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We argue that industries and industry segments are characterized by a *clockspeed* that gauges the velocity of change in the external business environment and sets the pace of their firms' internal operations. Using data from the electronics industry, we develop and validate an integrated metric for clockspeed that takes into account both demand- and supply-side factors. We show that after controlling for product complexity and other factors, higher industry clockspeed is associated with faster execution in product development and manufacturing (e.g., shorter development time, quicker stabilization of production) and more frequent changes in organizational structure. Our findings on the effects of clockspeed can help researchers studying other industries, and our results provide benchmarks against which practitioners can compare and classify their own organizations.
(*Clockspeed*; *Dynamics*; *Time-Based Competition*; *Electronics Industry*; *Computer Industry*; *Development Speed*; *Velocity of Change*; *Product Life Cycle*; *Innovation*)

## 1. Introduction

There are few areas of consensus among business leaders—and even fewer where academics largely agree with them. One of these is the proposition that a key challenge for corporations is the increasing velocity of change (i.e., *clockspeed*) in the business environment and that to survive, firms must manage to "be faster". Jack Welch, General Electric's CEO, is widely credited with first identifying this proposition. Starting in the 1980s, he put together a comprehensive set of new initiatives at GE, recognizing that increasing industry clockspeeds require radically different business processes. He writes:

> While restructuring our Company in the 1980s, we spent much of our time talking about the accelerating pace of change: in world politics, in technology, in product introduction and in the increasing demands of customers. We don't have to do that anymore. Change is in the air. Newspapers and networks hammer it home daily. GE people today understand the pace of change, the need for speed, and the absolute necessity of moving more quickly in everything we do, from inventory turnover, to product development cycles, to a faster response to customer needs. They understand that slow-and-steady is a ticket to the boneyard in the 1990s. ("To Our Share Owners", 1990 GE Annual Report).

In spite of the broad recognition of the importance and impact of industry clockspeed on business operations, much of what is known about it is qualitative. Thus, it is hard to corroborate the true extent and impact of clockspeed. This paper is a step towards remedying the situation, using data from business units in the fast-moving electronics industry (of which computer hardware is a major segment). We build on the notion of industry clockspeed introduced by Fine (1996) in a conceptual essay that suggests it as a useful way to classify industries and discusses the intricacy of the concept and its implications for supply-chain design.

We study industry clockspeed and its effects in two stages. First, we address the measurement of clockspeed, proposing a concrete quantitative measure and studying it in some detail. We believe this is important, since the ability to measure clockspeed is a prerequisite for quantifying its effects. Second, we study the proposition that industry clockspeed sets an inherent operational rhythm for business units that operate within

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the industry. Our hypothesis is that firms in faster-moving business environments tend to accelerate their internal operations so that their operational speed is attuned to the velocity of change in their business environment. Our results confirm that this is indeed the case. We find that the frequency with which a firm redesigns its products, the duration of its development projects, the speed at which its manufacturing operations are stabilized, and the likelihood of organizational restructuring, all correlate very strongly with the clockspeed of its industry environment.[1]

While our analysis is based on data collected from only one (albeit very large) industry, we expect that our results have broader applicability. In addition, we hope our results will help researchers studying other industries to formulate meaningful metrics and hypotheses. With this in mind, we have focused on measures that are meaningful in any manufacturing industry.

The remainder of this paper is organized as follows. Section 2 briefly discusses the origins of clockspeed acceleration in the electronics industry. Section 3 describes our data sources, and §4 addresses the measurement of industry clockspeed. Section 5 studies the proposition that the pace of a business unit's internal operations is largely driven by the clockspeed of its environment. Section 6 examines life cycle trends in the electronics industry, and §7 offers our concluding remarks.

## 2. Clockspeed Acceleration in the Electronics Industry

Our data originate from a large manufacturing industry—the electronics industry (which includes computer-hardware manufacturers). In 1996, the total worldwide output of this industry was on the order of half a trillion dollars. Our data were collected in two industry surveys that were conducted over 1992–93 and 1994–95. These surveys looked at manufacturers of a wide range of products, including computers (PCs, workstations, minis, and mainframes), peripherals (printers, network components, etc.), office equipment (e.g., digital copiers), consumer electronics (TV, VCR, etc.), and industrial and other electronics products (e.g., measurement instruments, control systems, and PABX). All of these products support information-processing tasks and have at their core the same fundamental technology component: the integrated circuit chip. We will use the term *industry segment* to denote a subset of the industry that is involved in the manufacture of a particular product (i.e., PC, TV, measurement instruments, etc.). Because many firms have diversified into several industry segments, our analysis is conducted at the level of the *business unit,* which is typically focused on a single industry segment.

Business units operating in this industry experience high rates of change in technology, customer choices, and market conditions, resulting in unprecedented changes in price/performance ratios and product life-cycle compression. Indeed, it is widely recognized that this industry is among the most dynamic sectors of the economy. Change is driven to a large extent by a phenomenal rate of technological performance improvement on the supply side, commonly popularized as *Moore's Law* (Gordon Moore, Intel's co-founder and chief visionary, predicted in 1975 that the number of components on a chip would double every two years). This rapid development of the underlying technology, and the corresponding fall in the cost/performance ratio on the supply side, gives manufacturers the opportunity to continually redesign their products and processes to take advantage of the newly available chips. The more competitive an industry segment, the greater the likelihood that this opportunity will be promptly seized by one or more of the competing firms.

The fast changes on the supply side are augmented by demand-side changes arising from changing customer tastes, from the effects of complementary products and from the threat of substitute products. One example of changing customer tastes is the change in management philosophy that resulted in more decentralized organizational structures. This tends to reduce the demand for large mainframe systems while increasing the demand for desktop and client-server products. Another industry clockspeed driver on the demand side is the effect of market conditions for complementary products—that is, products that the customer uses in conjunction with the original product. In

[1]For the implications of fast clockspeed on management practice, see Mendelson and Ziegler (1999).

the case of the personal computer (PC) industry segment, for example, the demand for higher performance has been fueled in part by the proliferation of graphical user interfaces and multimedia applications created by the software industry. In fact, the two industries interact closely with each other; as increasing hardware performance crosses new thresholds, more sophisticated system software and applications become feasible, creating even higher user demand for performance.

## 3. Data

Stanford University, McKinsey & Company, Inc., and the University of Augsburg, Germany conducted two detailed surveys, in 1992–93 and 1994–95, of manufacturers in the electronics industry covering North America, Europe, and the Asian Pacific region.[2] A pool of potential participants was identified for each survey. These pools were narrowed down on the basis of the likelihood of earnest participation and initial contacts. The resulting coverage was good for surveys of this type—31% of the potential pool for the 1992–93 survey, and 22% for the 1994–95 survey. Participation was secured at the highest corporate levels. Since many of the firms in the industry produce a variety of products, the surveys were conducted at the business unit level. The two surveys included, respectively, 102 and 67 business units. Within each business unit, one product group was examined in detail. Frequently, this product group was responsible for most of the business unit's revenue.

The survey instruments covered basic financial, managerial, human resources, manufacturing, product development, marketing, and sales data. After the completed surveys were sent back, a team of two research assistants conducted a set of on-site interviews over a one- or two-day period to validate the responses and add some qualitative assessments.[3] To ensure confidentiality, the names of all firms were suppressed from the database; a unique code number assigned to each business unit served as its identifier. The data items selected from the surveys, and their use, are discussed in §§4 and 5, in the context of the analysis itself. Summary statistics for the variables used in this study are presented in Table 1.

[2]See also Cimento and Knister (1994).

[3]The survey instruments were calibrated, validated, and revised using five pilot company sites.

## 4. Measuring Industry Clockspeed

The empirical measurement of industry clockspeed or *dynamism* (Miller 1987) has been largely of a subjective nature, often based on Likert scales that attempt to capture the opinions of industry practitioners. It is difficult, however, for practitioners in one industry segment to compare their own segment's clockspeed to that of other industry segments that they are unfamiliar with. Our surveys provide data that can be utilized to measure industry clockspeed on both the supply and demand sides using observable, quantitative metrics. Our measure of industry clockspeed is based on three components:

- The fraction of total revenue derived from new products (i.e., introduced within the preceding twelve months)—an indicator of product innovation;
- The total duration of the product life cycle (i.e., product life); and
- The rate of decline in the prices of input materials.

Since the first two components can be interpreted in terms of the product life cycle curve, we first provide a short discussion of the shape of this curve. We then explain how each of the three components are measured.

