. In virtually every respect, its operation epitomizes NIE manufacturing at its most efficient.

The emphasis at CSC is on low-cost automatic systems; computers are used only for accounting. To cut the steel tubing, CSC uses lathes that it has automated with pneumatic controls. It uses semi-automatic spot-welders to place the shifting cable guides. It has recently installed an automatic brazing line, designed and manufactured by a local subsidiary of a German company. After the frames are brazed, they are cleaned in an automatic acid treatment, also manufactured domestically. Other automated equipment includes a French painting machine and a ball-bearing parts assembling machine. Eventually, CSC may automatic its stamping and packing functions, as well as its design.

CSC's greatest bottleneck, in fact, is its dependence on foreign suppliers for components. Because local manufacturers cannot meet its demand, the company is forced to import some of the more complex components from Japan and Taiwan. Accordingly, it keeps a parts supply of a month or two. However, CSC is working with domestic manufacturers to help them meet the bicycle manufacturer's demand.
4. LEARNING TO PRODUCE

4.1 Objective

The state of manufacturing practice in a firm or a country is the result of organizational and shop-floor learning that has been undertaken in the past. The learning experiences of others may sometimes be embodied in advanced machines, reducing the further need for "soft" investments in worker training, improved work practices, and organizational changes. However, a central proposition of this study is that these so-called soft investments, for which we use the short-hand term "learning", are critical to international competitiveness.

We view learning as a process of experimentation aimed at increasing productivity. As such, it is something of an art form. However, modern tools and practices embodied in, for example, Total Quality Control (TQC) and Just-in-Time (JIT) provide structure and content to the learning process by specifying the elements of training, organizational change and infrastructure needed to continuously improve the production process.

In this chapter, we evaluate the quantitative impact of improved production practices that overcome inefficiencies in the production system. The procedure we follow is to generate a set of "scenarios." These are "what-if" exercises and, as such, are purely accounting devices that say nothing about how the transition is made from one state to another. Hence, after demonstrating the quantitative importance of changes in factory operating procedures and practices, we discuss issues relating to their implementation.

The first set of scenarios brings the LDC and DC factories on par with the NIE factories in terms of manufacturing parameters. The manufacturing parameters of the NIE factory can be considered the "current best practice," so this first set of scenarios brings everyone to the current best practice. The cost differences that remain at the end of this sequence are due to differences in costs of inputs.

However, the current best practice in the NIEs is a moving target. Trends indicated in the literature and our field interviews suggest clearly that further improvements in production management will occur in the next five years. These are modeled as "future best practice".

When we "move" a factory from its benchmark level of efficiency to current best practice and then to future best practice, we are assuming that the relevant learning process is in place. Learning, however, is not a trivial task, and it is costly for both the firm (e.g. investment in training) and for the economy (e.g. provision of relevant infrastructure). These costs are not easy to quantify, and so are discussed qualitatively. It could be concluded that these costs are so high that LDC firms should not be producing even a product as technically mature as the one considered in this study. Or, on a more positive note, we could conclude that significant efforts to
generate such learning are needed urgently if LDC firms are to be competitive in international markets.

4.2 Current Best Practice

The following changes were implemented sequentially:

**Improved process efficiency:** Scrap rates, machine reliability and in-house buffers were all brought to NIE levels. We start with these changes because these are internal to the firm and presumably under greatest control by the firm.

**Reduced inventories:** Raw materials and finished goods inventories were brought to NIE levels. These changes typically require cooperation from suppliers and buyers and from the transportation and communication system. However, large inventories cannot be blamed entirely on others' shortcomings. Better production management, greater specialization in procurement and composition of production can all help to reduce inventories.

**Improved management and overall operation:** Span of control, absenteeism, facility area, and days worked per year were all brought to NIE levels. For the DC, days worked per year was left at 240, as working on Saturdays was felt to be unrealistic.

The effects of all these scenarios on the cost of an assembled bicycle are summarized in Table 4.1.

<table>
<thead>
<tr>
<th>Table 4.1: STEPS TO CURRENT BEST PRACTICE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scenario</strong></td>
</tr>
<tr>
<td>Benchmark (as before)</td>
</tr>
<tr>
<td>Steps to Current Best Practice:</td>
</tr>
<tr>
<td>Improved process efficiency</td>
</tr>
<tr>
<td>Reduced inventories</td>
</tr>
<tr>
<td>Improved management</td>
</tr>
</tbody>
</table>

Recalling that the practices are introduced cumulatively, an LDC assembler saves $2.49 per bicycle (a 13 percent decline in cost) by improving production and management practices. Of the gain, $0.84 comes from internal process improvements such as reduced scrap rates, higher machine reliability, and lower in-house buffers. A further $0.60 is gained through improved management (larger span of control, reduced absenteeism, smaller facility area). Thus more than 60 percent of the savings come from internal improvements, implying that the major weakness lies within the firm. Inventory reduction, which depends more (though not entirely) on factors outside the direct control of the firm, lowers unit costs by $0.95 (about 40 percent of the cost reduction).
The significant payoffs from these improved work practices indicate an important role for enabling infrastructure. High machine reliability requires strong maintenance engineers and technicians both within the firm and outside. Reduced scrap rates require that the materials supplied be of high quality. Standards institutions to diffuse quality control, measurement and testing techniques, and machine calibration have very useful roles to play. Good communications and transportation are obvious needs.

Once all the production and management inadequacies have been removed, an LDC, not surprisingly, becomes competitive with an NIE. Even when using manual technology, an LDC firm produces at a lower than an NIE firm using automated methods. As discussed in the next chapter, an LDC can gain further from automation.

A DC firm also gains significantly from the same process improvements. The source of the gain is, however, somewhat different from that in an LDC. We have made the assumption that the DC firm is more efficient than an LDC firm (though less efficient than an NIE firm). However, a DC firm uses more expensive equipment and labor. Hence inefficiency is more expensive in a DC. It will be recalled that our value of scrap measure estimates not just the value of material scrapped but also the value that has been added to the scrapped material. When machinery and workers are expensive, a small amount of scrapped material can lead to great overall wastage.

4.3 Future Best Practice

Countries that have invested in the learning process (the NIEs) have developed a cost advantage that they are able to sustain by continuously redefining the frontiers of the "mature" technology. We expect such redefinition of the frontier to continue. Looking five years into the future, we develop a second set of scenarios. These scenarios take the manufacturing parameters of all the factories from the current best practice defined above, to a possible "future best practice." The following changes are implemented simultaneously:

- A further reduction in scrap and repair rates (e.g. yield at tube-cutting is raised from 93 to 98 percent, and at final assembly from 96 to 99 percent), improvement in machine reliability (increase in meantime between failure from 160 to 320 hours) and reduction of in-process buffers from 3 days to one.
- Raw material and finished goods inventories reduced by half.
- Process cycle times reduced by 10 percent.
- Span of control raised from 10 to 20 and facility area reduced by a further 15 percent.

These represents the outcome of learning-by-doing on the shop floor. Change is incremental and the result of extensive experimenting by workers, technicians and engineers. Firms achieve such learning through a variety of self-reinforcing means, which we discuss below.
When these changes are implemented, an NIE would lower costs by more than $1 per bicycle (a 6 percent decline). (See Table 4.2). An LDC that remains at the benchmark will assemble a bicycle at a cost that is $2.84 higher than the ever-leaner NIE firm. A cost difference of that magnitude would mean that the LDC would find it almost impossible to enter international markets. When we allow for the near-certainty that the NIE would be delivering a more consistent product, on time, the competitive position of a lagging LDC becomes completely unsustainable.

