Technological discontinuities and flexible production networks: The case of Switzerland and the world watch industry

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The twentieth-century history of the Swiss watch industry illustrates how cultures and industrial production systems experience great difficulty adapting to external change at different points in time. The current emphasis on production networks – unique reservoirs of potential technological innovation realized through cooperation rather than competition among firms – lacks a detailed appreciation of historic networks, and in particular their fragile character in times of economic turmoil. While networks can and do promote innovation within an existing technological framework, historical experience suggests their fragmented, atomistic structure is subject to disorganization and disintegration during periods of technological change. An exclusive focus on “production” ignores other constraints that are powerful forces governing the reaction abilities of regions. Previous research has largely relied on a model of oligopolistic competition to explain how the Swiss lost control of the world watch industry. I conclude, on the contrary, that the Swiss experience must be understood from the standpoint of how technological change challenges previous ways of organizing production, industry, culture, and society. Technology shifts present a series of strategic turning points that industrial leaders must navigate during a period of technological change.

Introduction

The history of the Swiss watch industry is instructive as countries and regions experiment with network production systems in attempts to maintain and augment their competitiveness in a global economy. On the eve of the electronics revolution, the Swiss watch production system, centered in the mountainous Jura region, was flexible, cost effective, and extremely profitable. Both horizontally and vertically disintegrated, the Swiss system offered enormous variety while maintaining quality and timeliness of delivery. “The multiplicity of enterprises, and the competition and emulation that characterized the industry, yielded a product of superior quality known the world over for high fashion, design, and precision” [21, p. 48].

Beginning in the 1970s, when foreign competition hurdled technological frontiers in watch movements, advancing from mechanical to electric, electronic, digital and finally quartz technology, the Jura’s undisputed dominance ended. Massive job loss and out-migration occurred as firms, unable or unwilling to adapt to new technologies, closed their doors. Today, while still world leaders in watch export value, Swiss watchmakers produce only a fraction of their pre-1970s output levels, and resources needed to invest in new product research and development are scarce [40]. In a span of less than 30 years, the world’s dominant watch region yielded technological leadership (in watchmaking and micromechanics) to its Far Eastern rivals. What lessons can be learned about network production systems and technological innovation from the experience of Switzerland’s watch region?

Industrial restructuring of the past 20 years has left once dominant manufacturing regions such as America’s industrial heartland and Germany’s Ruhr valley debilitated. Reincorporating technological innovation within production systems of deindustrialized regions has become a major concern. Even technologically vibrant regions such as Route 128, Silicon Valley, and Emilia Romagna confront uncertain futures in the current period of

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North-Holland

The Appendix provides a brief review of watch technologies.
intense technological development and international competition. How can a region remain innovative during a period of technological change? Do network production systems offer a more flexible and permanent means of regional adaptation? By examining the experience of the watch industry I hope to tie together empirical experiences of researchers asking similar questions concerning the relationship between structure of production, regional culture, technological change, the formation and maintenance of core skills, and state-led regional development in industrial hinterlands.

This article reviews the twentieth-century history of the Swiss watch industry. My purpose is to suggest that focussing solely on production transactions does not adequately explain how economic, social, and cultural conditions interact to form a complex of human relations that can remain flexible and innovative over time. While networks are quite proficient at production and innovation within an existing technological framework, disintegrated systems may neither accumulate profits nor demonstrate a collective will to make essential investments in research, marketing, and distribution in response to technological change. At a more refined level, this article suggests that the current emphasis on production networks – unique reservoirs of potential technological innovation realized through cooperation rather than competition among firms – lacks a detailed appreciation of historic networks, and in particular their fragile character in times of economic turmoil [29,30,31,32]. While networks can and do promote innovation within an existing technological system, historical experience suggests their fragmented, atomistic structure is subject to disorganization and disintegration during periods of major technological change [35,8,9].

Inter-firm networks are important ingredients of technologically innovative and flexible industrial production systems. This insight is an important addition to contemporary theoretical discussions about the relationship between regional and technology development. As the case of the Swiss watch industry suggests (within a particular structure of production and organization), a highly articulated system of production, tied together by elaborate cultural, institutional, and economic relationships, exhibits flexibility and adaptability within an existing technological framework. The case study also illustrates, however, that within any production system flexibility and innovativeness are time-dependent. Therefore, given specific historical circumstances, they are vulnerable.

The lack of coordination and organization within small firm complexes has precipitated discussions about the need for governing systems to regulate small firm atomistic behavior and to replicate functions performed by the vertically integrated corporation such as R&D, management training, marketing, and distribution. As Saxenian’s work suggests, network production systems are vulnerable to technological threats from the outside [30]. Calls for institution-building must be tempered with the knowledge that coordinating organizations quickly become absorbed into the regional fabric and ossify over time. During the course of two centuries the Swiss watch industry established elaborate institutions, organized technological competitions and other social events, and supported diverse organizations to bolster the industry’s innovative capabilities [8]. The strength of these institutions has been and still is significant. The Swiss Watch Industry Federation (FH) was the leading organization in trade negotiations for the world watch industry [24]. Long after the Swiss lost volume leadership, the FH continued to lead GATT negotiations [27]. Market share, quotas, and tariffs are still negotiated by the FH for the world watch industry. Yet despite its worldwide reputation, in the 1960s and 1970s the FH was unable to overcome resistance to new technology. While the organization sponsored Swiss R&D, it could not force members to incorporate new technologies into existing products.

This article departs from past treatments of the watch industry’s post-war experience by examining the rise of world competition through the lens of technological shifts. Previous treatments have largely relied on a model of oligopolistic competition to explain how the Swiss lost control of the world watch industry. I conclude, on the contrary, that the Swiss experience must be viewed from another angle. How do technological shifts challenge previous ways of organizing production, industry, culture, and society? Fundamental changes in technology present a series of strategic turning points for the world watch industry.
points that industrial leaders must navigate. The Swiss were no exception.

This article first considers the historic evolution of the Swiss watch industry during the final decades of the last century and shows its early adaptability to new production innovations within the framework of mechanical watch technology. The bulk of the remaining discussion traces the evolution of the industry – illustrating the difficulties experienced in the face of radical technological developments.

The Swiss watch industry provides an important case study of an industrial and cultural system that retained technological supremacy for two centuries and that still holds its dominant position within the earlier mechanical paradigm. The industry has, however, yielded technological leadership to foreign competitors in a major geographical shift in world production [36]. The Swiss are now followers rather than leaders of industry trends.