### 4.1. The Product Life-Cycle Curve

The life-cycle curve depicting product sales volume as a function of time reflects the effects of both *supply-side changes* (performance improvements) and *demand-side changes* (changing customer tastes and competition in the product market). This curve has been used by managers for over 30 years at both the industry and product levels. Empirical studies involving this curve have been conducted for a wide variety of products and industries like drugs (Cox 1967), personal-care products, food items, cigarettes (Polli and Cook 1969), household appliances (Olshavky 1980, and Qualls et al. 1981), engineering materials (Nelson 1992) and personal computers (Bayus 1994). Levitt (1965) provides a good overview of the different stages of the life cycle (market

**Table 1 Summary Statistics for Survey Variables Used in This Study**

| | 1992–93 | | 1994–95 | |
|---|---|---|---|---|
| Variable | Mean | Std. Dev. | Mean | Std. Dev. |
| *Clockspeed Variables* | | | | |
| Product-line freshness | 31.3% | 26.6% | 36.6% | 26.4% |
| Product life (months) | 44.2 | 29.4 | 38.1 | 20.9 |
| Input price decline rate | 7.93% | 6.80% | 6.06% | 5.66% |
| *Complexity Variables* | | | | |
| No. of printed circuit boards | 2,886 | 5,101 | 2,724 | 4,879 |
| Product price ($) | 133,272 | 467,466 | 98,257 | 399,765 |
| *Operational Variables* | | | | |
| Project duration (months) | 23.2 | 11.8 | 17.8 | 7.8 |
| Redesign intervals | 24.0 | 15.1 | 29.0 | 19.5 |
| Production ramp-up time | 3.3 | 2.7 | 2.9 | 2.7 |
| Organizational change | | | 73% | 45% |
| Life-cycle compression rate | 9.4% | 6.8% | 9.1% | 7.1% |
| *Other Control Variables* | | | | |
| Sales growth | 9.6% | 17.9% | 4.3% | 16.5% |
| R&D intensity | 9.5% | 8.8% | 7.8% | 5.6% |
| Cross-functional participation | 0.12 | 0.24 | 0.17 | 0.34 |
| U.S. companies | 0.33 | 0.47 | 0.28 | 0.45 |
| Asian companies | 0.23 | 0.42 | 0.16 | 0.37 |

development, growth, maturity, and decline), and discusses how managers should adapt their strategies to exploit the characteristics of each stage.

Bass (1969) has proposed a widely used mathematical model for the life-cycle curve based on diffusion theory, and Norton and Bass (1992) provide empirical evidence from a variety of industries to support this model.[4] The model posits a cumulative life-cycle curve of the form

$$F(t) = \frac{1 - e^{-(p+q)t}}{1 + (q/p)\, e^{-(p+q)t}} \tag{1}$$

where F(t) is the fraction of the total market for the product that has been penetrated by time t, commonly measured in years. The two key parameters of the model are the coefficient of innovation, $p$, and the coefficient of imitation, $q$. As we illustrate below, product line "freshness," our first measure of clockspeed, is related to the coefficient of innovation in Bass' (1969) model.

### 4.2. Product Line "Freshness"

At any given time, a firm is typically marketing several products from the same product line, each at a different stage of its life cycle. If the major share of revenues in an industry segment comes from products that are at the early stages of their life cycle, it is likely that there is a strong market demand for innovation and intense competition between firms on the demand side. If innovation is important for the customer, new products that have just entered the market will be favored over older products. Conversely, if the percentage of total sales from new products is small, this would indicate that the rate of innovation is low.

Several corporations—especially those that value innovation—monitor the share of revenues that come from new products. In particular, Hewlett-Packard presents these data in the form of "Vintage Charts" in its annual reports, and Packard (1996) refers to these charts as a measure of innovation. A similar chart is presented by von Braun (1990), who uses it as a measure of the innovativeness of a company. Innovation-driven 3M Corporation has specific targets for the share of sales coming from new products, and these targets have been accelerated over time.

We measure product *freshness* by the share of total revenue contributed by products introduced within

[4]Since its introduction in 1969, the Bass model was extended in numerous ways. We focus here on the original Bass (1969) model, which is at the core these extensions.

the previous 12 months. The observed values of product freshness in our two surveys were in the range of 0 to 90%, with the mean around one third.

Product freshness is related to the Bass model as follows. The fraction of total lifetime sales that occurs within the first year after product launch can be calculated from equation (1) as

$$\text{First-year Fraction} = [1 - e^{-(p+q)}]/[1 + (q/p)\, e^{-(p+q)}]. \quad (2)$$

Increasing the innovation parameter $p$ results in a larger fraction of lifetime sales occurring in the first year. As $p$ gets larger than $q$, sales become monotonically decreasing, with an even larger fraction of sales due to "fresh" products.

### 4.3. Product Life

We define *product life* as the time interval from the point when the product was first shipped to the market to the point when the firm stopped shipment of the product. This corresponds to the *market life* or *catalogue life* of the product (Cox 1967). Clearly, the shorter the duration of the overall life cycle, the shorter the duration of each stage, and the faster the speed with which the firm has to adapt—a shorter cycle necessitates quicker changes as the product moves from one stage of the life cycle to the next.

In our surveys, marketing managers were asked to provide an overall estimate of product life for the product group being studied. This estimate was based on the shape of the product life-cycle curve to date, on their past experience with similar products, and on their plans for the existing product. Thus, unlike the freshness variable, which is based on the business unit's data from past sales, this variable requires some projection into the future.[5] The reported values ranged from 6 months to 10 years, with the mean value decreasing over time from a little under 5 years in 1988 to an expected value of around 3 years in 1995. We use the negative value of the reported product life so the variable will correspond to clockspeed.

As might be expected, freshness and product life were highly correlated. The two variables, however, are conceptually different: the product-life variable measures the span of the product-life-cycle curve along the time axis, while the product-freshness variable gives an indication of the shape of the curve.

### 4.4. Change in Prices of Input Materials

This variable measures the overall annual percentage *decline* in the prices of electronics items that were inputs to manufacturing,[6] and is a supply-side measure of technological change. Clearly, faster input price changes mean that the firm has a strong incentive (and is sometimes required) to modify or redesign its products more frequently—implying a higher clockspeed. Firms respond to input price reductions through a combination of price cuts, product upgrades and new products that take advantage of improved price/performance ratios and reductions in manufacturing cost.

Many of the "raw material" inputs to the electronics industry come from sectors that are characterized by high performance improvement rates and rapidly falling prices (as exemplified by Moore's Law). Very few firms in our samples reported an input price increase.[7] However, researchers must exercise caution in extending this component of clockspeed to other industries, where the decline in input prices may not be as widespread or as important as in the electronics industry.

### 4.5. Aggregate Measure of Clockspeed

Since industry clockspeed is an attribute of firms' specific business environment, it is appropriate to compute its value at the industry segment level. For this purpose, we partitioned the business units in our surveys into industry segments, according to the primary product group that they manufactured. We then calculated the segment averages for each of the three variables discussed above, and assigned these mean values to the business units in each industry segment. This is

[5] In addition to the data used in our clockspeed measure, managers also reported the product life of past products and expected values for future products.

[6] A related measure, *viz.*, annual change in product prices has been used by Williams (1992) who classified industries as "slow-cycle," "standard-cycle," and "fast-cycle" depending on whether this price change was positive, close to zero, or negative respectively. He classified almost all segments of the electronics industry as "fast-cycle," whereas cars and household appliances were "standard cycle," and the health industry "slow-cycle."

[7] These were coded as negative values. Positive values imply a *decline* in the price.

reasonable, since we found relatively low variance among the values within each industry segment, as compared to the variation between segments. For segments that had only one or two representative firms, we retained the individual unit-level values for the three variables. To convert all component variables to a common scale, they were separately standardized to a zero mean and unit standard deviation over the sample of business units in each survey.[8]

We carried out a principal-component analysis among the three clockspeed variables and obtained the results shown in Tables 2(a) and 2(b) for the two surveys. In both surveys, the principal component with the largest eigenvalue, corresponding to clockspeed, had approximately equal loadings on each of the three variables. This eigenvalue was the only one whose magnitude was larger than one. It was also much larger than the others in magnitude, and it explained about 80% of the variance.[9] The cross-correlations in Tables 2(a) and 2(b) show that the two variables that measure predominantly demand-side parameters (product life and freshness) are closely related. The correlation between these and the supply-side parameter (input price change), though less strong, is still highly significant (at level $p = 0.0001$). This suggests that firms in the electronics industry are not content to merely transfer input price reductions to customers in a passive manner. Rather, they respond actively by developing new product configurations that deliver even greater value to customers. Finally, the patterns were consistent across the two surveys, whose sample populations and time periods were different, supporting the robustness of the results.