An LDC firm that moves to "future best practice" clearly has greater potential. The LDC cost advantage of $1.20 per assembled bicycle is not necessarily decisive in increasing market share; however, it is a major precondition for competing in international markets. If NIE wage rates rise rapidly, then the LDC advantage would become more substantial.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>LDC</th>
<th>NIC</th>
<th>DC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchmark</td>
<td>18.94</td>
<td>17.19</td>
<td>27.54</td>
</tr>
<tr>
<td>Current Best Practice</td>
<td>16.45</td>
<td>17.19</td>
<td>25.76</td>
</tr>
<tr>
<td>Future Best Practice</td>
<td>14.90</td>
<td>16.10</td>
<td>23.44</td>
</tr>
</tbody>
</table>

The move to "future best practice" also reduces the DC-NIE cost gap. The streamlining allows the DC firm to reduce not only its inventories and scrap, but also its labor cost. However, the cost difference continues to be substantial, implying that DC firms need to differentiate their products considerably in order to be successful. This explains why even Japan, though proficient in process technology, is focusing on product innovation and greater production flexibility. Successful U.S. and other Western producers are adopting the same strategy.

Just as NIE firms are moving to automated processes in anticipation of higher wages, developed country firms are fighting loss of competitiveness by redefining bicycle product and process technologies. NIE firms are not standing still in the meantime: they are experimenting with many technologies being pioneered in DCs and should soon acquire significant proficiency.

4.4 **The Learning Process**

Japanese and other East Asian firms have made an art form of continuous incremental change that, over time, leads to major gains in productivity. The art is being gradually codified into techniques covered under the rubric of just-in-time (JIT), of which total quality control (TQC) is a subset.

These modern techniques of organizational change offer significant possibilities for manufacturers in LDCs. Our cost analysis has shown that adoption of these techniques restores the cost advantage of LDCs over NIEs.
Scrap and inventory reduction under JIT are especially beneficial to LDCs. Reduction in waste confers an obvious benefit and high interest rates make it punitive to maintain large inventories.

The deceptive charm of JIT also is that there appear to be no costs associated with implementation. However, implementation of any change is an expensive activity and JIT is no exception. More importantly, JIT implementation is expensive in a resource that LDCs are not well-endowed with: human capital. Implementation requires tuning the technology to the organization and tuning the organization to the technology (Leonard-Barton 1988 and Schroeder, Gopinath, and Congden 1989). The skills required for such tuning include both formal training (to understand the principles underlying the technology and the theory of organizations) and experience in implementing change.

In addition, there are costs due to lost production during the period of implementation and more conventional costs of buying new equipment and hiring consultants.

It is also good to keep in mind that implementation of new technologies and practices in LDCs occurs in a context that is not conducive to change. The ability to source inputs in a timely manner from specialized producers is critical to the full implementation of JIT. This requires good physical communication, but it also requires the growth of specialized suppliers working in a cooperative mode with their buyers. Infrastructural deficiencies, regulatory barriers, and constraints on input supplies are some of the handicaps from which firms in developing countries suffer. Firefighting on these fronts is very expensive in terms of scarce managerial and entrepreneurial resources.

We discuss below these specific costs of JIT implementation in some detail.

Training and Organizational Change

While popularly viewed as an inventory reduction practice, JIT is an organized process of incremental change aimed at creating a closely integrated flow of work. JIT requires microscopic attention to detail and is aimed at streamlining procedures, reducing set-up times and scrap rates, improving machine reliability, reducing variability of production flow, and such like. Such internal efficiency measures make lower inventories possible; in turn, lower inventories unmask further inefficiencies and force changes. Greater decentralization of decision making (reduced span of control) reinforces these efforts by generating more information from the shop-floor, feeding the process of continuous minor modifications.

The process of implementing JIT is experimental in nature; however, well-defined techniques exist for such experimentation. The JIT toolbox consists of: industrial engineering techniques to reduce machine set-up times and facilitate easy changeovers in the use of machines; methods for streamlining plant layouts; techniques for quality control and maintenance; and organizational and engineering techniques for simpler product design.
(Zipkin 1991). Thus the most important investment required for implementing JIT is human capital. Only a workforce that is well-educated and trained can use these tools effectively.

Training takes many different forms. Workers may be sent to external institutions, such as local community colleges and vocational schools. Within the firm, formal courses may be organized or training may be imparted in many informal ways.

Japanese scholars have emphasized that the so-called informal training is probably the most important and most effective form of training for improved shop-floor productivity (Koike 1988). The important observation is that improvements are brought about by line workers who do not necessarily possess industrial engineering diplomas and degrees. However, effective supervisory support is crucial.

Informality in this context does not imply a lack of training plan or direction. Paradoxical as it may sound, informal training requires a strong institutional commitment and well-defined process. Limited reliance on the classroom is the main reason for using the term "informal". Mentoring by supervisors, collaborative problem solving with peers (quality-circles), job rotation through the plant and the firm are the more important elements of informal training.

The message on training is clearly out. U.S. firms attempting the adoption of JIT techniques are making serious efforts to institutionalize formal and informal training processes within firms.

A closely related concern that interacts with training is the need for organizational change. Delayering the traditional organizational pyramid by expanding the span of control yields significant cost savings in companies located in all country types, but especially in those countries (DCs and NIEs) where the cost of management is high. Take the example, of a factory employing 385 line workers. Using a span of control of ten; the plant require 35 first level, four second level, and zero third level managers. Table 4.3 shows that a relatively small change in the span of control produces a dramatic change in the number of managers required.

The greater gains from reduced span of control arise in the form of better information generation and decision-making. Workers close to the shop-floor have superior information on the work process and are potentially better positioned to rapidly analyze the information and take corrective measures before problems cumulate (see especially Aoki 1990 on such benefits in the Japanese context). These gains, however, are hard to quantify.
Table 4.3: SPAN OF CONTROL EFFECTS

<table>
<thead>
<tr>
<th>Managerial Level</th>
<th>Span of Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Third-Level</td>
<td>13</td>
</tr>
<tr>
<td>Second-Level</td>
<td>39</td>
</tr>
<tr>
<td>First-Level</td>
<td>116</td>
</tr>
</tbody>
</table>

The pressure to increase span of control grows when greater emphasis is required on reducing lead times, improving quality, and increasing product variety. No longer is time available for problem-solving decisions to filter through several layers of management and companies must flatten their traditional hierarchy. They must train production workers in problem-solving techniques and, at the same time, empower them to implement solutions. Autonomy and decision-making authority must be transferred from management to the shop floor (Deming, 1986).

However, the ability to delegate depends heavily on the quality of both management and labor. Management needs to be trained in the tools of JIT and thereby simplify the tasks to be performed. On the other hand, workers need skills to take on the responsibility of interpreting the operation of the factory and discovering creative solutions to problems.

Given the limitations of both managers and workers, increasing the span of control may not be cost effective. Savings are possible only when greater responsibility can be safely delegated to the production line employee. This creates particularly severe pressures on LDC firms to invest in training. However, the ability to train is constrained by low basic educational attainments of the employees. Limited knowledge exists on the form and magnitude of training incentives to which LDC firms respond, and this is clearly an important area for further investigation.

Productivity "Dip" and Other Investments

In addition to the costs of training often overlooked is the cost of disruption in the manufacturing process that JIT causes by reducing inventories. Drastic inventory reduction, resulting in a shortfall of raw materials, will create idle stations and disrupt production - potentially to such a point that the problems incurred will cost the company more than the benefits to be derived from JIT. Known as the "productivity dip," this disruption is common and should be addressed prior to JIT implementation (Suri and DeTreville, 1986).

The financial costs of such disruption may be minimized by proceeding sequentially. Experience has shown that JIT should be implemented in stages, in carefully selected areas, rather than being adopted immediately, company-wide (Barrett, 1988). A step in the successful implementation of JIT is a carefully chosen pilot project. A pilot project helps gain the confidence of both managers and workers, and provides training to engineers and
employees (Love, 1988). Starting with internal efficiency measures, over which the firm has more control, is a logical approach to implementing JIT.

Consultancy costs of developing and implementing JIT can be significant. In addition, LDCs tend to have underdeveloped consultancy services, particularly those directed towards small and medium-sized firms. Programs that tap and train private individuals (retired executives, university professors and graduate students, vocational school trainers, and capital goods suppliers) to work with small and medium-sized firms could have big pay-offs.

A network of government and industry run technology diffusion centers may act as a substitute (OTA 1990 and Cole 1989). National Bureaus of Standards and public and private productivity organizations, often organized by industry groups, play a very important role in technology diffusion. In Japan, for example, external consultants are used to a much smaller extent than in the United States. Diffusion centers are both a source of expertise and also a forum for exchange of lessons learnt.