The early twentieth-century history of the Swiss watch industry

Historically the Swiss industry has shown surprising resilience in the face of change. At the end of the last century (1876–1900) the industry was issued a major challenge by the U.S. watch production system. America’s watch manufacturers developed machinery to produce watches at high volume with low cost, low skill, and relatively high levels of precision. Watch movements were drastically simplified and more economical to produce. While hand-adjustment was still required in final assembly, the overall skill content in American watches was drastically reduced.

The Swiss response to U.S. technological challenges was decisive. Over a period of 20 years (1885–1905) they proved more than capable of making needed technical progress [7]. While the Swiss lost considerable market shares in the U.S., the country’s manufacturers did not yield control of global markets [19]. Over the course of two decades, the Swiss system adopted aspects of the American system that were cost effective. The Swiss system shifted from its reliance on small-scale cottage production to an intermediate form that combined mechanization and partial vertical integration. Standard parts were mechanically manufactured at large scale in centralized factories, while flexibility was maintained in dispersed design and assembly activities. Even the more complicated parts were eventually mechanized using “versatile machines which were susceptible of all manner of adjustment, hence required some skill to operate…” [20, p. 40]. Thus within the existing mechanical technology system, the industry achieved new levels of profitability and international renown.

There is no doubt that by the 1910s Swiss mechanical watches dominated the world watch industry [18]. The Swiss controlled the micro-mechanical export industry by cost competitiveness, superior manufacturing competency, high levels of precision, and extraordinary attention to detail and style. The vertically integrated parts manufacturers achieved economies of scale through volume production. This benefit was passed on to assemblers in the form of low cost movements. In the most labor-intensive aspects of the industry, the vertically disintegrated system of assembly and case manufacture kept overhead charges low.

International economic chaos and the call for regulation

The early 1920s was a period of great instability in the watch industry. Disruptions in the watch market presented the Swiss with new and different problems [18]. Significant sums of capital had been invested to meet the American manufacturing challenge. Firms were larger, and the industry represented a larger share of gross national product [21]. The severity of the crisis forced family businesses to take drastic steps simply to reduce inventory. Opportunism, price-cutting, and increased export of movements and parts further destabilized the industry [39]. This unprecedented threat resulted in a call for industry regulation, and a cartel was formed. 4

During the 1920s various associations were created to represent the interests of industry mem-

3 World War I created severe disruptions in the world watch market. Russia, a major Swiss market, closed its borders to international trade, while other countries raised protectionist barriers in attempts to preserve domestic industries. Demand for Swiss watches declined precipitously between 1916 and 1921.
bers. The Swiss Watch Industry Federation (FH) was organized to govern both firms assembling watches from component parts and the few firms with integrated manufacturing operations. The 17 manufacturers of ébauches (watch movements) were organized into a trust EBAUCHE S.A. Manufacturers of components other than ébauches (balance wheels, assortments, hair springs) were organized into the Union des Branches Annexes de l’Horlogerie (UBAH). In the late 1920s members of the various associations agreed to set levels of output and prices, and explicit rules were designed to restrict exportation of parts [18].

When this degree of collaboration proved insufficient to control opportunistic firms, the government intervened. In conjunction with industry and banking leaders, the federal government created the massive holding company ASUAG (which included EBAUCHE S.A. as well as other leading component producers). This final merger halted the exportation of parts and components to competitor countries [18].

The Statut de l’Horlogerie and the codification of the Swiss system

The Statut de l’Horlogerie of the early 1930s established a regulatory system that governed Swiss watch manufacturing for more than 30 years. Through a combination of cartelization and government ownership, the Swiss industry was regulated to control vertical integration, foreign sourcing, and off-shore production. Swiss manufacturers could buy only from Swiss component producers, and component producers could sell only to Swiss firms. To further limit competition, government regulated the sale of machinery. The Statut de l’Horlogerie regulated the volume of Swiss watch production by requiring permits for the construction and expansion of production facilities [15].

The resulting industry structure consisted of the parts manufacturers who sold their output to assemblers, the assemblers, and the brand name manufacturers. ASUAG could sell only to firms recognized by the Swiss government under the law. It could not export parts or technology. Manufacturers fabricated complete watches but were restricted from selling movements and other parts to assemblers – thus eliminating competition with parts suppliers. They were also restricted from setting up production in other countries. Assemblers were prohibited from establishing production outside Switzerland, and they could buy parts from non-Swiss manufacturers only if prices were 20 percent below Swiss levels. The law’s greatest effects were in regulating who was allowed to produce, what could be produced, and how much could be produced. By requiring export and manufacturing permits, the government essentially held supply below world demand and ensured Swiss firms handsome profit levels.

From 1933 to 1961 the Swiss watch industry experienced considerable stability matched by handsome growth. All industry sectors enjoyed the benefits. Under the Statut de l’Horlogerie, market shares were effectively stabilized. This predictably encouraged firms to reinvest profits in new process technology. High profits earned in this period allowed firms to develop a mechanical watch manufacturing system unparalleled in efficiency.

Abandoning industry regulation: Instituting industrial change

In the early 1960s three decades of stability once again gave way to uncertainty. Foreign competition ended the Swiss monopoly on mechanical watch production and the country’s quasi-monopoly on the world watch industry. The slow erosion of Swiss world export market share met with cries from industry members to change laws that had regulated the industry for 30 years.

Reasons for industry discontent were numerous. The more profitable and better run firms lobbied against the cartel arguing that it protected firms that were producing low quality watches [39,21]. Laws were also criticized for fixing the level of Swiss production at a time when other countries were making substantial inroads in the Swiss world export market share. In 1961 the Federal Assembly of the Swiss Confederation ratified a new decree eliminating the regulation of output and encouraging rationalization of the industry. The new law took effect in 1962, but it was

\[\text{\textsuperscript{4}}\text{ It was the larger firms which had made the capital investments in equipment that wanted to inject order into the historically anarchistic industry. To recoup capital investments, the more advanced firms had to control the small firms that easily sprang up and produced cheap watches [15].}\]
not until the early 1970s that restrictions on watch manufacturing were entirely eliminated.

As expected, the watch industry underwent a series of unprecedented mergers. The healthier and larger establishments joined forces to match the sizes of their Far East Asian and American rivals. Within two years three firms were producing 32 percent of Swiss exports. SSIH (formed in the 1930s with the merger of Tissot and Omega to become a leading vertically integrated manufacturer) became the third largest watch manufacturer in the world (behind Timex and Seiko). In 1971 the ASUAG expanded beyond strictly component production by creating the General Watch Company, a holding organization of several brand names and component manufacturers [18]. A third holding company, Société des Garde-Temps (SGT), was created primarily to manufacture low-price and electronic watches.  