The component loadings given in Table 2 can be used to create an overall clockspeed score for each

[8]Outliers (standard deviation $> 2.5$) were Winsorized (cf. Huber 1981).

[9]The second largest eigenvector, which explains about 15% of the variance, can be interpreted as a measure of the dissimilarity between the supply-side and demand-side clockspeed characteristics.

**Table 2(a) Cross-Correlations and Principal Components for Clockspeed Variables: 1992–93 Survey**

The top table presents the correlations between the variables. The bottom table presents for each principal component:
- The component loadings;
- The eigenvalue corresponding to the component; and
- The proportion of the variance explained by the component.

| **1992–93 Survey** | Product Line "Freshness" | Product Life | % Decline in Prices of Inputs |
|---|---|---|---|
| Product Line "Freshness" | 1 | 0.78*** | 0.59*** |
| Product Life | 0.78*** | 1 | 0.60*** |
| % Decline in Prices of Inputs | 0.596*** | 0.60*** | 1 |

***significant at $p = 0.0001$

| **1992–93 Survey** | Component 1 | Component 2 | Component 3 |
|---|---|---|---|
| Product Line "Freshness" | 0.594 | −0.395 | −0.700 |
| Product Life | 0.596 | −0.368 | 0.714 |
| % Decline in Prices of Inputs | 0.540 | 0.841 | 0.017 |
| Eigenvalue | 2.32 | 0.46 | 0.22 |
| Proportion Explained | 0.78 | 0.15 | 0.07 |

**Table 2(b) Cross-Correlations and Principal Components for Clockspeed Variables: 1994–95 Survey**

The top table presents the correlations between the variables. The bottom table presents for each principal component
- The component loadings;
- The eigenvalue corresponding to the component; and
- The proportion of the variance explained by the component.

| **1994–95 Survey** | Product Line "Freshness" | Product Life | % Decline in Prices of Inputs |
|---|---|---|---|
| Product Line "Freshness" | 1 | 0.80*** | 0.71*** |
| Product Life | 0.80*** | 1 | 0.60*** |
| % decline in Prices of Inputs | 0.71*** | 0.60*** | 1 |

***significant at $p = 0.0001$

| **1994–95 Survey** | Component 1 | Component 2 | Component 3 |
|---|---|---|---|
| Product Line "Freshness" | 0.604 | −0.162 | −0.780 |
| Product Life | 0.576 | −0.588 | 0.568 |
| % Decline in Prices of Inputs | 0.550 | 0.793 | 0.263 |
| Eigenvalue | 2.41 | 0.41 | 0.18 |
| Proportion Explained | 0.80 | 0.14 | 0.06 |

business unit (Dillon and Goldstein 1984, Ch.2). Since the three loadings are consistently similar in magnitude, it is reasonable to represent the overall level of clockspeed by a single aggregate variable with equal weights on the three standardized measures. Thus, for each business unit, we calculated the standardized mean of the three components, which served as our aggregate measure of clockspeed.[10] We then calculated the clockspeed for each industry segment by averaging the clockspeed variables across the business units in the segment.

Figure 1 shows the variation of clockspeeds across the major industry segments represented in the 1994–95 sample. Note that manufacturers of general-purpose computer systems are subject to higher industry clockspeeds than the manufacturers of special-purpose industrial electronics products, with consumer electronics in–between. Among the different types of computers, one sees a distinct progression in clockspeeds as we go from large systems to personal computers.

The three variables constituting our industry clockspeed measure were deliberately chosen so they would not be unique to the industry studied here. They can be used in other manufacturing industries and even in some service industries. Hence, our measure of industry clockspeed may be applicable beyond this particular study.

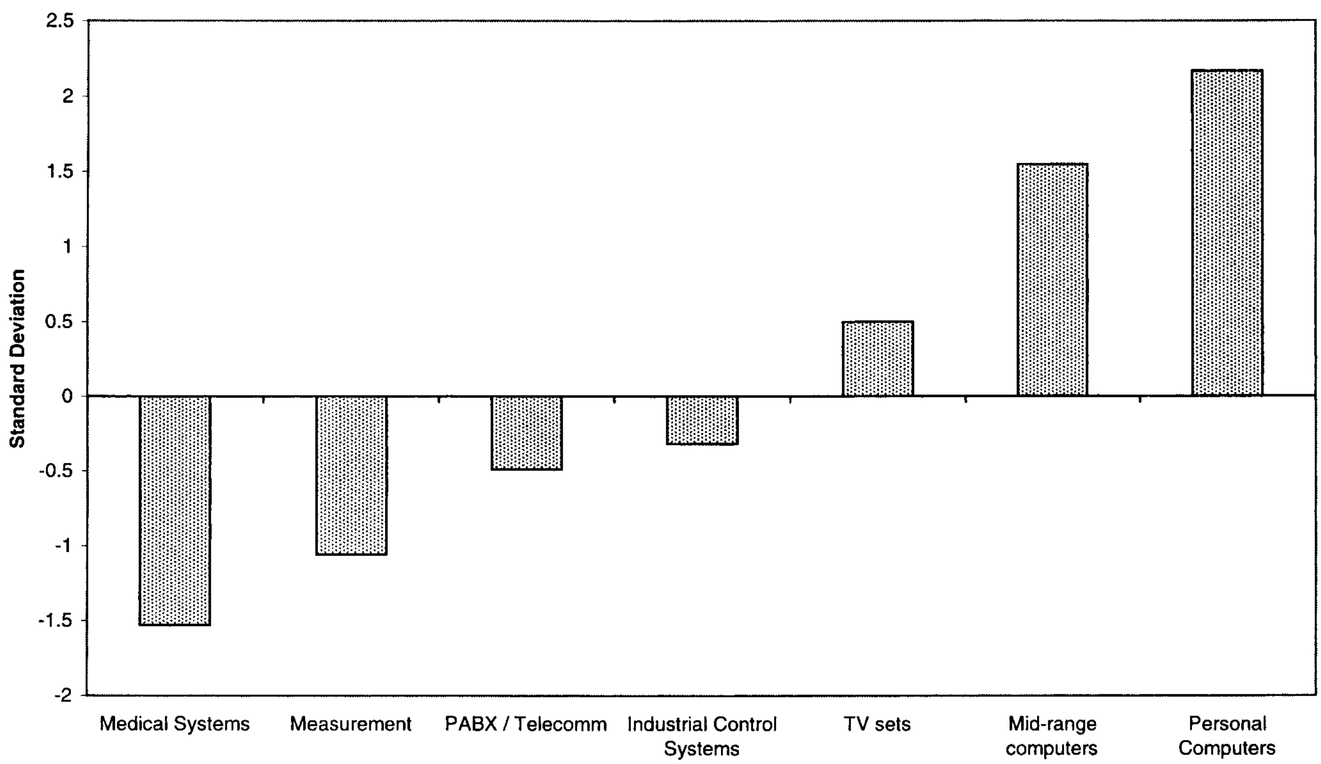
### 4.6. Validation of Clockspeed Measure

We validated our segment clockspeed measure, for both internal coherence and consistency with data external to our survey, as follows:

*(i) Validation between the two survey samples:* Even though most business units in the two survey samples were different, we could correlate the industry

[10]The distribution of these clockspeed variables was close to Normal (tested by the Shapiro-Wilk method, with $W = 0.97$) for the 1992–93 survey sample, but less so (Shapiro-Wilk $W = 0.945$) for the 1994–95 survey. The latter sample had a relatively larger proportion of firms that were operating in product markets whose level of industry clockspeed was low.

**Figure 1** **Industry Clockspeeds for Major Industry Segments: 1994–95 Survey**



clockspeed values between the surveys since they are calculated at the industry segment level. The segment-wise Pearson correlation coefficient between the two sets of industry clockspeed values was 0.87 (significant at $p = 0.0001$), indicating a high level of consistency between the two surveys.[11]

*(ii) Validation against external data:* As discussed above, our clockspeed measure is an indicator of the velocity of change faced by businesses operating in different industry segments. We validated the measure using external data, relating our clockspeed measure to the variation and uncertainty in sales for firms in different industry segments. We obtained quarterly sales data over the period 1986 through early 1996 (42 quarters) from the *Compustat* database for about 200 companies that fit into the industry segments represented in our survey samples. For each company, we computed the mean and standard deviation of quarterly sales over the 42 quarters. The coefficient of variation (i.e., standard deviation divided by the mean) was then taken as a measure of *total variation in sales* that the company had undergone over this period.