Though JIT techniques are directed primarily at changing the organization, new machinery is often required (Zipkin 1991). Improving the quality of machinery is sometimes a prerequisite for achieving lower set-up times and greater machine reliability. Often production capacity also needs to be increased as inventories are being lowered in order to accommodate sudden surges in demand.

**Infrastructure**

Besides the obvious need for transport and communications infrastructure, unreliable suppliers also impede the movement toward JIT in LDCs. Manufacturers we interviewed most often cited the lack of reliable suppliers as an impediment to JIT in an LDC company. This perception needs to be interpreted cautiously. We have discussed above the importance of many internal improvements which lead to substantial productivity gains.

Manufacturers that have recently implemented JIT programs have reduced the total number of their suppliers, established long-term relationships with the remaining suppliers, and created certification programs for key suppliers.

Such programs are not without precedent even in LDCs. Recently, Caterpillar Inc., in conjunction with P.T. Natra Raya of Indonesia, has begun to qualify suppliers for its Indonesian factories. There are few such qualified suppliers in Indonesia now, but Caterpillar has offered training and technology to those suppliers willing to work toward qualification. Caterpillar thus hopes to manufacture in Indonesia internationally competitive products and components (Cat World, 1989).

Programs that supplement the initiatives of major international companies such as Caterpillar are needed to diffuse widely international standards in quality control practice and provide certification services.
Such programs are, in principle, no different from the general technology diffusion programs described above.

4.5 Summary

JIT may be considered the institutionalization of a learning process within the firm. Economists are used to thinking of "learning" in a somewhat mechanistic manner. Learning is often viewed as a costless by-product of production or investment. If that were the case, Eastern European firms would be amongst the lowest cost producers in the world. The reality is that learning is an expensive process requiring considerable experimentation with the production process and, more fundamentally, with the organizational structure of the firm.

JIT implies one or both of the following propositions: 1) human capital requirements, in particular, but also the need for physical capital, are so strong, even for so-called "low end" products, that most developing countries do not have a real comparative advantage in simple manufactured goods; 2) to overcome this disadvantage, access to international sources of knowledge and increased domestic investment in knowledge creation, with a clear focus on improving basic manufacturing productivity, must be a major priority for LDCs.

The implication is that greater experience with modern industrial practices is needed in a setting where such experience can be absorbed. Close links with foreign firms that possess the knowledge needed for efficient absorption is likely to be a must.

In the early 1980s, JIT was labeled a strategy possible only in the restrictive operating conditions prevalent in Japan. Yet today, U.S. manufacturers provide the success stories so abundant in the literature. They are learning to better manage suppliers, train employees and update their manufacturing techniques. Not long ago the U.S. manufacturing environment was classified as not conducive to the use of JIT. Today the same is being said of the LDCs.
5. NEW DRIVERS OF COMPETITION

Firms in newly industrializing economies (NiEs) have sustained international market share through proficiency in manufacturing. However, when efficient manufacturing is possible in a low wage economy, then the competitive advantage of NiEs falls. The growth of bicycle manufacturing in China and Thailand, albeit with considerable foreign inputs of marketing and technological knowledge, is creating severe pressures on NiE firms. At the same time, developed country (DC) firms have taken the initiative in many directions. Attempts to rationalize and coordinate production, aggressive promotion of brand names, greater customization, and more rapid new product introduction are some of the strategies being followed.

Competition in the bicycle industry today has, therefore, many new drivers. Different country types are using strategies best suited to them. We discuss below the role of scale economies, greater automation, increased flexibility, and use of new materials.

5.1 Economies of Scale

To study the benefits of economies of scale, we modeled production volumes from 50,000 to 2 million bicycles per year. Other characteristics (particularly the efficiency parameters) of the production process were not changed. The basic conclusion of these exercises is that costs go up very sharply when production is reduced below 250,000 units a year (decline in production from 250,000 to 50,000 can raise costs by a third even for processes with relatively low automation). Increase in production in the LDC benchmark factory from 250,000 to 1 million bicycles a year lowers unit costs by about 5 percent; most of this gain occurs when production is raised to about 500,000 units.

Automation increases the efficient size of the plant, but only to a small extent. It is often conjectured that the modern automated equipment is also more modular, resulting in an actual decline in the efficient size of the plant. There is no support from our simulations for such a conjecture. What the modern automated equipment does allow is the production of small lot sizes because the time to change machine settings for a different product range become smaller with such equipment. However, to use the equipment efficiently, the annual throughput of the plant must increase, if only marginally.

These simulations of economies of scale are consistent with observed plant sizes. Plant sizes smaller than 250,000 units are almost non-existent among internationally competitive mass producers. Large volume producers have plant capacities of a million or more bicycles per year. New plants being built in China appear to be targeting capacities between 500,000 and 1 million bicycles; these plants are going to use modern semi-automated or automated equipment.
Giant Manufacturing Co., Ltd., Taiwan's top bicycle maker, expects to produce 1.7 million bicycles in 1991, about the same as in the past two years. The bulk of the production comes from a single factory; 250,000 bicycles are produced in a former subsidiary (Mepu Manufacturing) which has since been merged into the parent company. About half of Giant's bicycles are marketed under its own label; the rest are produced for other brand names.

In describing the rationale for merging the subsidiary with the parent company, Giant's Chairman, King Liu, provided some indication of why bigger may be better:

"We needed to consolidate our business infrastructure and rationalize our management systems. Up to now Giant and Mepu independently managed everything from merchandise development, parts acquisition, production quality control and marketing. However, we discovered that for the price of supplies, volume is the key. We realized that purchasing independently was completely irrational. Our ultimate objectives are the rationalization of management and consolidation of the business infrastructure by having unified management of all activities from merchandise development to marketing."

The need for coordinated components sourcing is especially acute in the bicycle industry since component suppliers have strong monopolies. In addition, Giant furthers its goal of spreading its brand name by producing larger volumes of quality output. Distribution subsidiaries and joint ventures have been set up in major international markets to promote the Giant brand name.

Another example of conglomeration in the bicycle business is the recent series of acquisitions by Luxembourg-based Derby International. Since March 1987, the company has acquired Raleigh brand companies in the UK, Canada, Australia, South Africa, and the US; it has also acquired Holland's Gazelle and West Germany's Neu Kalkhoff. A parts maker, Sturney Archer, has been another acquisition. At present, Derby's various acquisitions produce 2.5 million bicycles a year. If the company's plan to acquire Peugeot Cycles had gone through, it would have truly dominated international markets.

Large firms gain other benefits besides cost reduction. Some of the world's largest firms produce 2 million or more bicycles a year. They gain from the ability to secure low prices for materials and components ordered in bulk, through spreading marketing expenditure over a larger volume, and, in general, through economizing on management overheads. (See Box 5.1) Large bicycle producers such as Taiwan's Giant Manufacturing Company are buying marketing outlets in major bicycle consuming nations. China's leading bicycle exporter, China Bicycle Company, is similarly in the process of acquiring a U.S. distributor.

Another dimension of scale economies which we were unable to explore is the effect of agglomeration. International sales of bicycles have typically been dominated by one or two countries. In the past decade, Taiwan has produced almost half the international flow of bicycles. China has risen very rapidly to second position and could acquire a more commanding role. In manufacturing, such heavy dominance by one or two countries is unusual, indicating that co-location of bicycle producers possibly has a synergistic effect.

We can only speculate on the sources of synergy. Flow of information design and production techniques between proximate bicycle producers (through movement of personnel, conferences, and informal contacts) may be of some importance. In the late 1970s and early 1980s, Taiwanese standards-setting institutions played an important role in diffusing bicycle-making technology and created a forum for bicycle producers to talk to each other.

Perhaps more importantly, close communication between bicycle designers, assemblers, and parts producers could create greater efficiency. Whether such links exist in NIEs and LDCs is not evident from the trade press and was not a subject we explored in our interviews. Taiwan has a thriving parts industry, second only to Japan. The ready availability of parts is viewed widely as a major competitive advantage; or alternatively, lack of a local components industry is thought to be a disadvantage even in a country with a relatively easy import regime, such as Korea.