In addition to the three holding companies, there were a number of important groups. Rolex, although privately held, had 1972 sales estimated at 200 million Swiss francs (almost a quarter of Swiss exports by value) [17]. There were also four middle-sized groups including two subsidiaries of U.S. companies, Zenith and Bulova, and the prestige brands, Piaget, Patek Philippe and others. The remainder of the industry was made up of hundreds of small companies assembling and selling watches.

The world market for watches

At the end of the 1980s watch producers manufactured approximately 500 million watches annually worldwide (not including Eastern European production). The market for watches is made up of segments in a pyramid-like structure. The base of the pyramid consists of mass producers selling watches with a wholesale value of less than $50 (1990 dollars). These sales account for 90 percent of total volume. Although this segment of the market is dominated by Hong Kong producers, it also includes American Timex and the Swiss Swatch watch. The mid-price ($50–500) watch market segment makes up 9 percent of all watch sales. Firms marketing in this segment include well known Swiss (Tissot, Omega, Longines, Rado), Japanese (Seiko and Citizen), and specialty American name brands (Hamilton).  

The luxury market segment comprises only 1 percent. Luxury watch prices start at about $750. There are 20 brands in this category and include such world-renowned names as Cartier, Ebel, Rolex and Patek Philippe. Some firms span more than one market segment. These include firms such as Rolex that add value to the basic steel case watch model by altering the external parts of the watch (e.g. diamond-encrusted bezel).

Structure of the Swiss watch industry

The structure of the Swiss industry emerging after the collapse of the cartel maintains important vestiges of the old system. The Swiss watch industry reflects both horizontal and vertical disintegration of establishments. Although the number of individual producers has declined over time, the shares of establishments in the different industry segments have remained the same [25,26]. The watch industry consists of four levels of production: movements and parts manufacturers; case and bracelet manufacturers; subcontractors; and assemblers and integrated manufacturers. Table 1 lists the number of Swiss watch firms and their employment by industry level.

### Table 1

<table>
<thead>
<tr>
<th>Industry structure</th>
<th>Houses</th>
<th>Employment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movements and parts</td>
<td>40</td>
<td>8000</td>
</tr>
<tr>
<td>Casing and bracelets</td>
<td>135</td>
<td>6500</td>
</tr>
<tr>
<td>Subcontractors</td>
<td>135</td>
<td>6000</td>
</tr>
<tr>
<td>Integrated manufacturers and assemblers</td>
<td>250</td>
<td>12000</td>
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Source: Radja [26].

### Parts and assemblers

Production of parts and components passes through various channels to arrive at final assemblers. Final assemblers assemble for all price segments of the watch market under nationally and internationally known brand names. Together,  

5 The SGT holding company also acquired two American watch companies, Waltham and Elgin.

6 The Hamilton Watch company is American in name only. The Swiss corporation SMH owns the brand.
parts manufacturers, subcontractors, and assem-
blers employ approximately 20,000 workers with a
turnover of more than 3 billion dollars, or 40
percent of total industry revenues (1990). Mid-
price watch assemblers include such well known
names as Chopard, Century, Corum, Eterna, and
Raymond Weil. The luxury end of the assembly
industry includes “international names” such as
Cartier, Chanel, Christian Dior, Gucci, and
Dunhill. These brand labels represent individual
designers that subcontract with Swiss component
and case manufacturers to assemble their watches.7

Manufacturers
In contrast to the disintegrated structure of
parts manufacturers and assemblers, the Swiss in-
dustry also includes enterprises that are vertically
integrated. Manufacturers produce the entire
product from movements through parts, casing,
and final assembly. There are a dozen important
integrated watch manufacturers. Rolex is the single
largest manufacturer and enjoys 25 percent of
total Swiss industry revenues. At the very high end
luxury market segment are found the most presti-
gious integrated manufacturers, including Piaget,
Patek Philippe, Audemars Piguet, Breguet, Ebel,
and Blancpain. These firms produce watches that
sell in the thousands of dollars and are produced
in small numbers.

Movement manufacturers
In response to economic instability in the 1930s,
movement manufacturing was concentrated in a
single firm (ASUAG). In the early 1980s reorga-
nization further concentrated this activity. ASUAG
was combined with a number of large previously
independent manufacturers (Tissot, Rado, Long-
ines, Omega, Certina, and Swatch) into SMH.
SMH accounts for approximately 30 percent of all
watch revenues and controls almost 25 percent of
total watch employment. While SMH is the single
largest supplier of parts and movements, there are
a number of other movement producers including
Fabrique D’Ebauches de Sonceboz et Ebosa,
Piguet, and La Novelle Lemania et Laeger-
Lecoultre. These firms cater to the luxury watch
industry.

Movement production in the Swiss watch in-
dustry is the most vertically integrated. It is com-
pounded of 40 firms employing 8000 workers with an
average plant size of 200 employees. This compo-
nent of production is the most technologically
advanced and enjoys significant economies of
scale. Parts and case makers, subcontractors, and
independent manufacturers represent the majority
of establishments but employ far fewer workers
per firm (averaging 45 employees). Observing size
of establishment verifies the disintegrated struc-
ture of production. Table 2 lists the number of
firms by employee size category. The structure of
the industry is essentially the same as it was in the
1970s.

Global competitors and the world market for
watches
In the early 1970s the Swiss struggled to re-orien-
t their factories while nimble competitors
flooded the field. But their production system was
not easy to dismantle or rearrange. Japanese,
American and Hong Kong firms posed unique
challenges to Swiss watchmakers. This new and
rising competition and the advent of a new move-
ment technology were both significant problems.

The Japanese industry was vertically integrated
and therefore a low-cost producer [18,22]. Seiko
and Citizen made major inroads in the world
watch market as both component and finished
watch manufacturers. The Japanese made high
quality low-priced movements that were sold to
firms around the world. By the early 1970s,

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7 Until recently these international brands did not operate
their own manufacturing plants. Cartier (one of the largest
international brands) previously subcontracted production to
EBEL, a Swiss prestige manufacturer. The French firm re-
cently opened a plant to manufacture its own products.
Japanese watch companies had succeeded in capturing 14 percent of the world watch market.

The Japanese increased their share of world export markets through various means. They had lower labor costs and an undervalued currency. They were vertically integrated and employed manufacturing automation. The Japanese developed the capacity to manufacture standardized movements and watch models. Japan was also selling large volumes of movements to the U.S. and Hong Kong. Although the Japanese produced models for every price range, they targeted the lucrative middle range, undercutting Swiss competitors.