The total variation in sales stems from two components: variation due to deterministic temporal effects (sales growth and cyclic seasonal fluctuations), and variation due to random effects (turbulence and uncertainty). We separated the two components as follows. For each firm, we performed a regression of *log* (sales) against time to determine the growth trend, and also included independent dummy (binary) variables for each quarterly period to control for cyclic seasonal variations. The slope of the regression line was taken as the *growth component* of sales variability. The residual values from the regression, which reflect the unpredictable variation in sales, were normalized by dividing by the mean value of *log*(sales), and this ratio served as a measure of the *random component* of sales variation.

The correlation between these measures of market volatility and the corresponding industry clockspeed values are shown in Table 3 for the two surveys. The correlations are highly significant (for the most part at $p = 0.0001$), indicating a strong link between market volatility and our industry clockspeed measure.

[11]The Spearman (rank) correlation coefficient between these two sets of values was 0.90.

**Table 3 Correlations Between the Industry Clockspeed Measure and External Measures of Market Volatility**

| | Pearson Correlations | | Spearman (rank) Correlations | |
|---|---|---|---|---|
| Variable | 1992–93 Coefficient | 1994–95 Coefficient | 1992–93 Coefficient | 1994–95 Coefficient |
| Total Sales Variation | 0.79*** | 0.78*** | 0.80*** | 0.82*** |
| Growth Component | 0.34*** | 0.28** | 0.46*** | 0.47*** |
| Random Component | 0.21** | 0.41*** | 0.36*** | 0.43*** |

***Significant at $p = 0.0001$
**Significant at $p = 0.01$

## 5. Industry Clockspeed and the Pace of Internal Operations

In his book *Thriving on Chaos,* Tom Peters tells the following story about Lee Iacocca, Chrysler's past CEO: At one time, Iacocca sensed that convertibles, which had long been out of favor, could be back in vogue. Iacocca asked Chrysler's chief engineer to come up with a prototype so he could test his idea. The engineer responded that he would do that as quickly as possible—in nine months. In response, Iacocca roared, "You just don't understand. Go find a car and saw the top off the damn thing!" Iacocca got his prototype quickly, jumped in and drove around Detroit, his head in the breeze. The number of waves and honks he drew convinced him that this was a good idea, and he ordered the car built. (By Peters' account, the car was very successful in the marketplace).

The moral of the story is self-evident: Rapid changes in business conditions require organizations to shorten their response times in a commensurate manner. If time-to-market and fast cycle times are key competitive priorities (Stalk and Hout 1990), organizations will strive to cut them down. And if, as we argue, fast response is more critical in high-clockspeed environments, there should be a positive association between the clockspeed of an industry segment and the speed of the internal "clock" that paces the internal operations of business units in that segment. Thus, when an organization operates in a faster-changing environment, we expect it to respond by accelerating its operational clockspeed to cope with those changes.

Fine (1996) proposes a number of alternative submetrics for internal clockspeed, including *product technology clockspeed* that measures the frequency of new product introductions or the intervals between those introductions, and *organizational clockspeed,* measured by the rate of change of organizational structures. As discussed below, we operationalized these two measures in our study (notwithstanding the fact that our measures were independently developed). Our results strongly support Fine's (1996) proposal to use these measures.[12]

Our concept of industry clockspeed is more diversified than Fine's (1996), but it reflects a similar point of view: industry clockspeed should have a paramount effect on the firm's internal operations. If indeed industry clockspeed drives operational speed, then it is a key characteristic of firms and industries, and it must be included in any cross-sectional analysis of operational performance. As Fine (1996) points out, these types of relationships are not straightforward, calling for empirical tests of our proposition. In this § we perform such tests. Our hypothesis is that, other things being equal, a higher industry-segment clockspeed is associated with a faster business-unit internal clockspeed in multiple operational dimensions. We first describe our dependent (operational) variables, then our control variables, and finally our empirical tests.

### 5.1. Operational Variables

Our dependent variables are related to operations in the product-development and manufacturing areas, as well as to the organizational structure of the business unit. In the product-development area, we look at the total duration of development projects and also at the frequency with which products are redesigned. The time taken to stabilize production of a new product serves as our measure of speed in manufacturing. We also assess the likelihood of organizational restructuring using the actual incidence of restructuring events over a particular time period. We describe the associated operational variables below.

**5.1.1. Duration of Development Projects.** Because a higher level of industry clockspeed goes hand-in-hand with faster product obsolescence and more rapid changes in supply conditions, we expect the pace of product development to accelerate with industry clockspeed. Our hypothesis is that higher industry-segment clockspeed is associated with a faster pace of product development at the business unit, measured by the speed at which comparable projects are completed. In both surveys, development managers were asked to describe the characteristics of a recently-completed major development project undertaken by their unit. Typically, the projects had been completed within the twelve months preceding the survey and had commenced about two years before that date. On average, about 30 people were engaged in the execution of each project. The duration of a project was measured as the time from the predevelopment study through the completion of pilot runs.

**5.1.2. Product-Redesign Intervals.** Faster obsolescence in the product market is also expected to be associated with a higher frequency of product redesign. Thus, another measure of operational speed is the length of the time interval between successive product redesigns. Whereas the project duration variable measures the actual time spent in developing a new version of the product, this variable measures the time interval between consecutive redesigns.

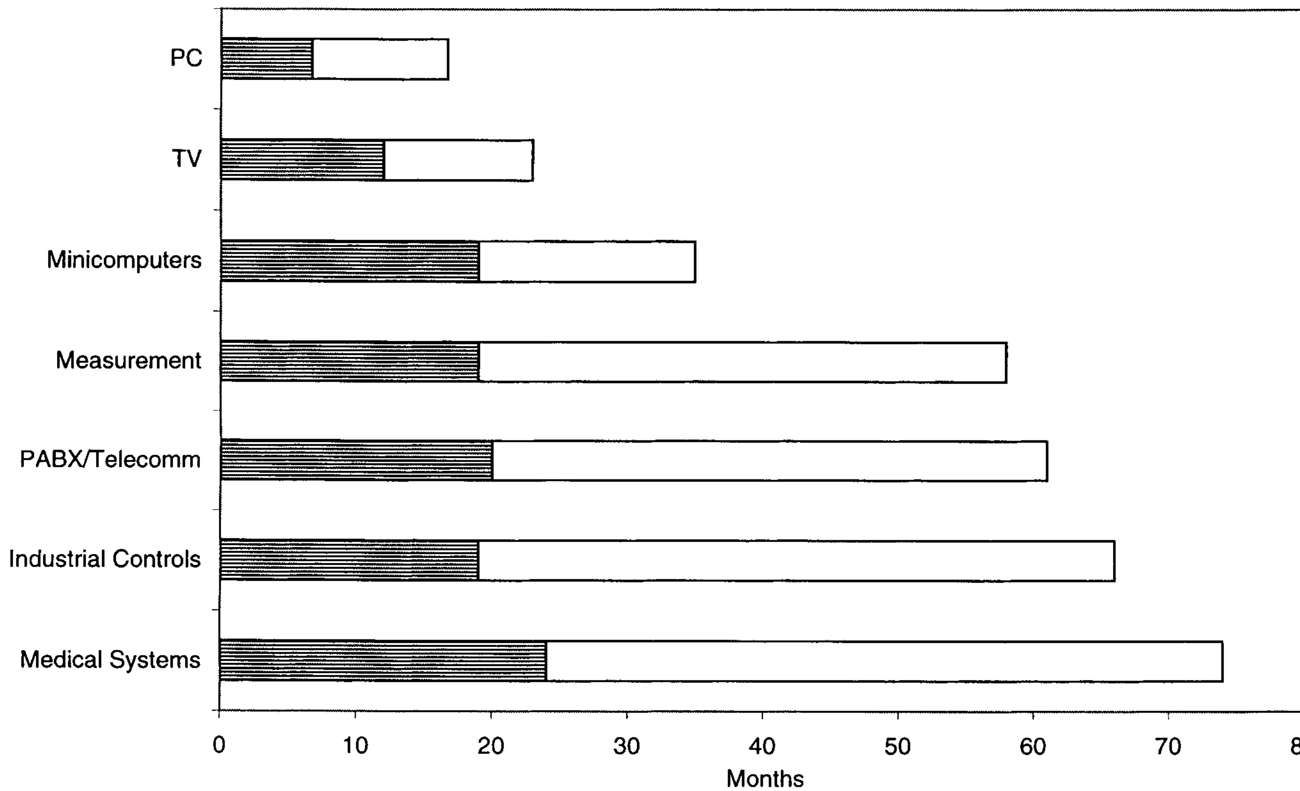
The development activity in a product category over time is made up of cycles (or product redesign intervals), each consisting of an active development period and an "idle" period. Figure 2 shows the average length of the product redesign interval (the entire cycle), and of the active development period (represented by the shaded area), for different industry segments based on our 1994–95 survey data. As shown in Figure 2, industry segments with higher clockspeeds generally have shorter project durations,[13] as well as shorter product-redesign intervals, implying a higher

[12]Fine's (1996) asset-based measures were not available in our surveys. A cursory examination suggests it would be difficult to operationalize those at the business unit level in the future.