In the DC context, a recent example of close collaboration to draw on complementary strengths is the relationship between three French companies: Look, Procycle, and Peugeot. Look is a well-known producer of carbon frames and clipless pedals. It has entered into a collaboration with Procycle to produce bicycles, which will be marketed through Look's existing distribution network. The bicycles produced will use a special Peugeot brazing process in which the welding is done by heating the inside of the tube, thus preventing "beads" from appearing on the outside (Cycle Press International, January 1991, p. 5).

In some areas of bicycle-making, economies of scale are irrelevant. A thriving group of small and innovative firms exists, particularly in United States. Located primarily in California, these firms operate in the spirit of the high technology firms in Silicon Valley, experimenting with new materials and design concepts that produce very high priced bicycles for very select customers. Intensive in human capital, their relevance to developing countries is limited. A good example of such a firm is described in Box 5.2.
Box 5.2: CRAFT PRODUCTION

It takes Fat City Cycles between four and five weeks to produce one of its fat-tired mountain bicycles, but high productivity is not the object of this privately-owned company in Somerville, Mass. Fat City is exemplary of the way a company in a high-wage, developed country can thrive in a labor-intensive industry. The company, which says its goal is to "build consistently the finest hand-made fat tire bike available," makes only 1,500 bicycles a year; they retail between $1,500 and $2,500.

Much of the production at Fat City is done by hand, starting with the welding - performed by a craftsman, who welds every joint meticulously. Alignment of the frame, a very important feature in a high-performance bicycle, is done completely by hand. Each bicycle is painted separately, and by hand, so that Fat City can meet customers' specific demands.

Fat City employs about 20 people, and does not regard wages as a major expense. Although the workforce must be highly-skilled, labor represents only 16% to 20% of the company's costs; as much as half the cost is in raw materials. It imports most of its components from a company in Japan, chosen for its quality and on-time delivery.

Against all odds, Fat City is internationally competitive. In the past, it has sold all its production in the US, where mountain bicycles now comprise half of the industry's sales to adults. Recently, however, the company has begun to export bicycles to Europe.

5.2 Automation

We study here the impact of automating the LDC and NIE factories to the level assumed in the DC benchmark factory. Automation results in a substitution of machines for labor. The key question addressed here is whether it still makes sense to automate even at low wages. That would be the case if automation increased productivity to an extent that unit costs of capital actually fell. Such is indeed the case in other sectors we have studied. As noted in Chapter 3, painting even in low wage countries is significantly automated because both capital and labor productivity increase with automation, at least up to a point. The other advantage of modern automation is increased production flexibility. That is discussed in the next section.

The nature and degree of automation at the different stages of production is described below:
**Cutting.** The steel tubes are automatically fed into a machine which is preprogrammed to cut lengths of 30-40 inches. The machine allows tubes of multiple lengths and thickness to be cut.

**Pressing.** The pre-cut lengths of tubing are put into a hopper that bends (or crimps) the tubes in prespecified locations and at prespecified angles.

**Brazing.** The cut and pressed tubes are placed manually in a fixture to hold them together. Then an automatic vehicle moves them to a robot that brazes the joints. The brazed frame is returned to the operator.

**Painting.** Even in the benchmark LDC factories, automatic conveyor lines move bicycle frames through automatic spray painting machines. The additional automation introduced here has a programmable facility, higher speed and higher capacity.

In keeping with our observations above that automation introduced without prerequisites in process control and quality management leads to an increase in scrap rates, we make the assumption that scrap rates increase by about 5 percentage points (from 5 to 10 percent or 10 to 15 percent, depending upon the operation). However, we also examine the implications of automation when the prerequisites have been met.

Unit costs increase in both the LDC and NIE when the factories are automated to levels prevailing in the DC benchmark factory. See Table 5.1. Labor costs fall in each case but capital costs increase, as may be expected. More importantly, the value of scrap increases and this has a decisive influence in the LDC case.

**Table 5.1: The Right Way to Automate**

<table>
<thead>
<tr>
<th></th>
<th>Benchmark Process Automated to DC Level</th>
<th>Benchmark Factory moved to Future Best Practice</th>
<th>Future Best Practice Plus DC Level Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LDC</td>
<td>NIE</td>
<td>LDC</td>
</tr>
<tr>
<td>Material</td>
<td>8.75</td>
<td>8.75</td>
<td>8.75</td>
</tr>
<tr>
<td>Direct Labor</td>
<td>2.09</td>
<td>2.43</td>
<td>1.24</td>
</tr>
<tr>
<td>Direct Equipment</td>
<td>0.91</td>
<td>0.89</td>
<td>1.33</td>
</tr>
<tr>
<td>Non-prod. Direct Labor</td>
<td>0.50</td>
<td>0.59</td>
<td>0.40</td>
</tr>
<tr>
<td>Non-prod. Direct Equipment</td>
<td>0.28</td>
<td>0.39</td>
<td>0.58</td>
</tr>
<tr>
<td>Indirect Labor</td>
<td>2.35</td>
<td>2.45</td>
<td>2.09</td>
</tr>
<tr>
<td>Land and Buildings</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td>Administrative</td>
<td>0.38</td>
<td>0.39</td>
<td>0.38</td>
</tr>
<tr>
<td>Inventory and WIP</td>
<td>2.28</td>
<td>0.69</td>
<td>2.23</td>
</tr>
<tr>
<td>Valued Scrap</td>
<td>1.24</td>
<td>0.43</td>
<td>1.90</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>18.94</td>
<td>17.19</td>
<td>19.09</td>
</tr>
</tbody>
</table>

Rise in value of scrap in the LDC factory occurs partly because of our assumption that handling more complicated machines without adequate training and streamlining of procedures will lead to greater waste. But value
of scrap also rises because now the material wasted has been processed by more expensive machines. As noted, our measure of scrap value includes not only the material wasted but also the value that has been added to it. For this reason, scrap value rises even in the more efficient NIE factory.

Notice also that NIE capital costs increase because both the productive and the non-productive costs of equipment increase. Once again, when more expensive equipment is used the effects of poor plant layout, non-streamlined workflows, and poor maintenance get magnified. This is true even when, as is typical of NIES, the level of efficiency is already relatively high.

We, therefore, repeat the enhancement of automation in the LDC and NIE factories but after factory processes have been streamlined to the level described in our "future best practice" scenario discussed in the previous chapter. Now the effect of automation is reversed. NIE unit costs fall by 3 percent and LDC costs fall by 5 percent. Unit capital costs scarcely rise and unit labor costs fall, creating a competitive advantage for automation.

To summarize, expensive automation is unforgiving of errors and magnifies waste. As modern techniques of quality control are further honed to eliminate errors and waste, automation will become increasingly economical. In the meantime, as the price-performance ratio of automatic equipment improves, the incentive to automate will further increase.

For developing countries, the message is a mixed one. The gains possible through techniques of quality control and automation are great. An LDC firm at the frontier of management practices (in the specific sense discussed in this study) and willing and able to install modern equipment can be very competitive in international markets. A firm lagging in these respects will gradually be eliminated from international competition.

5.3 Flexibility

Production flexibility is of value because customers are willing to pay for a product designed to their specifications and delivered in a short period of time. For a manufacturer, flexibility is expensive since costs increase when an attempt is made to tailor products to customer tastes. We investigate here the trade-off between flexibility and costs when alternative technologies and organizational forms are used.

We focus on the ability of a firm to respond rapidly to shifts in market demand. This ability is proxied in our models by the number of models (varieties) produced in a day. Consider a factory that has the capacity to produce 100 bicycles of a single variety in one day. A difference in color, wheel size, or component mix results in a different variety. If the factory is producing more than one variety per day, then it will complete the day's production of one variety before moving to the next. The reason is simple: each time a change is made, time is lost in the new set-ups. Presumably, therefore, when more than one variety is manufactured, the factory's output will be less than 100 bicycles a day: if it is in fact producing 100 bicycles, then the plant may be considered highly flexible.
The first question is: how does daily production decline when the number of varieties per day is increased? Since the factory overhead does not decline when more varieties are produced (in fact, overhead may go up), one could alternatively ask: how do unit costs increase as the number of varieties rises? The second question is: does this trade-off differ by level of technology (benchmark, future best practice, future best practice plus some appropriate level of automation)?