Unlike the Swiss, the Japanese had the advantage of a large protected home market. Because other watch manufacturers were effectively locked out of their domestic market, Japanese producers enjoyed artificially high domestic prices that covered fixed costs. Thus in international markets watches could be sold close to or at marginal costs.\(^8\)

Government regulation and financial assistance (R&D grants) accelerated Japanese penetration of the world watch industry. The Japanese watch industry continued to rationalize — undergoing further vertical integration that streamlined operations and reduced inefficiencies. The government encouraged vertical integration to “minimize the proliferation of marginal watch producers and to minimize the drain on foreign reserves caused by the importation of watch machinery” [18, p. 23]. In 1978, 88 percent of Japanese production was attributable to two firms. Switzerland’s leading manufacturer accounted for only 9 percent of total national Swiss production [2].

The structure of the Japanese watch industry

The level of vertical integration in the Japanese watch industry is high by national standards. High levels of vertical integration are primarily associated with the small number of industry competitors (Citizen, Seiko and Casio) and individual company product development strategies [10]. Citizen and Casio are primarily electronics firms which concentrate on digital watch manufacturing [3,4]. Both companies pursued watch manufacturing to assure a market for their primary product, electronic components [8]. Seiko dominates Japan’s watch industry. The company is responsible for 60 percent of the nation’s output. Vertical integration was part of a conscious strategy to be the industry leader [34,14]. After World War II (like other Japanese firms such as Honda), Seiko followed a product diversification strategy built around the company’s core competence, precision manufacturing.\(^9\)

The most critical advantage of Japan’s capital-intensive system is the ability to manufacture components in huge volumes at low cost. The sale of movements and watch kits cemented the industry’s 1970s world volume leadership.

The U.S. market and American watch manufacturers

Japan was not the only significant challenger to the Swiss watch industry. The U.S. was both the world’s largest and most competitive watch market [8]. The vast majority of American demand was satisfied by domestic firms. America’s two stellar watch manufacturers, Timex and Bulova, essentially controlled two-third’s of the nation’s market [19]. American watchmaking firms were dominant in the U.S. partly because of high tariffs that were based on the number of jewels in the watch movement and implemented to protect the domestic industry. Swiss manufacturers responded by redesigning their watches to include fewer jewels. But by redesigning watches, production was further fragmented with more models designed for the U.S. market. A bad side effect of this strategy was an inability to produce at volumes that would allow for productivity gains [27]. On the other hand, American firms enjoyed a loophole in trade policy which permitted off-shore watch assembly by low-wage laborers. Because American firms could avoid paying duties, they could sell cheaper products than the Swiss.

\(^8\) When domestic wages began to rise, the Japanese quickly shifted assembly to Hong Kong where wages were lower (creating a spatial division of labor to ensure low price and timely product delivery).

\(^9\) Today Seiko has major market share in certain types of semiconductors, micro machinery, miniature circuit board manufacturing, and small plastic and rare metal parts. The company has capitalized on the original core skill by pursuing markets and product niches in related fields.
Bulova and Timex presented significant problems for Japanese and Swiss manufacturers. Both corporations followed the American system of mass production. Employing a combination of sophisticated production technology and labor flexibility (through internationalization of production), Bulova produced a range of products spanning all price categories. Bulova's strength was the medium price range. The company produced hundreds of different styles in its Swiss factories. An international production system maximized site-specific advantages such as skill levels, technology, and markets. The company's international orientation provided important opportunities to test-market new products. By having a strong brand policy and aggressively marketing products, Bulova moved into markets worldwide. At the high end, with its aggressively marketed tuning fork technology, Bulova was unique.

Alternatively, Timex sold a product that was cheap, simplified, and standardized. It was therefore easily mass produced. The company developed highly efficient, dedicated production equipment to produce huge volumes of standardized products. Timex also engineered true interchangeability. Parts could be exchanged not only within but between plants [21]. Because the U.S. lacked skilled watch workers, Timex pursued a capital-intensive production strategy. Machines were automated to reduce human involvement to a minimum. The company designed a dramatically simplified but well-manufactured watch with a relatively long life.

But Timex did not confine itself to the low-price market segment. By the early 1960s Timex had developed a low-priced higher quality jeweled watch line. In addition to its traditional and effective distribution channels (high traffic locations such as drug stores), Timex introduced its watches into jewelry stores and other, more conventional watch sales outlets. Within 20 years the company had gone from bankruptcy to control of 45 percent of the U.S. market and 86 percent of U.S. domestic watch production.12

The Hong Kong industry 13

While the Swiss were battling for market share with U.S. and Japanese firms, the Hong Kong industry emerged. From its experience as Japan's low-cost assembly location and a long standing preeminence in case and bracelet manufacturing, in less than 30 years the Hong Kong watch industry rose to become the world's volume leader. With little capital investment, Hong Kong watchmakers developed the capacity to produce thousands of watch models each year. Assembling in excess of 300 million units in 1988, Hong Kong produced more watches than any other nation. Based on value of exports, the country recently surpassed Japan to become the second largest watch producer, behind the Swiss 14.

12 Like Bulova, Timex established international market presence and production capacity. The company had 20 plants scattered around the globe. Each market was carefully analyzed, and sales strategies were adjusted according to local customers [18].
13 In 1988 there were approximately 1,386 watchmaking firms registered in the Hong Kong government. From 1983 to 1988 employment increased steadily from 25,200 to 26,444. Over 90 percent of firms employ fewer than 50 employees. The structure of the watch industry is remarkably similar to that of electronics in Hong Kong. A recent study by the Hong Kong Government Department of Industry indicated that many of the structural weaknesses evident in the watch industry are also apparent in electronics. These include lack of local brands and design capacity, a fragmented production structure, and low levels of capital investment.

Hong Kong watch prices (FOB) are extraordinarily low by world standards. The average wholesale price of a watch in 1988 U.S. dollars was $3.00. Advertised wholesale prices ranged from $4.00–10.00 per watch (with a lead time of between 25 and 60 days). Even jeweled watches cost a fraction of those manufactured in Switzerland. Orders can be as small as 100 watches, and in some cases firms have no minimum lot size.
14 Hong Kong is an established forerunner in innovation and exportation of watch parts, cases, bands, and accessories. The case and band industry is well-developed, and Hong Kong firms export finished products to major watch producing countries that include Japan, Switzerland, and the U.S. Surprisingly, even up-scale companies such as Cartier use Hong Kong watch bands. In 1984 (the latest year for which statistics are available), there were 484 case-making firms employing 9,200 workers in Hong Kong. This is almost four times the number of case producers in Switzerland.