[13]The only exception is the Measurement Instruments segment, which is characterized in our sample by products of relatively low complexity, which in turn reduces the project duration.

**Figure 2 The Rhythm of Development Activity for Major Industry Segments: 1994–95 Survey**

Note: The total length of each bar represents the average time interval between product redesigns. The shaded areas represent the average duration of development projects.






frequency of development activity. In contrast, the low-speed segments are characterized by longer time periods between redesign projects. Together, the project duration and product-redesign interval operationalize Fine's (1996) concept of *product technology clockspeed.*

**5.1.3. Production Ramp-up Time.** *Production ramp-up* is the transition phase from product development to manufacturing. During production ramp-up, the firm produces a low level of volume while training its employees and working out any remaining problems in the production process. This phase ends when the production system has stabilized at its target volume level (Clark and Wheelwright 1993). Time-to-market considerations suggest that the production ramp-up time should be shorter in faster-moving environments. As noted in §5.1.1., we collected data on the characteristics of a recently completed project from the business units in our survey. One of the items collected was the production ramp-up time, which we used as another operational variable.

**5.1.4. Organizational Change.** Higher industry clockspeed should lead not only to faster operations but also to an increase in the rate of *organizational* change. Radical shifts in the market environment cause firms to reappraise their strategies and restructure their internal processes and organizations. Hence, we expect a positive relationship between industry clockspeed and the incidence of organizational change—a measure of Fine's (1996) *organizational clockspeed.*

In the 1994–95 survey, business units were asked to indicate whether they had carried out programs of strategic reorientation or restructuring (i.e., major organizational change) over the three-year period 1991–

93. About 75% of the business units indicated that they had undergone change of this nature. To examine the relationship between the frequency of major organizational change and industry clockspeed, we used a binary variable $M$ that took on a value of 1 if the firm had undergone major organizational change during 1991–93 and 0 otherwise.

## 5.2. Control Variables

In §5.3, we analyze the relationships between industry clockspeed and the operational variables described in §5.1. These relationships, however, may be affected by additional factors. Controlling for the effects of these factors may change the coefficients of the variables under study or reveal additional relationships. These control variables are briefly discussed below.

**5.2.1. Product Complexity.** Speed of development is likely to be affected in an adverse manner by higher product complexity, because of the additional effort required to integrate a larger number of modules, to coordinate a larger staff or to bring a more comprehensive product to market. Several measures of complexity have been used in prior research on product development time. Clark and Fujimoto (1991) measure product complexity in the auto industry using two variables: product price and the number of different body features. Griffin (1993) constructs a simple aggregate measure of complexity from two variables—the number of functions performed by the product and the number of persons with different expertise involved in the development of the product (*management complexity*). Murmann (1994) uses a binary classification for complexity, based on the number of parts constituting the product.

Our survey provided us with three different indicators of complexity:

- The unit selling price of the product, which is an overall measure of product size (Clark and Fujimoto 1991). Higher-priced products generally tend to be more complex than lower-priced ones, especially given the broad range of prices for the electronics products covered by our surveys.
- The number of electronic components (measured by the number of printed circuit boards) in the product. In addition to being a direct measure of structural complexity (Murmann 1994, Clark and Fujimoto 1991), it is also indicative of the number of functions performed by the product (Griffin 1993), since each circuit board in an electronics product is typically designed to deliver a specific function (e.g., disk controller or graphics card).
- The average project staffing on a major project for the development of the product. This variable operationalizes the concept of *management complexity* (Griffin 1993).

Our analysis of the data revealed that all three variables were characterized by highly skewed distributions (Shapiro-Wilk tests of normality yielded $W$ values between 0.3 and 0.6). We thus followed the common practice (e.g., Maddala 1977, Ch.13) of using the logarithms of these variables, whose distributions were indeed close to Normal, with Shapiro-Wilk $W$ values exceeding 0.95 in all three cases. We standardized the transformed variables to a common scale (zero mean and unit standard deviation) and performed a principal-components analysis on the standardized variables. The results, shown in Tables 4(a) and 4(b),

**Table 4(a) Cross-Correlations and Principal Components for Complexity Variables: 1992–3 Survey**

The top table presents the correlations between the variables. The bottom table presents for each principal component
- The component loadings;
- The eigenvalue corresponding to the component; and
- The proportion of the variance explained by the component.

| **1992–93 Survey** | *log* (No. of PCB) | *log* (Product Price) | *log* (Project Staffing) |
|---|---|---|---|
| *log*(No. of PCB) | 1 | 0.72*** | 0.27** |
| *log*(Product Price) | 0.72*** | 1 | 0.38*** |
| *log*(Project Staffing) | 0.27** | 0.38*** | 1 |

***significant at $p = 0.0001$
**significant at $p = 0.01$

| **1992–93 Survey** | Component 1 | Component 2 | Component 3 |
|---|---|---|---|
| *log*(No. of PCB) | 0.621 | −0.407 | 0.670 |
| *log*(Product Price) | 0.650 | −0.209 | −0.730 |
| *log*(Project Staffing) | 0.438 | 0.889 | 0.135 |
| Eigenvalue | 1.94 | 0.79 | 0.27 |
| Proportion Explained | 0.65 | 0.26 | 0.09 |

**Table 4(b) Cross-Correlations and Principal Components for Complexity Variables: 1994–5 Survey**

The top table presents the correlations between the variables. The bottom table presents for each principal component
- The component loadings;
- The eigenvalue corresponding to the component; and
- The proportion of the variance explained by the component.

| 1994–95 Survey | *log* (No. of PCB) | *log* (Product Price) | *log* (Project Staffing) |
|---|---|---|---|
| *log*(No. of PCB) | 1 | 0.61*** | 0.49*** |
| *log*(Product Price) | 0.61*** | 1 | 0.33*** |
| *log*(Project Staffing) | 0.49*** | 0.33*** | 1 |

***significant at $p = 0.0001$
**significant at $p = 0.01$

| 1994–95 Survey | Component 1 | Component 2 | Component 3 |
|---|---|---|---|
| *log*(No. of PCB) | 0.631 | −0.139 | −0.763 |
| *log*(Product Price) | 0.578 | −0.572 | 0.581 |
| *log*(Project Staffing) | 0.517 | 0.809 | 0.281 |
| Eigenvalue | 1.96 | 0.68 | 0.35 |
| Proportion Explained | 0.65 | 0.23 | 0.12 |

indicate that there is only one principal component with eigenvalue greater than one. This component has approximately equal loadings on the number of printed circuit boards and product price, and a slightly lower loading on the project-staffing variable. The project-staffing variable may be problematic, however, since it is codetermined with other variables that pertain to the business unit's development activities described in §5.1. Hence, our analyses applied two alternative measures of complexity, the first (*complexity_1*) being the average of the three standardized variables, and the second (*complexity_2*) excluding the project-staffing variable.

**5.2.2. Other Control Variables.** Other control variables used in this study were as follows:[14]

*Sales growth:* High growth rates may induce a business unit to speed up its internal processes, so products can be moved to market in a more expeditious manner. However, it is also possible that this effect will be subsumed by our industry clockspeed measure, particularly since our validation procedure (§4.5) showed that clockspeed captures much of the growth effect. We used a *sales growth* control variable defined as the (compound) annual growth rate of the business unit's sales over the two-year period immediately preceding each survey.

*R&D intensity:* Greater availability of development resources makes it possible for firms to speed up their development projects to some extent, even though there are limits on how far this can be sustained. Our *R&D intensity* control variable was calculated as the ratio between R&D spending and sales.

*Consistent cross-functional participation:* A number of authors have suggested a connection between *cross-functional participation* and effective product development (Clark and Wheelwright 1993). In a study of the timeliness of development projects, Cooper (1995) identifies the use of dedicated cross-functional teams as the primary driver of fast-paced, on-time development. He goes on to define true cross-functional participation as the full-time involvement of personnel from different functions throughout the duration of the project. The use of cross-functional teams as a driver of development speed and effectiveness was also suggested by Murmann (1994), Eisenhardt and Tabrizi (1995), and Ittner and Larcker (1997).

Our surveys obtained data on whether or not personnel from the Manufacturing and Marketing functions participated full-time in all three stages (specification, design, and testing) of the business unit's development projects. This reflects consistent participation by the respective function throughout the project. We averaged the variables across the two functions to obtain a measure of consistent cross-functional participation.