We focus only on the LDC case, since the trade-offs discussed are similar for all country types. The effects of increasing the number of varieties per day in the benchmark LDC factory are shown in Table 5.2. Purchasing personnel, and design/support staff need to be increased; also the span of control decreases because the production control system becomes more complex. On both counts, the number of "indirect" workers rise. We also assume that greater variety results in lower volume purchases of a larger range of materials and components, raising these input costs. All other costs (facilities, administration, number of direct workers, and machines) are assumed to remain unchanged.

Table 5.2: Changes due to increased number of products/day

<table>
<thead>
<tr>
<th>Number of Products/day</th>
<th>3</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Direct Labor</td>
<td>167</td>
<td>167</td>
<td>167</td>
<td>167</td>
<td>167</td>
<td>167</td>
<td>167</td>
<td>167</td>
</tr>
<tr>
<td>Number of Machines</td>
<td>72</td>
<td>72</td>
<td>72</td>
<td>72</td>
<td>72</td>
<td>72</td>
<td>72</td>
<td>72</td>
</tr>
<tr>
<td>Number of Indirect Labor</td>
<td>54</td>
<td>59</td>
<td>63</td>
<td>67</td>
<td>71</td>
<td>75</td>
<td>79</td>
<td>88</td>
</tr>
<tr>
<td>Per cent increase in raw material costs</td>
<td>0.00</td>
<td>2.50</td>
<td>5.00</td>
<td>7.50</td>
<td>10.00</td>
<td>12.50</td>
<td>15.00</td>
<td>17.50</td>
</tr>
<tr>
<td>Lot Size</td>
<td>208</td>
<td>102</td>
<td>50</td>
<td>32</td>
<td>23</td>
<td>18</td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>Flow time (days)</td>
<td>42.51</td>
<td>21.21</td>
<td>10.78</td>
<td>7.15</td>
<td>5.33</td>
<td>4.32</td>
<td>3.49</td>
<td>2.88</td>
</tr>
<tr>
<td>Annual Production (000's)</td>
<td>250</td>
<td>245</td>
<td>240</td>
<td>231</td>
<td>211</td>
<td>213</td>
<td>202</td>
<td>190</td>
</tr>
<tr>
<td>Unit Costs</td>
<td>18.94</td>
<td>19.45</td>
<td>20.01</td>
<td>20.82</td>
<td>21.74</td>
<td>22.63</td>
<td>23.73</td>
<td>25.41</td>
</tr>
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To increase the number of products produced in a day, the size of each lot (or batch) entering the factory is lowered. This lowers waiting time at a machine and hence allows the product to flow through faster. However, machine set-up times increase and, as discussed above, aggregate annual production falls and unit costs rise with increase in variety. The important point to note is that the trade-off between unit costs and flexibility worsens with the number of varieties. An increase from 10 to 30 varieties raises unit costs by $1.37; unit costs rise by $1.81 when the number of varieties increases from 30 to 50 and by $2.79 when varieties increase from 50 to 70.

This worsening trade-off is important because variety is becoming a competitive instrument. In the introduction, we described a Japanese company that offers numerous variations on several aspects of the bicycle, thus claiming to produce millions of varieties. While these claims need to be viewed with healthy skepticism, it is clear that even when several hundred varieties are produced in a short span of time, costs can rise sharply.
Technology choices have a major impact on these trade-offs. We consider some of these choices.

**DC Benchmark Level of Automation Adopted in an LDC Factory**

Such automation has some flexibility since machines can be programmed. However, the time for change-over between models can still be quite large. With expensive equipment, these large change-over times quickly raise cost. Beyond about 40 varieties, such automation becomes prohibitively expensive. (Figure 5.1)

**Just-in-Time.** Many features of JIT that lower unit costs also help increase flexibility. JIT techniques are used to reduce set-up times of machines and cycle times for processing; also, the focus on preventive maintenance increases machine reliability. As Figure 5.1 shows, variety still has a cost. However, now the whole flexibility-unit cost curve shifts down, allowing greater flexibility to be achieved at lower cost when compared to the benchmark. Also, the rise in unit costs with increasing variety occurs more slowly than it did in the benchmark factory. Unit costs for 70 varieties after adopting "future best practice" are lower than benchmark unit costs for only 5 varieties.

Figure 5.1 also shows that the serious disadvantage of hard automation (the current DC benchmark level of automation) declines when "future best practice" is adopted. However, unit costs do rise rapidly even in this case making hard automation unsuitable for flexible production.

**Flexible automation.** The ability to program machines is increasing. However, these machines are more expensive and the operating software costs are also higher. These larger fixed costs raise unit costs when the level of variety is low. However, the payoff occurs when variety increases. For great variety, flexible automation costs fall below that of the benchmark. In technical economic terminology, flexible automation exhibits significant economies of scope.

In the scenario for Figure 5.1, we have assumed that flexible automation is adopted along with "future best practice". The slope of this curve is the shallowest and at 70 varieties it dominates.

Hard automation uses devices such as CAM-following mechanisms and gears whereas flexible automation uses numerically controlled devices such as stepper-motors, and hydraulics controlled by programmable controllers, resulting in numerically controlled machines or programmable robots. Hard automation tends to be lower cost (in terms of fixed outlays on machines, software and training) and is capable of prespecified set-ups, whereas flexible automation is more expensive but allows a much wider range of set-ups to be programmed. It should be emphasized that both types of automation presume a degree of training and education but the amount of training for flexible automation tends to be much greater. The risk of errors and failure is greater in the case of flexible automation since its complexity level is higher.
Figure 5.1: The Costs of Variety

Note: This set of scenarios is based on changes made to the LDC benchmark factory.
Group Technology. This is an increasingly popular "soft" technique intended to increase production flexibility. As the name implies, components and processes are unified and grouped, reducing substantially the main enemy of variety: set-up times. Also costs of purchased inputs fall since volume buying increases (See Box 5.3). Introduction of group technology greatly lowers unit costs at high levels of variety (Figure 5.1). The major requirement for successful implementation of group technology is human and organizational skills, as with JIT.

To summarize, while variety is expensive, numerous techniques are being devised to lower unit costs while increasing flexibility. These include microelectronics-based solutions embodied in so-called flexible automation, and "soft" techniques such as JIT and group technology. Even the microelectronics solutions require considerable programming, and hence human skills.
Box 5.3: GROUP TECHNOLOGY

Group Technology (GT) is a philosophy that exploits similarities in the attributes of components or machines. The goal is to replace parts made of the same material and similarly shaped, with one unified part. When complete unification is not possible, GT is used to identify families of parts in order to reduce duplication in purchasing, design and engineering.

In the same manner, an attempt is made to process similar components and materials in a single lot through the same set of machines. This reduces the set-up times required in change-overs. The use of GT in manufacturing often results in the formation of small "cells" of machines where a family of similar parts is manufactured.

The benefits of GT include reduced set-up times (and hence throughput times), lower unit costs of purchased materials and lower work-in-process inventory. Increased worker satisfaction and productivity (since workers are now given wider responsibilities to manage a whole product or subassembly) are also sometimes reported. In one recent GT-based factory reorganization, 700 of the 1,400 machine tools were eliminated. Benefits are particularly high when the ratio of setup time to process time is high and when much material moves between process departments.

The costs of GT are, however, not trivial either. As in the implementation of JIT, disruption during the changeover period results in a "productivity dip". Often, existing equipment is not appropriate for a cellular layout. Demands on software are particularly high. Specialized parts databases need to be created to implement GT. Clustering analysis on large databases to identify common parts and process flow analysis to determine the appropriate cell layout are necessary.