10 For example, Accutron was made in the U.S. where technology levels were high despite lesser manual labor skills. Medium- and low-priced mechanical watches were manufactured by high-skilled Swiss workers.
11 Given that their watch was cheap, Timex made no pretense of providing after sales service. When the watch stopped running, it was simply thrown away and a new one purchased.
Early in the 1970s, with advances in diode technology, Hong Kong watchmakers moved into light-emitting digital (LED) display watches. LED watches dominated output for a short time, but declined when liquid crystal display watches emerged later in the decade. Until the early 1980s, this newer technology dominated the Hong Kong watch industry. In the early 1980s, the emergence of quartz analog watches breathed new life into the industry. Like other components of watch manufacturing, quartz analog watch production in Hong Kong relied upon foreign parts. And because it also required a higher level of capital investment, Hong Kong’s production system took time to adjust.

But adjust it did. In the late 1980s quartz analog watches began to dominate the industry, and evidence of their growing importance is striking. In 1980 digital watches accounted for approximately 60 percent of the value of total watch output. Analogs made up only 8 percent, and mechanical watches accounted for the remainder. In 1984 quartz analogs and digitals each made up approximately 43 percent of total output value [13]. By 1988 quartz analog watches dominated the market, accounting for 82 percent of total output by value. Digital watches made up only 12 percent. Because of its extremely fluid industrial structure, a rapid and complete transformation of the watch industry’s product mix was possible [8,13].

Hong Kong’s flexibility to respond to technological change derives from the fact that its watchmaking industry is a user, not a producer, of new technology. Hong Kong has been unable to develop its own movement technology due to a lack of skills and capital investment. The “sweatshop” nature of the industry means that labor absorbs the cost of change. Watchmaking in Hong Kong is ephemeral. Like other low-wage assembly industries, Hong Kong’s momentary advantage can evaporate with the slightest increase in wages. A significant portion of watch assembly is already done in mainland China. Thus, while at the moment watchmaking thrives in Hong Kong, the industry has little long-term attachment to the island.

### Technological change and industrial instability

Until the 1970s, the world watch industry grew steadily, and production was shared among three countries, the U.S., Japan, and Switzerland. Trade liberalization in the 1950s, coupled with GATT and U.S. tariff reductions in the 1960s, set the stage for enormous expansion of markets in the 1970s. In a span of 10 years the market for watches doubled from 230 to 450 million watches [41].

In the early 1970s world demand for watches was overwhelmingly for mechanical devices. Only 2 percent of export sales were electronic watches. But in just two decades, the structure of demand changed. The competitive terrain shifted from precision based on mechanical know-how to accuracy based on electronic engineering. By the late 1980s electronic products comprised 76 percent of world consumption — approximately 60 percent digital, and the remainder analog. While the Swiss were the first to develop electronic watch technology, competitors succeeded in commercializing it.

### Science replaces art in watch manufacturing

The introduction of electronic watches in the early 1970s had a profound impact on the Swiss share of world markets (table 3). In 1974 Swiss watches made up 40 percent of the world export market (by volume). Ten years later this figure had fallen to 10 percent. The loss occurred almost entirely in the high volume, low- and medium-price watch market segments.

How was it that the Swiss share of world markets fell so precipitously? The watch cartel

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15 We do not include Eastern Block country production in these figures. A considerable volume of watches is produced in the Soviet Union, East Germany, and other Eastern Block nations [18].
insulated Swiss manufacturers from the effects of inter-firm competition. Enjoying (volume) control of the world market (based on mechanical devices), it was easy for firms to become myopic about external events and new technology introduced by distant competitors. Because ASUAG looked only to members of the Swiss Watch Industry Federation (FH) for market information, new developments outside Switzerland did not filter into existing information channels.

When pressured to incorporate radical technological innovations, the Swiss industry proved unprepared to commercialize new ideas. Although inventions were very frequent, industry leaders were often skeptical about the viability of new proposals - particularly if they implied a radical reorientation of existing timekeeping methods. As one leading watch family head commented on the industry's failure to capitalize on tuning fork technology: "Every day someone came to the factory door with a so-called innovation. Claims of new and different technologies were a dime a dozen. Given production pressures, problems and uncertainties, what was one to do?" As Morgan Thomas notes, "many firms attempt to screen basic science and technical knowledge relevant to the firm's mission" [37]. This skeptical complacency proved costly when Hetzel, the Swiss inventor of tuning fork technology was ignored by Swiss watch manufacturers. After he successfully commercialized his new technology in the United States, the Swiss were forced into a defensive position just to gain access to the new technology.

The organizational structure of the Swiss watch industry

The tightly articulated network surrounding watch manufacturing strengthened the status quo. The watch industry was heavily geographically concentrated in the Jura Mountain region. To the outside world towns were identified by the factories of either major manufacturers (Longines in St. Emier; Tissot in Le Locle), or by specific watch products (Bienne and SMH formerly made ASUAG watch movements).

Regional institutions were interwoven into the fabric of the industry. Educational institutions were steeped in watchmaking tradition, turning out skilled workers who spent up to four years learning to make watches from start to finish. Machine tool firms such as Dixie, the originator of the jig bore, provided equipment to parts houses and claimed world preeminence in the manufacture of precision tools. Banking institutions were deeply implicated in the fortunes of the watch industry. In the early 1970s regional banks were known to have as much as 50 percent of their loanable funds invested in family-run watch-related enterprises. And the industry made heavy investment in collective R&D laboratories. The complicated web of watch manufacturing permeated the core of the region's social, political and economic institutions.

Watch manufacturing's fragmented production structure also presented problems. Subcontracting levels were high, and the region's dominant firms could not exercise control over the myriad component producers. Fixation with precision had lulled the region's firms into believing they were invulnerable to external forces [11,5]. Supreme precision, however, did not require a theoretical understanding of new scientific developments; rather it necessitated great attention to detail. As Pierre Rossel notes, "the region's firms were unprepared to overcome a technological paradigm shift that devalued the region's long-standing comparative advantage" [28].

Transferring a foreign technology into existing products was crippled by a manufacturing culture steeped in tradition. Rapid change was the antithesis of watch culture which rewarded patient methodical actions within an existing technological trajectory. This was the key. The transition from mechanical to electronic movement manufacturing called into question the heart of the Swiss watch industry. To say that precision metal machining no longer ruled the sacred domain of timekeeping accuracy was simply too much for the centuries-old Swiss tradition to endure. Rather than embracing this new threat as they had done when confronted by the American system of mass production, they chose to diminish its significance - with grave consequence.