*Geographic location:* The speed of execution may also be influenced by local culture, legal system, or infrastructure. For example, at least for a period of time, Japanese manufacturers have managed to accelerate their product-development processes in the auto industry over and above their U.S. and European peers (see Womack et al. 1990 and Clark and Fujimoto 1991). We controlled for regional effects by using locational

[14] We thank an anonymous referee for suggesting several of these variables.

dummy variables in our regressions. Specifically, we divided our sample into three regions—U.S., Europe, and the Asia-Pacific region—and used the corresponding regional dummy-variables as controls.

### 5.3. Empirical Results

Our hypothesis on the relationship between industry segment clockspeed and the pace of internal operations was tested by regressing the operational variables described in §5.1 against the industry segment clockspeeds. To account for the fact that developing and stabilizing the production of a more complex product requires more time, we used the two measures of product complexity, defined in §5.2.1, as control variables in the regressions. We also performed separate regressions using all the control variables described in §5.2.

**5.3.1. Project Duration.** We have hypothesized that, other things being equal, business units will speed up their development projects when they are in industry segments with higher clockspeeds. As explained in §5.1.1, we use the total project duration (starting with the predevelopment study and ending with pilot runs) as a measure of slowness (i.e., the inverse of speed). Table 5 shows the effects of clockspeed, complexity and the other control variables on project duration for both surveys. For each survey, we estimated four separate regression models, two using only the different complexity variables[15] as controls and then two including all other control variables, namely sales growth, R&D intensity, cross-functional participation, and geographic location.

The coefficients of industry clockspeed in Table 5 are consistently negative in all the regressions, at a high level of statistical significance. This clearly indicates that, in faster business environments, firms are compelled to compress development activity into shorter time periods. The coefficients of clockspeed are also of the same order of magnitude throughout, confirming the stability of the clockspeed effect. As expected, greater product complexity tends to slow down the development process; the regression coefficients are for the most part positive and significant for both complexity variables. All the other control variables are insignificant. Sales growth is apparently subsumed by the overriding effect of clockspeed. R&D intensity has little or no effect, and the same is true of cross-functional participation.

The regional dummy variables are insignificant:[16] after controlling for segment clockspeed and product complexity, the region the business unit is in makes no difference. This is in sharp contrast to the auto industry, where researchers (see Womack et al. 1990 and Clark and Fujimoto 1991) found dramatic performance differences between American, Japanese, and European manufacturers. The difference between these findings and ours may reflect either differences between the electronics and auto industries or the different time frames. Either way, our findings here and in the analyses that follow are consistent with the notion that in the 1990s, the electronics industry is truly global: it matters which industry segment a business unit is in, not *where* it is located.

**5.3.2. Product Redesign Intervals.** In addition to the speed of execution of the projects themselves, we also expect the frequency with which these projects are rolled out to be greater in higher clockspeed environments. As explained in §5.1.2, we used the time interval between successive product redesign decisions as our (inverse) measure of this frequency. We investigated the relationship between industry clockspeed and product-redesign intervals following the same methodology as in the case of project duration. The results are shown in Table 6. Once again, the coefficients of industry clockspeed are consistently negative and significant: higher clockspeed makes it necessary for firms to undertake new design efforts with greater frequency. Complexity is positively related to the length of the redesign interval, although the relationship is not as strong as with the project duration variable, which is directly impacted by product-specific factors. The other control variables do not appear to

[15]Recall that we defined two measures of complexity in §5.2.1—the first (*complexity_1*) in terms of all three complexity indicators, and the second (*complexity_2*) excluding the project-staffing variable.

[16]We also tested whether the two dummy variables were *jointly* significant by performing an F-test to compare this regression to a restricted regression (without the two dummies). The resulting F values were insignificant.

**Table 5 Regression Results for Models Relating the Duration of Development Projects to Industry Clockspeed, Controlling for Complexity and Other Factors**

The dependent variable, which measures the time from the predevelopment study through the completion of pilot runs, has mean values of 23.2 months and 17.8 months respectively for the two surveys. Complexity_1 is the mean of the logarithms of the number of printed circuit boards, product price, and project staffing. Complexity_2 is the mean of the logarithms of the number of printed circuit boards and product price.

| | Model 1 | | Model 2 | | Model 3 | | Model 4 | |
|---|---|---|---|---|---|---|---|---|
| Variable | 1992–93 Coeff. (t-stat.) | 1994–95 Coeff. (t.stat) | 1992–93 Coeff. (t-stat.) | 1994–95 Coeff. (t.stat) | 1992–93 Coeff. (t-stat.) | 1994–95 Coeff. (t.stat) | 1992–93 Coeff. (t-stat.) | 1994–95 Coeff. (t.stat) |
| Intercept | 22.8 | 18.2 | 22.9 | 18.2 | 22.0 | 16.2 | 20.0 | 16.1 |
| Clockspeed | −3.79 | −4.92 | −3.38 | −4.84 | −4.39 | −4.60 | −3.94 | −4.43 |
| | (−4.0)** | (−4.0)** | (−3.3)** | (−3.6)** | (−3.7)** | (−2.6)** | (−3.0)** | (−2.4)** |
| Complexity_1 | 6.03 | 4.01 | | | 6.32 | 3.12 | | |
| | (6.0)** | (3.2)** | | | (4.7)** | (2.0)* | | |
| Complexity_2 | | | 5.06 | 2.93 | | | 4.40 | 2.27 |
| | | | (4.8)** | (2.4)** | | | (3.3)** | (1.5) |
| Sales Growth | | | | | 0 | 0.125 | 0.04 | 0.142 |
| | | | | | (0.0) | (1.5) | (−0.1) | (1.6) |
| R&D Intensity | | | | | 0.05 | 0.275 | 0.229 | 0.305 |
| | | | | | (0.2) | (1.0) | (0.9) | (1.0) |
| Cross-Functional Participation | | | | | 7.68 | 3.03 | 8.10 | 3.82 |
| | | | | | (1.5) | (0.7) | (1.5) | (0.8) |
| Dummy Variable—US | | | | | −1.78 | −4.27 | −1.03 | −5.49 |
| | | | | | (−0.6) | (−1.2) | (−0.3) | (−1.4) |
| Dummy Variable—Asia | | | | | 4.25 | −0.19 | 5.59 | −0.36 |
| | | | | | (1.3) | (−0.0) | (1.6) | (−0.1) |
| Degrees of Freedom | 89 | 50 | 89 | 50 | 71 | 37 | 71 | 37 |
| F Value | 26.9** | 18.2** | 19.1** | 14.4** | 7.8** | 2.9* | 5.5** | 2.5* |
| $R^2$ | 0.38 | 0.43 | 0.30 | 0.38 | 0.46 | 0.40 | 0.37 | 0.37 |

**Significant at $p = 0.01$
*Significant at $p = 0.05$

have a significant effect on the redesign intervals in any of the models. In particular, there are no significant differences between the different regions in which the business units were located, consistent with our earlier findings on the global nature of the electronics industry.

**5.3.3. Production Ramp-Up Times.** Since time-to-market assumes greater importance in high-cockspeed environments, we expect that business units will attempt to stabilize the production of new products faster in such environments, implying a shorter production ramp-up time (see §5.3.1.). The regression results with production ramp-up time as the dependent variable, and clockspeed, complexity, and the other controls as the independent variables, are shown in Table 7 for both surveys.

Consistent with our hypothesis, we find that the regression coefficient of industry clockspeed is significantly negative in all cases. The coefficient of complexity is positive, as expected. All other control variables are again insignificant, indicating the overriding strength of the clockspeed and complexity variables and the global nature of the electronics industry.