5.4 Blue-Sky Scenario

We conclude this discussion with a somewhat futuristic scenario based on trends in materials development and robotics. The scenario envisages the availability of a very high performance bicycle at about today's prices (high performance because of the quality of the frame and because of the quality of the assembly). This scenario is based on our assumption that new developments will be used commercially principally to lower the costs of high quality bicycles and less to reduce further the costs of the average bicycle sold today. The implication is that the types of bicycles in mass use today will gradually be rendered obsolete.
Two elements of the scenario are futuristic. We assume that composite frames that require little or no assembly will become commonly-available as high-volume production increases, providing both economies of scale in production and a learning experience. At the same time, basic and applied research in materials technology can be expected to lower costs of high performance materials (See Box 5.4).

For this reason, we suggest in this scenario that costs of composite frames could come down to approximately the cost today for the material of a steel frame (which then has to be brazed). This is a substantial drop from today's composite frame prices. Thus we assume that a frame costing a few hundred dollars would fall to less than $10. This is undoubtedly a very large, and possibly unrealistic, drop.

The second blue-sky element is the introduction of very sophisticated robotics of a type that does not currently exist. We assume that the entire assembly would be done by several robots, each costing $50,000 (for the benchmark parameters, 26 robots would be required). Labor of only a supervisory and maintenance nature would be needed, and cycle times would sharply decline.

When both these developments are incorporated into a single, blue-sky scenario, we conclude that this high performance bicycle would cost $23 apiece. Clearly, this is very optimistic scenario. However, the basic point probably still holds. In the future, advances in materials and robotics will make higher performance bicycles available at lower prices, committing today's bicycles to the same fate that has befallen the hardy roadster bicycles of yesteryear.
Box 5.4: HIGH-TECH MATERIALS

While the vast majority of the world's bicycles are still built from steel, manufacturers at the upper end of the market have been experimenting with some unusual metals - titanium, magnesium, aluminum and boron - and even synthetics. One company is developing a radically redesigned bike made from the injection of vacuum-molded plastic. But the greatest potential seems to lie with composites.

Widely used in aircraft, boats and cars, composites are lightweight and strong, and have the added attraction of being substantially cheaper than the exotic metals. Their use also allows the frame to be molded in one piece, and for special features to be molded right into the equipment. At this point, such molds are very expensive. However, once production reaches a certain volume, this process could cut production costs, as well as improve the bicycle's reliability. (Machine Design, June 8, 1989, p.80)

For now, composites are mainly limited to companies that cater to bicycle enthusiasts. Laminated composites are making a big impact on the design of custom off-road and racing cycles. The Kestrel 4000 from Cycle Composites is an all-composite (carbon/epoxy) bicycle that is 20 percent stiffer, 2.5 times stronger and 30 percent lighter than bicycles made with steel frames. Its tubes are formed from unidirectional fabric tapes, and the tube shape can be modified to improve aerodynamics - so significantly that the Kestrel has been banned from international competition because, judges said, it gave cyclists an unfair advantage.

Recently, exotic metal-matrix composites have been added to the other fibers to cut weight. Not only are metal-matrix composites stiffer, they can be processed with the same techniques as conventional metals, averting the need for exotic production techniques. Specialized Bicycle Components has begun producing rims for MTBs with an extruded aluminum composite reinforced with 10 percent aluminum-oxide particulate. Trek Bicycle Co. makes aluminum and carbon-fiber bicycles with frames that are adhesive-bonded - a technique that, it claims, enhances the safety of the bike's joints.
6. CONCLUSIONS

Even in a relatively mature industry, the potential exists for substantial differences in the use of productive resources. These differences can overwhelm any advantage accruing from low input (e.g., wage) costs. As our snap-shots, or scenarios, showed, technical change (occurring in both "soft" practices and "hard" equipment) can easily magnify initial productivity differences if speeds of adoption vary.

We should reemphasize that our scenarios of new technologies were meant to depict engineering practice that is considered well within reach, now or in the next five years. As such, the range of productivity differences depicted here should be considered within the realm of current possibilities. Towards the end we took the liberty of examining more speculative, "blue-sky", scenarios which, if they come about, could create further productivity gaps.

A central implication of this study, therefore, is that factors that impede the diffusion of knowledge are likely to have a powerful effect on international competitive ability. As the speed of change and the knowledge-intensity of production increase, the effects of differences in knowledge will become more potent.

From the perspective of this report, knowledge absorption is impeded by inadequate human capital, organizational inertia, and deficiencies in infrastructure (including networks of supplies and sources of marketing and production information).

One conclusion of our study could be that the knowledge content of even mature, traditionally "labor-intensive" sectors is so high that many low-wage countries have no real comparative advantage in these sectors. An alternative, more positive, view is that efforts directed at creating a broad knowledge infrastructure could have a major pay-off. The example of coastal areas of China discussed in this and companion reports indicates the importance of actively seeking foreign sources of knowledge in any such strategy. Below we discuss some general policy initiatives. But first, we summarize our results.

6.1 Technical Change

Modern, microelectronics-based automation has so far made only minor inroads into bicycle manufacturing. Our study, however, indicates that this is likely to change significantly. The use of computer-aided design to innovate and to customize products is on the increase. Automation will become more cost effective as factory processes become more streamlined through the continued application of JIT-type techniques. Further cost cuts in automation hardware and continued innovation, spurring greater productivity of microelectronics-based equipment, are slowly but inevitably rendering many manual processes obsolete.

The implications for LDCs are clear. They will have to adopt the more capital-intensive, automated techniques to stay competitive. This will create further pressures on LDCs to adopt the soft practices described in this study, as these become more important when expensive equipment is installed.
The conditions under which LDC firms operate are becoming more unfavorable as the DC firms seek to redefine bicycle product and process technologies. The heavier emphasis on differentiating bicycles through rapid design changes, the growth in production flexibility allowing customization of the end product, and the use of more exotic materials that require greater precision in handling and less labor in assembly, all point in the same direction.

6.2 Players: Old and New

When bicycles are efficiently manufactured, low-wage countries can produce them at costs below those of developed countries or newly industrializing economies. An important barrier to doing so lies in the slow speed at which they absorb modern manufacturing practices and techniques. Of particular relevance to low-wage developing countries are organizational innovations that are transforming the manner in which production is conducted. Organizational innovations provide substantial cost reduction in themselves but also lay the foundation for adopting automation technologies and new materials.

A passive trust in the power of the product cycle to move mature products to LDCs is likely to be unhelpful at best. We have noted that NIE firms are on their way to automating production as wages rise and DC firms have introduced new elements of competition (particularly, greater product innovation and customization) to counter pure cost-based competition. LDC firms will, therefore, have to be active in seeking international alliances and persuading their governments to provide them the enabling environment required to compete internationally.

Experience suggests that the best course for a low-wage producer is to seek an alliance with an NIE or DC producer that will afford access to soft-technologies, with an emphasis on quality control. Chinese success in international markets has much to do with close marketing and technological links with firms that have wide experience (See Box 6.1).

6.3 Policy Implications

The main thesis of this report has been that continuous learning to produce better bicycles is a key component of success in international markets. We have also argued that such learning has occurred faster in the NIEs than elsewhere. The question may be asked: why do the natural forces of competition not induce learning more widely, particularly since much investment in hardware often is not required? Surely, the argument would go, firms competing for survival would see what is best for them and make the necessary changes.

Rarely can the required changes be quickly implemented. Western firms seeking quick fixes to compete against the Japanese have realized this truth rather painfully. The interdependent nature of the integrated manufacturing process raises a paradox. Learning inside the firm proceeds in small steps. However, to make learning possible, discrete changes need to occur inside the firm and in its environment.
Box 6.1: RE-CYCLING KNOWHOW

One of the hallmarks of bicycle manufacturing is the large number of international alliances. The most typical is a joint venture between China and a manufacturer from a developed country or a newly industrializing economy, or both. But there are numerous examples as well of ventures between two DCs, or a DC and an NIE, for manufacturing or distribution purposes. Below, we list some of the major joint ventures:

CBC (China Bicycles Co. in Shenzhen, China), a joint venture since 1985 of Shenzhen, Hong Kong Bicycles and Schwinn Bicycle Co. (U.S.). (For more information, see Appendix A.)