Invention does not guarantee innovation: Technological discontinuity and the advent of quartz

Organizational limitations inhibited ASUAG, the major movement producer, from moving into quartz. Because its market was literally hundreds of mechanical watch assemblers, no individual
firm's demand was enough to persuade ASUAG to commit to one quartz movement design. But neither did any single manufacturer have an incentive to switch technologies. And even when ASUAG recognized the importance of quartz technology, the company lacked the marketing capability to successfully sell a quartz product to its primary market, Swiss assemblers [38]. A captive producer (unable to sell movements outside Switzerland), ASUAG lacked the incentive, necessity, and the ability to develop the marketing skills to compete internationally. Simultaneously, key watch manufacturers such as SSIH were unable to decide upon a quartz model. They therefore invested in numerous efforts to develop a quartz movement.

As with other challenges, the Swiss responded initially to the new quartz threat. Convinced that quartz was a passing fancy, nonetheless the Swiss rose to confront the new menace. Setting technicians to the task, the Swiss produced the first quartz watch movement simply to show that it could be done. But the elaborate network then stopped in its tracks, confident that quartz would eventually be relegated (as the electric watch had been) to the status of curio.

By the time the Swiss developed an industry-wide response to quartz technology, they lagged two years behind the Japanese. Having developed the initial technology, they failed to commercialize it. The Swiss are not alone in this fate. As Hoffman notes, "an innovation may be a technical success but a commercial failure in the innovator firm but a commercial success in the imitator firm" [12]. While the Swiss could claim that they were the first to develop a quartz watch (1971), they had to buy the necessary accompanying semiconductor technology from the Americans. Increased investments in R&D could not overcome the Swiss lag in microelectronics technology. The Swiss failure to act in the face of quartz technology could perhaps be blamed on bad judgement. But the problem was more fundamental and went to the heart of its highly fragmented network system of production.

The Swiss did not anticipate that the new technology would dominate the market in such a short time. But as integrated circuit prices fell precipitously, quartz watches became increasingly affordable. Because the Japanese had been vertically integrated since the 1960s, companies such as Seiko were poised to take full advantage of manufacturing developments occurring at various stages in the watch manufacturing process — further cementing their technological lead. Simultaneously, they could cross-subsidize component manufacturing, reducing per unit prices while raising per unit performance. The late development of Swiss domestic production of integrated circuits in a free-standing enterprise could not take advantage of information passing between component producers and watch manufacturers.

Unlike the Japanese watch manufacturers who saw semiconductor technology as an end in itself, the Swiss' forays into microprocessor technology were oriented strictly toward watches. This end-market focus did not facilitate synergies between semiconductor manufacturers and a wide range of users. In contrast with Japanese watchmakers who had a commercial electronics industry to rely upon for market outlets, the Swiss watch industry had to go it alone. Given the size of the watch industry's demand for chips, it was difficult to operate a chip production facility at optimal scale. It also made investments in R&D very costly per unit of expected demand for chips. Based on the network tradition, companies such as SSIH attempted to overcome their lack of technological capacity through a joint R&D project with Battelle. FH also initiated a joint R&D project to lessen Swiss dependence on U.S. semiconductor technology. With the FH, Brown Boveri and Philips of the Netherlands formed FASELEC, a laboratory to develop Swiss semiconductor production capacity. By the mid-1960s it was hard to judge the success of the venture because operations were never made public [18,39].

Complicating matters further was the rapid development of digital display technology. The commercialization of digital watches occurred with lightening speed. Digital display technology increased demand for quartz watches, leading to further price declines. This time the competition included American semiconductor manufacturers producing their own brands. Price reductions were dramatic, and by 1975 Texas Instruments had introduced a very inexpensive digital watch in a plastic case for $19.95. Although problems with the battery momentarily resulted in high reject levels, and consumers really wanted watches with more visual appeal, it did not take long to solve these problems. Battery longevity was vastly im-
increased, watch designs improved aesthetically, and within an astonishingly short period of time, digital watches took over a large share of the market.

The Swiss responded slowly to change in digital technology largely because when it was introduced, it was crude. Given what promised to be a reasonably long developmental period between the introduction of the quartz technology and its eventual market success, the Swiss were understandably skeptical. As Dosi characterizes this moment,

Especially when a technological trajectory is very "powerful", it might be difficult to switch from one trajectory to an alternative one. Moreover, when some comparability is possible between the two (i.e., when they have some dimensions in common) the frontier on the alternative (new) trajectory might be far behind that on the old one with respect to some or all the common dimensions. In other words, whenever the technological paradigm changes, one has got to start (almost) from the beginning in the problem-solving activity [6, p. 154].

The quartz "problem" permeated the Swiss watch manufacturing network. Every segment of the industry was affected. The rapid development of quartz meant there were now many sets of tools needed to produce cases and dials. Uncertainty in both technology and consumer preference forced the Swiss watch companies to compete in three watch markets – digital, tuning fork, and quartz. The succession of innovations and new model development resulted in excess inventory. It seemed that just as a watch was developed, it became obsolete. During this period of rapid technological change, Swiss firms (and others) were forced to take back and in many cases write down inventory – an extremely costly endeavor [39]. The problems of the industry did not become widely apparent, however, until hidden reserves were consumed, and firms were forced to reveal their weakened position.

The limits of the network

The experience of the Swiss watch industry is indicative of the turmoil experienced when a new technological trajectory unfolds. Signals about which direction the technology will ultimately take are filtered through networks of institutions which often have competing short-term interests. In the case of the watch industry, firms had a vested interest in mechanical watchmaking. They were receiving positive signals about their existing product, and demand was strong. Therefore suggestions about a possible technological shift seemed misplaced. While the market provides a good focusing device after a decision is taken by industry participants, it is rarely helpful in deciding ex ante which direction the technology will ultimately take. As Dosi suggests,

... the point we wish to stress, however, is the general weakness of market mechanisms in the ex ante selection of technological directions especially at the initial stage of the history of an industry. This is, incidentally, one of the reasons that militates for the existence of "bridging institutions" between "pure" science and applied R&D. Even when a significant "institutional focussing" occurs, there are likely to be different technological possibilities, an uncertain process of search with different organizations, firms and individuals "betting" on different technological solutions. With different competing technological paradigms, competition does not only occur between the "new" technology and the "old" one which it tends to substitute, but also among alternative "new" technological approaches [6, p. 87].