**5.3.4. Organizational Change.** We measured the

**Table 6 Regression Results for Models Relating Product Redesign Intervals to Industry Clockspeed, Controlling for Complexity and Other Factors**

The dependent variable, which measures the time between successive product redesigns, has mean vlaues of 24.0 months and 29.0 months respectively for the two surveys. Complexity_1 is the mean of the logarithms of the number of printed circuit boards, product price and project staffing. Complexity_2 is the mean of the logarithms of the number of printed circuit boards and product price.

| | Model 1 | | Model 2 | | Model 3 | | Model 4 | |
|---|---|---|---|---|---|---|---|---|
| Variable | 1992–93 Coeff. (t-stat.) | 1994–95 Coeff. (t.stat) | 1992–93 Coeff. (t-stat.) | 1994–95 Coeff. (t.stat) | 1992–93 Coeff. (t-stat.) | 1994–95 Coeff. (t.stat) | 1992–93 Coeff. (t-stat.) | 1994–95 Coeff. (t.stat) |
| Intercept | 24.2 | 29.5 | 24.3 | 29.9 | 26.9 | 26.5 | 25.3 | 27.1 |
| Clockspeed | −7.00 | −10.1 | −6.79 | −8.98 | −5.42 | −11.6 | −5.05 | −10.4 |
| | (−5.2)** | (−4.0)** | (−4.9)** | (−3.5)** | (−3.2)** | (−2.9)** | (−2.9)** | (−2.6)** |
| Complexity_1 | 4.49 | 5.9 | | | 5.24 | 5.2 | | |
| | (3.3)** | (2.3)* | | | (2.9)** | (1.6) | | |
| Complexity_2 | | | 3.70 | 6.63 | | | 4.11 | 5.67 |
| | | | (2.6)** | (2.4)* | | | (2.4)* | (1.6) |
| Sales Growth | | | | | −0.130 | 0.292 | −0.133 | 0.316 |
| | | | | | (−1.3) | (1.6) | (−1.4) | (1.8) |
| R&D Intensity | | | | | 0.109 | 0.106 | 0.239 | 0.102 |
| | | | | | (0.3) | (0.2) | (0.8) | (0.2) |
| Cross-Functional Participation | | | | | 3.91 | 4.79 | 4.50 | 6.15 |
| | | | | | (0.6) | (0.5) | (0.6) | (0.6) |
| Dummy Variable—US | | | | | −4.24 | −0.33 | −3.65 | −3.32 |
| | | | | | (−1.0) | (0.0) | (−0.8) | (−0.4) |
| Dummy Variable—Asia | | | | | −4.78 | 10.4 | −3.62 | 11.2 |
| | | | | | (−1.0) | (1.2) | (−0.8) | (1.3) |
| Degrees of Freedom | 84 | 47 | 84 | 47 | 66 | 36 | 66 | 36 |
| F Value | 21.2** | 11.3** | 18.6** | 11.7** | 4.7** | 2.9* | 4.1** | 3.0* |
| $R^2$ | 0.34 | 0.33 | 0.31 | 0.34 | 0.37 | 0.42 | 0.33 | 0.42 |

**Significant at $p = 0.01$
*Significant at $p = 0.05$

incidence of major organizational change using a binary variable $M$ that took on a unit value if such change took place during the three-year period preceding our second survey (see §5.1.4). We examined the relationship between $M$ and industry clockspeed by performing a Probit regression analysis of this binary dependent variable on industry clockspeed (the independent variable):[17]

$$Pr\{M = 1\} = \Phi(a_0 + a_1 \cdot Clockspeed),$$

where $\Phi(\cdot)$ is the cumulative standard Normal distribution function. We also performed similar Probit regressions using sales growth and the regional dummy-variables as controls (the other control variables are not relevant to organizational restructuring).

The results, shown in Table 8, confirm our hypothesis that clockspeed is a driver of organizational change. The numbers in parentheses below the coefficients in Table 8 are the $\chi^2$ values for the maximum-likelihood estimates of the coefficients. The coefficient of industry clockspeed is significant at the level $p = 0.03$ in both regressions, while the control variables are not significant. The probability that the average firm

[17]Following the usual interpretation of the Probit regression model, the left-hand side is the probability that the dependent variable $M$ is equal to 1.

**Table 7 Regression Results for Models Relating Production Ramp-Up Time to Industry Clockspeed, Controlling for Complexity and Other Factors**

The dependent variable, which measures the time taken to stabilize production after start-up, has mean vlaues of 3.3 months and 2.9 months respectively for the two surveys. Complexity_1 is the mean of the logarithms of the number of printed circuit boards, product price and project staffing. Complexity_2 is the mean of the logarithms of the number of printed circuit boards and product price.

| | Model 1 | | Model 2 | | Model 3 | | Model 4 | |
|---|---|---|---|---|---|---|---|---|
| Variable | 1992–93 Coeff. (t-stat.) | 1994–95 Coeff. (t.stat) | 1992–93 Coeff. (t-stat.) | 1994–95 Coeff. (t.stat) | 1992–93 Coeff. (t-stat.) | 1994–95 Coeff. (t.stat) | 1992–93 Coeff. (t-stat.) | 1994–95 Coeff. (t.stat) |
| Intercept | 3.35 | 3.52 | 3.37 | 3.55 | 4.11 | 3.12 | 3.58 | 3.12 |
| Clockspeed | −0.705 | −1.42 | −0.619 | −1.18 | −1.04 | −1.63 | −0.877 | −1.37 |
| | (−2.8)* | (−4.6)** | (−2.4)* | (−3.8)** | (−3.3)** | (−3.4)** | (−2.6)** | (−2.8)** |
| Complexity_1 | 1.25 | 1.29 | | | 1.69 | 1.15 | | |
| | (4.7)** | (4.3)** | | | (4.5)** | (3.0)** | | |
| Complexity_2 | | | 1.09 | 1.32 | | | 1.22 | 0.99 |
| | | | (3.9)** | (4.6)** | | | (3.2)** | (2.8)** |
| Sales Growth | | | | | −0.008 | 0.012 | −0.006 | 0.015 |
| | | | | | (−0.4) | (0.7) | (−0.3) | (0.8) |
| R&D Intensity | | | | | −0.121 | −0.024 | −0.075 | −0.016 |
| | | | | | (−1.9) | (−0.3) | (−1.2) | (−0.2) |
| Cross-Functional Participation | | | | | 1.39 | 1.20 | 1.97 | 1.52 |
| | | | | | (0.9) | (1.2) | (1.3) | (1.5) |
| Dummy Variable—US | | | | | 0.626 | 0.410 | 0.739 | −0.168 |
| | | | | | (0.8) | (0.5) | (0.9) | (−0.2) |
| Dummy Variable—Asia | | | | | 0.695 | −0.240 | 0.873 | −0.023 |
| | | | | | (0.9) | (−0.2) | (1.0) | (−0.0) |
| Degrees of Freedom | 84 | 47 | 84 | 47 | 66 | 32 | 66 | 32 |
| F Value | 14.6** | 20.8** | 18.0** | 22.2** | 5.2** | 3.8** | 3.5** | 3.5** |
| $R^2$ | 0.26 | 0.48 | 0.21 | 0.50 | 0.38 | 0.52 | 0.29 | 0.50 |

**Significant at $p = 0.01$
*Significant at $p = 0.05$

(with *industry clockspeed* = 0) would undergo major organizational change was 76%. The corresponding probability for a firm that was two standard deviations above the average industry clockspeed was 95%, while for a firm that was two standard deviations below the mean industry clockspeed it was 40%. The incidence of organizational change is quite high even for the firms with relatively low levels of industry clockspeed—indicating the highly dynamic nature of the electronics industry as a whole. The results also illustrate that the most dynamic business units were almost certain to undergo major organizational change within a three-year period.

### 5.4. Summary of Clockspeed Results

Our results clearly indicate that higher industry clockspeed goes hand-in-hand with a higher frequency of product redesign and with shorter project development times for products of comparable complexity. Furthermore, production ramp-up time is closely related to industry clockspeed: manufacturers in the faster industry segments tend to stabilize their production processes more quickly than those subject to lower industry clockspeed. In addition, the level of industry clockspeed is strongly correlated with the likelihood of organizational restructuring.

Given these strong relationships, it is reasonable to ask whether an alternative industry clockspeed measure could be formulated in terms of the *dependent* variables in the above analyses (i.e., project duration, redesign intervals, etc.). We believe such measures would not be as representative of the industry segment's environment as our clockspeed variables. As we have shown, the lower-level operational measures reflect product complexity in addition to clockspeed. More importantly, our thesis is that the attributes of the external environment drive the business unit's internal practices, hence our industry clockspeed measures reflect traits that are largely common to business units within a given industry segment. In contrast, internal operational measures like project duration are more firm-specific and relate to the actual execution of projects within the business unit. Indeed, we found that only about 30% of the variation in the operational parameters could be explained by the industry segments, compared to about 60% to 70% of the variation for our industry clockspeed variables. That is, the variation *within* an industry segment is much higher for the operational measures than for the industry clockspeed measures. Clearly, the latter are truer measures of clockspeed at the industry level.

## 6. Life Cycle Compression

The phenomenon of progressively shorter life cycles has been noted repeatedly in the popular press over the last decade. In the academic literature, trends in the life cycles of different products (in particular, the shortening of "market life") have been examined by a number of authors. Olshavsky (1980) and Qualls et al. (1981) examined penetration rates and the rates of sales growth over time for a number of home appliance products. Both studies found a significant positive relationship between product introduction dates and sales growth rates, which they interpreted as evidence that product life cycles were shortening over time. Bayus (1994) challenges the notion of shortening life cycles, and, to back up his hypothesis, he analyzes the life cycles of different IBM PC models from 1981 to 1991. However, available data on models of the Apple Macintosh (DiNucci (1994)) show that there has been some reduction in the life-cycle duration between 1984 and 1994.