ABC (Asia Bicycles Co in Shenzhen, China), a joint venture formed in 1988 by Shanghai Bicycle Factory (China), CMG (Hong Kong investment group) and Grand Bicycle (Hong Kong), to export middle- and high-end bicycles to U.S., Europe, Australia, Japan.

Xiamen Euro-Bike (Fujian, China), a joint venture set up in 1987 by Xiamen Bicycle (China), B&B Investment (German bike maker and distributor) and Goldwood International (Hong Kong trader), to export high-quality bicycles to Europe, U.S.

Shimano-Thun (Italy), a joint venture since early 1990 of Shimano Industrial, Japanese bicycle components manufacturer, and the Italian subsidiary of Alfred Thun & GmbH of Germany. The goal is to increase production of MTB parts, in strong demand worldwide. The venture also gives Shimano access to European Community.

Suntour (Maeda Industries) of Japan and Joy Industrial Co. of Taiwan, formed a partnership in early 1990 under which Suntour in Taiwan handles development and design, and Joy manufactures Suntour-brand hub products for Taiwanese assemblers who ship to U.S. and Europe. The arrangement helps Suntour increase output of parts, compete with Shimano.

An analogy is of help. For a firm to move from its conventional system of manufacturing with large internal and external buffers supporting the process to a new system in which such buffers disappear is akin to, but much wider-reaching than, an organizational shift from IBM PCs to Apple computers. Just as the latter shift requires file translations, new training and new methods of networking, a shift to integrated manufacturing requires new methods and procedures of documentation, new individual and group skills, new plant lay-out and new relations with buyers and suppliers. Such changes
are extremely disruptive and impose high short-term costs on the organization. Besides direct costs of new software and training, indirect costs of lost production add up to substantial sums. Many firms have suffered large financial losses in the process of transition.

A central proposition of this study has been that learning is occurring increasingly through systematic techniques. While learning is a process of experimentation, the experiments themselves are conducted in well organized ways using tested tools and techniques. There are a few key reasons why these techniques are not widespread despite their proven efficacy. These relate to organizational and infrastructural inertia.

Thus the shift to integrated manufacturing within a firm must be supported by wider environmental changes that reduce the inertia. Better educated workers, reliable and inexpensive transportation and communication, and industrial extension services are all elements of a support system.

The success of NIEs and, more recently, of China, must be seen in this context (see also Appendix on China). It should be remembered here that when we talk of China, we are referring principally to the regions on the east coast that have specialized in exporting. The four factors that have supported competitive exports are:

- long-term relationships with buyers
- investment in training
- development of communication and transportation infrastructure.
- institutional infrastructure (including support services and local specialized supplier networks).

While these are closely related and reinforce each other, historical evidence from East Asia suggests that they may come partly in sequence (Rhee, Ross-Larson and Pursell 1984).

Long-term relationships with buyers serve a number of important functions. They provide the information necessary to make the manufacturing changes. More importantly for the present discussion, they allow for the leeway in time and resources to tide the firm over the period of disruptive organizational changes. East Asian NIEs built such links with Western buyers. China has had the benefit of links with Hong Kong and Taiwanese firms.

Long-term links with buyers are only one way to achieve these goals. The central theme here is the need to be tied into the best international information networks and mechanisms that support organizational change within the firm. Singapore has relied more heavily than others on foreign investment for this purpose. All East Asian countries have extensive and effective industrial extension services and credit schemes that finance recommended improvements.

Training has been a major focus of international alliances and domestic extension efforts. A Taiwanese or Hong Kong firm that starts sourcing shoes, clothes, bicycles or electronics products from China typically invests substantially in training. Such training is not evident in a specific training budget. The Taiwanese (more so than the Hong Kong) firm locates
half-a-dozen or more supervisors, each with as much as 15 to 20 years of experience, in the Chinese firms. These supervisors stay in the Chinese firms as long as two years even when only simple products involving repetitive tasks, such as shoes and garments are being produced.

In addition to close international links, firms need an enabling environment in which training can be provided, organizational changes can be made, materials with consistent quality are readily available, and investments in learning processes that result in temporary losses represent a reasonable risk. Establishing such an environment requires changes in laws and regulations that place certain restrictions on firms when conducting their business.

Investment in infrastructure is another critical area for public policy. Asian NIEs have set very high standards in this regard. The scale and efficiency of Singapore's port are well known. In telecommunications, all Asian NIEs have taken advantage of new technologies and leapfrogged to the most modern equipment ahead of Western nations (Mody and Sherman, 1990).

A more general point is that any artificial barriers to the movement of information or goods and services will seriously hinder the ability of firms to organize their internal affairs efficiently. Lengthy import procedures or restrictions on location of production create the need to invest in buffer mechanisms which sharply reduce the capability and the incentives to reorganize for greater efficiency.
APPENDIX A:  BICYCLE-MAKING IN CHINA

Shenzhen is well on its way to becoming an international hub of bicycle production. In the next two or three years, this so-called "special economic zone" in China may be producing at a rate of 4.5 million bicycles annually. To appreciate how extraordinary that achievement would be, it is useful to note that in 1990, China exported 2.5 million bicycles and Taiwan exported 6.5 million bicycles. If China does succeed in pushing out bicycles at this high rate, it will be at the expense of other exporting nations. Some analysts (and many investors) are betting that Taiwan will be displaced as the leading bicycle exporter.

As this report has demonstrated, bicycle production requires significant organizational skills. Cheap labor is always a plus but is never enough. Foreign manufacturers fueling the bicycle boom in Shenzhen are eager to exploit China's large and inexpensive pool of labor; but they are also very attracted by skilled technicians (who have survived in outdated state-owned factories) and by bicycle parts suppliers. But ultimately, growth is occurring because of self-fulfilling expectations. Bicycle producers are attracting parts suppliers, who in turn are attracting more bicycle producers. All firms are investing large resources in training their workforces so that cheap labor is not the only source of competitive advantage.

Foreign manufacturers from Hong Kong and, increasingly, from Taiwan, have been key to bringing production and marketing skills to China. The largest bicycle producer, China Bicycles (CBC), is a joint venture since 1985 of Shenzhen City, Hong Kong Bicycles and the prestigious U.S. firm, Schwinn Bicycle Co. (See Box A.1). Other sizable bicycle-manufacturing companies are Shenzhen Yinhai Bicycle Co., a Chinese company managed indirectly from Taiwan, and Asia Bicycles (ABC), a company established in 1988 with mainland and Hong Kong partners. This year Merida, Taiwan's second largest bicycle assembler (after Giant) began building a plant in Shenzhen. Inevitably, they have already attracted numerous Taiwanese makers of chains, handlebars, pedals, derailleurs and other components.

The leading producers practice international standards of quality control and training. ABC, for example, provides each employee with training in total quality control (TQC). The company follows the precept that the operator should also be a quality controller. Incoming and outgoing parts receive close scrutiny for quality standards. The final product is tailored to meet internationally acceptable standards of safety and function.

A point of some importance is that these producers are not targeting the lowest price/quality end of the bicycle spectrum. CBC sells its average bicycle for $100, which places it well above the bottom in a quality range where it competes with Taiwanese mass producers. ABC is a newer firm and is, therefore, starting at a somewhat lower quality level but also expects to move up rapidly.

Similarly, the leading firms are quickly taking on design tasks rather than merely producing to customer designs. At ABC, once a customer
sends the broad specifications, a team based in Hong Kong does the detailed design and interacts with the customer till an agreement is reached. This is followed by sample lots and then by high volume orders. CBC has gone a step further in acquiring a major U.S. distributor and a recognized brand name (Box A.1).

Shenzen is not the only Chinese city to which foreign bicycle manufacturers have been attracted. Some 50 Taiwanese companies - assemblers and parts makers - have reportedly set up a number of production bases across China, through subsidiaries or agents based in Hong Kong or the United States. The attraction is immense for Taiwan, the world's leading bicycle exporter, now beset by rising wages and labor strife. Labor costs in China are about half those of Taiwan, even taking into account the lower productivity of Chinese factories and the cost of needed additional supervisory personnel.