The introduction of the electronic watch resulted in unprecedented change in the organization of watch production. The differences between electronic and mechanical watches were dramatic. Whereas labor costs constituted as much as 70 percent of a mechanical watch, in electronic watches labor costs were very low (less than 10 percent). Another major difference was the control of technology. The Swiss effectively controlled mechanical watch technology (due to the watch statute), and Bulova controlled the tuning fork. Electronics were fundamentally different. The technology was widely available, thus increasing the likelihood of new competitors with little or no prior watchmaking experience. Given the evolution of electronics, it was almost a foregone conclusion that price declines would occur in tandem with increases in capability. Thus, even the cheapest watch could be a good watch.
Network rigidities hamper industry response

Internal industry organizational and cultural impediments hampered a rapid response to the electronic watch. For example, the production planning time horizon for mechanical watches differed radically from electronics. The manufacturing cycle was organized according to the lead time needed to manufacture tools and dies for the fabrication of a new caliber, or watch dimension. Once committed to a design, tools and dies were crafted to cut the necessary metal parts. After parts were manufactured, movements were assembled and sold. Introducing a new watch model took up to two years. With electronic watches there were fewer parts to be manufactured. Consequently the time needed to make a watch dropped dramatically. Thus, when the Swiss were faced with the need to shift to a new technology, they were already two years behind, given the differences in the manufacturing cycles.

Ironically, product variety further hampered the industry. Few factories specialized in a single caliber. Therefore, firms were unable to achieve economies of scale. And because most factories produced several calibers' parts, inventory overhead was costly. Parts were required for each caliber – resulting in huge volumes of work in process. And the manufacturing cycle had to be managed across a wide range of products from tool making to product assembly.

Manufacturers had no choice but to focus on quality to differentiate themselves from the assemblers. Moreover, marketing strategy dictated the need to produce a family of watches to preserve firm market share. Since manufacturers could not sell movements, they could not achieve sufficient economies of scale to enjoy minimum efficiencies. Low volume of output led to high prices.

The effort required to overcome technological deficiencies associated with quartz technology required an industry-wide response. Given the industry's weakened condition, no single firm could afford the costs of developing such an uncertain technology. Numerous industry associations were formed to develop the technology. This new form of collaboration created serious problems, however, because no single firm could appropriate the fruits of collective research and translate it into a competitive advantage to capture new markets. Unlike times past, when pursuit of new innovation formed the basis of market share, collective research became collective knowledge. Firms were compelled to embark upon research to create technological differentiation based on the original quartz innovation. These efforts were costly, uncertain, and occasionally unsuccessful.

Distribution

The Swiss also had to contend with a centuries-old distribution system built around the watch as a piece of jewelry. Mechanical watches were traditionally distributed through jewelry stores, and jewelers made steady profits on repair. But quartz technology threatened to change all that.

Swiss distribution outlets initially balked at the quartz watch. Early rejection was partially attributable to awkward styling: electronic watches were bulky and unattractive [39]. But more importantly, watch distributors effectively stalled the introduction of Swiss quartz analog watches in defense of their own market for watch repair. Quartz watches were more accurate and relatively unbreakable compared with mechanical watches.

Unlike the Swiss, the Japanese did not have an age-old distribution system. Market channel conflicts did not confront Japanese quartz watch manufacturers. Indeed Japanese channel strategy selected outlets through which the benefits of quartz longevity and error-free operation were maximized. The quartz watch was easier to sell, and it was more accurate. Timing was also important. The Japanese quest for large markets occurred simultaneously with the retail revolution. Mass marketing greatly expanded the number of outlets for watches. By the 1970s consumers were more likely to buy a watch in a variety store than a jewelry shop.

By the mid-1970s the Swiss were running just to catch up. Major Japanese competitors introduced increasingly cheap, long-lived, and refined watches. They pursued a strategy of short production runs; each time improving upon previous designs and climbing the learning curve more rapidly. Because the manufacturing cycle for the electronic watch was much shorter than for the mechanical watch, the Japanese could experiment within a relatively short time period.

The final blow came when the benefits of quartz converged to produce a cheaper, smaller, thinner, stylish, and accurate woman's watch. Before quartz
efforts at further miniaturization, women's watches had been less accurate and more costly to manufacture than men's. Now accuracy no longer distinguished cheap from expensive watches. The entire basis of Swiss market hegemony — precision — had evaporated.

Reorganization and rationalization

By the early 1980s the Swiss industry was in disarray. The international recession dealt the final blow to the Swiss watch industry's historic organization. Faced with operating losses and massive inventories, SSIIH was eventually a victim of industry reorganization. The company could not solve the equation of low prices, wide assortment, small volume, rapid change, short delivery time, and large model series [38]. Seiko, Japan's largest watch producer, was able to respond because it had the market volume to offer a wide assortment with economical series, low prices, and short delivery. A single statistic says it all, "on the average Japan produced, under each brand name, 6 million watches in the 1970s compared with fewer than 100,000 in Switzerland" [16, p. 221].

In the early 1980s SSIIH and ASUAG were forced by the banks to merge. While the national significance of the Swiss watch industry could not be abandoned, neither could industry organization be allowed to continue as it had in the past. The merged SMH Group was taken over by powerful Swiss industrialists. One of the most dramatic changes arising from the merger was the introduction of a wholly new product, the "Swatch," propelling the Swiss back into the low-priced segment of the market [2,23].

Summary, reflections and conclusions

Over the course of the last 20 years the Swiss lost both volume market leadership and technological supremacy. Given the industry's well-tuned production system, high level of profitability, and persistent success in its traditional line of business, what precipitated this historic reversal?

Beginning in the late 1920s the industry organized as a cartel to reduce the opportunistic behavior of industry participants. The resulting structure, though highly efficient and profitable, outlived its usefulness. Following the rescission of the Statut de l'Horlogerie, the network structure of production, while efficient and flexible, was also fragmented. Faced with the need to shift from a technology based on mechanics to one based on electronics, a time-lag built into the fragmented system inhibited rapid information flow. Shifting technological systems required that institutions and other critical components of the existing system be substantially modified. But this task proved difficult. The 200-year dominance of the previous paradigm constituted an "outlook which focused the eyes and efforts of technologists, engineers, and institutions in defined directions" [6, p. 158]. Initially, the region did not have the training capacity to provide electronics engineers. These skilled workers had to be imported from outside. In the case of Swiss watches, the decades old distribution system promoted Swiss watches based on their mechanical precision. Other organizations which represented the industry, such as the FH, were still predicting mechanical watch supremacy as late as the early 1970s. Educational and technical institutions — the core of the region's production complex — took even longer to respond to the new technological regime.