**Table 8** **Regression Results for Probit Models Relating the Incidence of Major Organizational Change to Industry Clockspeed and Control Variables for Sales Growth and Geographic Location (1994–5 survey).**

$\chi^2$ statistics are in parentheses. The binary dependent variable, which indicates the presence or absence of major organizational change in a 3-year period, has a mean of 0.73.

| | Model 1 | Model 2 |
|---|---|---|
| Variable | 1994–95 Coefficient ($\chi^2$-statistic) | 1994–95 Coefficient ($\chi^2$-statistic) |
| Intercept | 0.722 | 0.781 |
| | (14.4)** | (8.2)** |
| Clockspeed | 0.479 | 0.578 |
| | (4.8)* | (4.9)* |
| Sales Growth | | −1.78 |
| | | (−1.9) |
| Dummy variable—US | | 0.033 |
| | | (0.0) |
| Dummy variable—Asia | | 0.658 |
| | | (1.1) |
| N (obs) | 60 | 56 |

**Significant at $p = 0.01$
*Significant at $p = 0.05$

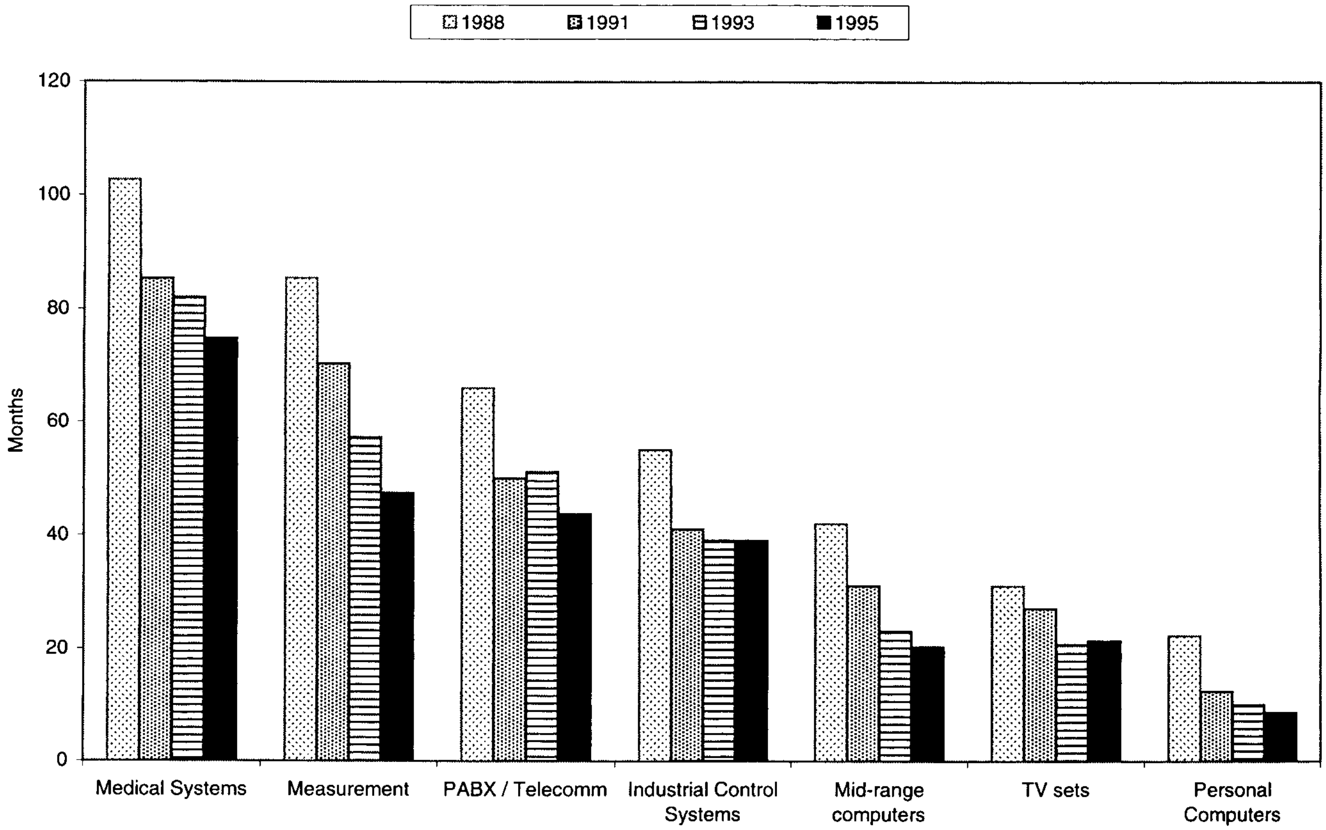
Because our surveys had obtained estimates of product life duration at different points in time, we were able to directly test whether life cycles were getting shorter. We estimated the annualized rate of change in product life separately for each business unit in the two survey samples.[18] The sample mean and standard deviation of the annualized rate of change for the 1992–93 survey were −0.0940 and 0.0866 respectively. A t-test established that the mean rate was significantly different from zero (t = 11.1, $p = 0.0001$). The corresponding results for the 1994–95 survey showed a mean of −0.0939, a standard deviation of 0.0707, and a t-value of 10.4 ($p = 0.0001$).

These results indicate a steady decrease in the duration of product life cycles. Figure 3 shows the variations in product life over time for the major industry segments included in our sample. For the industry as

[18]These were estimated over 1988–91 and 1991–93, respectively.

**Figure 3 Product Life Cycle Compression for Major Industry Segments, 1988–1995.**

Note: The 1995 figures are estimates provided by respondent to the 1994–95 survey.




a whole, the duration of product life cycles has been decreasing steadily over the period from 1988 to 1995, at an average rate of 9.4% per year. The rate of decrease is much higher in some of the more dynamic industry segments; for example, it is 16.7% on average for the PC segment, which has the highest level of clockspeed.

## 7. Concluding Remarks

Academics and practitioners alike recognize that an understanding of increasing business dynamics and accelerating industry clockspeeds is critically important in today's economic environment. For such discernment, it is necessary to measure the volatility and speed of business environments in a precise fashion, so researchers can provide meaningful, comparable analyses and managers can formulate appropriate responses in a rational manner. In this paper, we addressed this issue by developing an integrated metric for industry clockspeed that takes into account both demand- and supply-side factors. We validated our measure and used it to study the links between the dynamics of a firm's business environment and the speed of its internal operations.

We related our industry clockspeed measure to metrics that implement Fine's (1996) concepts of *product technology clockspeed* and *organizational clockspeed*. We established that higher clockspeed went hand-in-hand with higher frequency of product redesign and with shorter project duration for comparable product complexity. We also found that production ramp-up time was closely related to clockspeed—manufacturers in more dynamic industry segments tended to stabilize their production processes more quickly than those in slower-moving segments. The view that electronics firms are disposed to high organizational turbulence was supported by the extent of major organizational change observed in the sample as a whole. In addition, clockspeed was strongly correlated with the likelihood of such organizational change.

We also examined the phenomenon of product life-cycle compression, which has been a subject of recent debate. We found that not only were product life cycles being compressed at a rapid rate, but the *extent* of compression was strongly linked to the actual level of clockspeed. This, in effect, means that clockspeed is increasing in a runaway fashion throughout the industry, making it all the more important to categorize its effects and develop adequate responses.

In his conceptual essay on industry clockspeed, Fine (1996) had surmised that a measure of speed would have several potential uses, including industry classification and cross-industry benchmarking analysis:

> Biologists study the "fast-clockspeed" fruitfly species to observe many generations in a short time period, and build models of genetic dynamics that are then applied to moderate-clockspeed mammals or glacial-speed reptiles. . . . Similarly, industry analysts can observe fast-clockspeed industries (e.g., electronics) to build models of industry dynamics that can then be applied to slower-moving industries. . . .

This increases our confidence that the results of our study of the fast-paced electronics industry will be useful in a wider context. With this in mind, we proposed measures of clockspeed that could be readily monitored in any manufacturing industry, and we conducted the analysis so it would be applicable beyond the boundaries of this study. In fact, other industries are experiencing increasing levels of business dynamics, and they can learn from an industry that leads the way. Electronics may be to operations management what fruitflies are to genetic science: a rich, fast-moving testbed for new business processes and approaches that are designed to cope with advancing trends.[19]

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