China was already the world's largest bicycle manufacturing, turning out slightly more than 41 million units in 1988. It had concentrated on its vast domestic market, producing bicycles of outdated designs and quality acceptable only to the Chinese. By 1987, however, one in every four Chinese owned a bicycle, and supply exceeded demand. Output fell to 36.7 million units in 1989, and even further to 30 million units in 1990. As a result, China has been seeking to encourage exports by forming relationships with foreign bicycle manufacturers that can provide capital and technical expertise.

Though the vast bulk of Chinese bicycles are the sturdy roadsters designed for the domestic market and produced using relatively dated technology, the Chinese base of production technicians and parts suppliers is sufficiently competent that the new foreign producers are interested and willing to make use of existing strengths. Some mainland bicycle factories have taken relatively large stakes in the modern joint ventures and a system of seconding workers (both from the mainland factory to the joint venture and the other way around) seems to be in place. In addition, the joint ventures are working to upgrade local suppliers.

At the moment, the other developing nations are offering China little competition. India is the world's largest bicycle maker, with 9 million units in 1990 - Hero Cycles is the world's largest bicycle company, with 3.2 million units - but production has historically been of poor quality and sold locally. Now India, too, is looking abroad, since the domestic market turned sluggish. The government has offered tax breaks and cash incentives to exporters, and slashed the import duty on bike production machinery. New bicycle factories - including one built jointly by Hero and Honda Motors of Japan - are among the most modern in the world, with welding, assembling and painting machinery imported from Europe. So far, however, the most important foreign market has been the Soviet Union.

Southeast Asia is also seeking to emerge as a low-wage production base challenging Korea and Taiwan. In 1988, that region produced 2 million bicycles, of which Indonesia accounted for half and Thailand for 35 percent. Some industry observers believe that Thailand could become a major bicycle exporter; the labor force is relatively inexpensive and high-quality. The leading company is Thai Bicycle Industry, which makes 400,000 bikes and has
half of the domestic market. With local demand waning here, too, companies are looking increasingly to the U.S. and European markets. The main problem is that, due to a shortage of local parts manufacturers, Thai manufacturers must pay a premium for imported components.

And even for the Chinese bicycle-makers and their foreign partners, there is a hard road ahead. The factories in Shenzhen need to continue heavy investment in employee training and quality control. The quality of locally made parts has been unsuitable for bicycles designated for export. The investment by Merida may be a pointer to the future. A producer of relatively high quality bicycles, its investment in China is likely to attract parts producers of superior quality. And it may demonstrate that China can move up the quality ladder at a surprisingly good clip.

**Box A.1: BIG PLANS AT CBC**

China's largest bicycle maker, with 1.5 million units, CBC is opening its second factory in Shenzhen this year. The plant will be immense: it will occupy a 200,000 square meter site and have floor space of 160,000 square meters. This is about five times the size of its first plant in Shenzhen, and on a mammoth scale unknown anywhere else. The target for the first year's production is 500,000 units, running heavily to the popular MTBs.

From the first, CBC's emphasis has been on quality, not price. Its factories are among the most modern in the world. In 1990, the company exported 95 percent of total production, chiefly to Europe and the United States. Shipments to Japan and Australia are also growing.
APPENDIX B: MODELING THE FACTORIES

An overview of the way a factory's operation can affect its performance is useful in understanding the modeling approach. Discrete manufacturing facilities typically possess complex system dynamics. Multiple products need to move through various types of work centers, and in doing so they compete for resources. Different products have different "cycle times" (the time to complete operations on one piece, also called "run times") at the various work centers. Changing a work center's readiness to work on a product, after it has completed a different type of product, requires a "setup"—which can be much longer than the cycle time itself. Equipment can fail unpredictably. Intermediate products can be below specifications and require rework or may even have to be scrapped altogether.

All of these factors cause delays or consume additional resources, add to the work-in-process (WIP) and material costs, and thus affect the overall capacity and efficiency of the factory. Many of the manufacturing alternatives that are available today aim at ameliorating these factors, and thus it is important to model their effects. Thus, to capture such effects accurately, one needs to construct a model of factory dynamics.

Rather than write from scratch a software package with such a model, we used an available factory modeling package called ManuCost from Network Dynamics Inc. (Burlington, MA).

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Figure B.1 SCHEMATIC OF THE COST MODEL
This factory modeling software package has a number of features that make it well-suited for our use:

- It allows detailed specification of operations and the links between them. At each operation, the resources used (equipment, labor and materials) are specified. Labor is split by skill category.

- The routings (the sequence of operations required, as well as the equipment on which they must be performed), yields (the proportion of good parts obtained from an operation), rework rates, and set-up and cycle times (defined above) for each operation on each available machine are also specified. If equipment is automated or semi-automated, these times can be separated into those when an operator is needed, and those when the operation can continue unattended.

- The model contains a set of dynamic equations. For given machine reliability rates, variability in arrival of material from one station to another, yields, set-up and cycle times, the equations predict the average utilization of various resources installed in the factory. The model is, therefore, able to estimate performance measures such as total production capacity, work-in-progress (WIP), specific equipment and labor utilization rates, and product lead times (the time it takes for an order to go through the entire factory).

- The package also incorporates an economic model that allows one to specify costs of various direct inputs (such as material, equipment and labor) as well as indirect inputs (such as management salaries and facility costs). It then combines the manufacturing model with the economic model to accumulate costs (including appropriately allocated indirect costs) through the production process, up through components, subassemblies and final products.

- A particularly interesting and important feature of the model is its system of scrap estimating. The model keeps track of scrap through data on yields and rework rates at each operation. The model not only estimates the material value of the scrap, but also keeps track of the value added at earlier stages that goes along with the scrapped material. Similarly, the model's ability to predict the quantity of WIP at each stage of production, leads to an accurate prediction of WIP carrying costs. As we shall see, these costs are important in determining opportunities for improvement.

- The package is based on the Rapid Modeling approach to manufacturing modeling, as distinct from the "discrete-event simulation" approach (e.g. see Suri 1989). Rapid Modeling is less ambitious, but as a consequence also requires less data and allows much faster turnaround for examining alternatives. This package has been successfully used in manufacturing analysis by firms such as Alcoa, Digital Equipment Corp., IBM, and Siemens.
Note that the model is purely an evaluation tool. No optimization is done, only prediction. Thus if a desired production rate or other performance measure is not achieved, the analyst must decide on what alternative to try, and then modify the inputs accordingly. The performance reports provided by the model usually assist in directing the analyst towards the necessary modification. For example, if a production rate is not achieved, the model will show the bottleneck resource(s). The analyst can then explore various alternatives, the most obvious one being to add more resources.

Furthermore, in the benchmark cases, the set of alternatives may be limited by the observed data in the actual factories. However, in the scenarios for improvement, many other alternatives may be available, such as the use of methods to improve yields, or ways to shorten set-up or cycle times, or the use of new materials or automation. These alternatives require a wide knowledge of manufacturing processes as well as considerable design creativity, and thus render the use of an optimization scheme extremely difficult. Instead we use an iterative approach that allows the analyst to try alternatives until the desired performance indicators are obtained.

Relation to Activity Based Costing (ABC)

New accounting methods for manufacturing, such as Activity Based Costing (ABC), are gaining acceptance (e.g. see Cooper and Kaplan, 1988). While our approach is in the spirit of ABC, there are some important differences. ABC provides accurate cost analysis of existing operations, but would have been less appropriate for our "what-ifs". In most of the scenarios that we undertake, the structure and dynamics of the manufacturing system change in a nontrivial way. For example, new technology (e.g. fixtures and hydraulic clamps that reduce setup time) combined with a new operating approach (smaller lot sizes) can drastically decrease the amount of work-in-progress (WIP). It is important to model the manufacturing dynamics first, in order to predict the new resource utilizations and the new WIP, and then conduct the cost allocation on the outcomes. ABC is designed to do the latter, thus it can only be meaningfully applied to what-ifs that are "in the neighborhood" of the current process structure and system. Our approach predicts the new operating conditions first, and then does the cost analysis. However, both ABC and our methodology share an important attribute: they underscore the need for development of improved costing methods in evaluating manufacturing alternatives.
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