Amid radical change, organizations could not form a single voice to respond. The watch industry's collective research efforts to pioneer new technology could not overcome organizational inertia and infighting that arose with the need to commercialize the new technology. Without detailed and prearranged specifications about how the benefits of research were to be distributed, institutional inertia slowed the process of change. Since no single firm could be the "first" to introduce the collectively developed innovation, each firm had to develop its own [39]. When industrial reorganization eventually occurred, efforts were insufficient to address the structural crisis. Longstanding inefficiencies embedded in the production system led many firms into bankruptcy, resulting in bank ownership of some of the region's most famous and successful firms.

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16 Swatch is a plastic watch manufactured at high volume using advanced automation and assembly-line methods. But the real innovation is in marketing the watch as a high fashion, mood-oriented product. Ownership of multiple models is stressed, and marketing is targeted toward specific age groups [1].
As the Swiss case attests, elaborate network production systems suffer like any other organizational form in the face of unexpected technological change [36]. All prior means of governance are called into question. The peculiar advantage of decentralized systems are also potentially their greatest flaw. Extreme change often necessitates radical reorientation. In such instances the ability to respond rapidly dictates who will be the ultimate victors. Although watches represent a specific case, their longevity as a product should bring pause to pronouncements that network production systems are somehow immune to technological change.

Appendix – History of watch technology

Evolution of the watch

Since its creation almost 300 years ago, the watch has remained remarkably the same. Up until the 1960s alterations in the watch occurred mostly to the exterior in response to fashion and consumer tastes. The internal mechanism remained stable. The advent of electronics represented the first significant departure in the internal functions of the watch. The impact of this new technological development was profound. Centuries-old traditions in the manufacture of watches were revolutionized over night. Prior to electronics, timekeeping accuracy was associated with the precision with which metal parts were cut, filed, and fitted together. The most accurate watches were made by a single craft worker who cut each part, polished each metal edge, and placed each tiny part in the watch movement. Tuning the watch to achieve accuracy required very careful attention to detail. A short description of the evolution of watches helps clarify the meaning of electronics to the industry. This section draws heavily from Knickerbocker’s treatment of watch development [18].

The standard spring-powered watch

A standard mechanical watch consists of three groups of parts: the “ébauche”, or movement blank; the regulating components; and other generic parts. The ébauche consists of the framework (or back bone) of the watch, the gear train, and the winding and setting mechanism. Regulating components make the movement work at a correct rate. The miscellaneous parts include the case, crystal, etc.

A mechanical watch is driven by a main spring which transfers stored energy (in the spring coil) to the gears that move the hands. The release of energy is controlled by the escapement mechanism. Although numerous escapement models were developed over time, the mechanism is constrained by the anchor fork to give up a precise amount of energy. The anchor fork rocks back and forth allowing the escapement wheel to advance in tiny increments, and these increments are converted by other gears to the watch hands.

The anchor fork moves in conjunction with a balance wheel that moves back and forth. The balance wheel is motivated by a hairspring that coils and uncoils keeping the balance wheel in motion. As the anchor fork disengages from the escapement wheel, it transmits enough power to the hairspring to coil it. As the hairspring uncoils, it rotates the balance wheel in the opposite direction. This motion rocks the anchor fork in the opposite direction, starting the next cycle of the regulating mechanism.

Not all watch movements are the same. Differences in movement quality relate to the technical composition of the parts used. Precision, ornamentation, and movement miniaturization differentiate a high from a low quality watch. Internal jeweling in watches does not reflect differences in quality. Jewels are used to reduce friction between touching metal parts. The majority of jewels used in the interior of a watch are made out of synthetic materials and do not add significant value to the watch. Within mechanical watches there is a qualitative difference between jeweled and pin lever watches. The pin lever watch contains a more simplified movement compared to a jeweled watch (an example is Timex). A pin lever watch has few moving parts and does not use jewels to reduce friction between metal parts.

The electric watch

In this century, the first major technological advance in watch movement manufacture was the introduction of the electric watch. The electric watch movement was made possible by World War II R&D developments in the miniaturization of motors and batteries. The electric watch was
only a partial step away from the mechanical watch. The main spring and many of the components of the escapement were eliminated and replaced by current from a battery that drove a tiny balance wheel motor. The electric watch was introduced in 1957 and was available worldwide by the 1960s. Because electric watches were no more accurate than most mechanical watches, they did not make major inroads in the medium- and high-price watch markets.

The tuning fork watch

The second major innovation in watch technology, the tuning fork, had a profound effect on the watch industry. The tuning fork is stimulated by an electric current from a battery. The current causes the tuning fork to vibrate at 360 cycles per second. A tiny strip of metal connected to the tuning fork transfers the vibration to a set of gears, which like a conventional watch, drives the watch hands. Because the tuning fork vibrates 31 million times a day, the mechanism is far more accurate than a mechanical watch. Tuning fork technology was invented in the early 1950s and became commercially available in the early 1960s. A women's version was eventually introduced in the early 1970s.

The quartz crystal watch

The third, and most significant innovation in watch manufacturing occurred in the late 1960s with the use of quartz crystals to regulate increments of time. When electric current is passed through quartz it vibrates at very high frequency. Micro circuitry subdivides the crystal's frequency into electric pulses which drive the watch. In some cases the quartz is used to power a stepping motor, which is connected to a gear train that moves the hands. Quartz technology can also be used to stimulate a tuning fork device. In solid state watches the pulses are fed into integrated circuits that convert the pulses into minute and second time increments. This last type of watch incorporates no moving parts. The face and hands of a solid state watch are replaced with different methods to display time.

Changes to the watch face

Prior to the introduction of the quartz crystal watch, changes in the timekeeping mechanism were completely internal to the watch. With the advent of the quartz crystal, time could be displayed by conventional means (analog) or by digital display. Two primary displays are important: light-emitting diodes (LED) and liquid crystal display (LC). LEDs are semiconductors that emit light (much like a light bulb). Originally used in calculators, LEDs became fashionable in watches in the early 1970s. Because LEDs require considerable power they are not illuminated at all times. A push-button activates the display. In contrast, an LC display consists of a glass sandwich with a thin coating of electrically sensitive chemical between the glass plates. When a current is passed through an LC, the chemical changes its crystalline structure. The altered crystals reflect light coming from an outside source. While less power consumptive than an LED, LC's brightness and precision depend on the brightness of the external illumination.

The advent of quartz altered both internal and external features of the watch. With high levels of accuracy, the quartz watch could also incorporate numerous functions. Within an incredibly small space, a quartz watch could include multiple timekeeping mechanisms including alarms and other sophisticated functions. In combination, quartz technology revolutionized the watch industry.

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A. Glasmeier / Switzerland and the world watch industry


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