Sustainability — in light of competitiveness

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Abstract

There is cause for concern that many current practices in the strategic use of advanced manufacturing technologies are unsustainable since they lead to increased resource consumption in the aggregate. This article examines the ways the current generation of production technologies structure the formation and growth of product markets and explains why firms, driven to stay competitive, are adopting manufacturing strategies based on reducing the time it takes to develop and manufacture new products. As experience in the use of advanced manufacturing technologies has accumulated, distinctive patterns in market organization have emerged, which, in turn, cause more firms to adopt these technologies. In effect, the markets and production systems have co-evolved. Faster product cycles presage new product variants and faster product obsolescence linked to intensified customers' needs. This interdependency of market needs and the strategic use of manufacturing technologies has significance for drafting sustainable consumption policy. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

New manufacturing technologies are radically changing the terms of market competition with significant consequence for the ways we consume as well as the ways we produce. In the name of competitiveness, numerous initiatives in the past few decades, both public and private, have aimed to accelerate the transition from mass production to the knowledge-based economy. They are largely succeeding. However, being competitive does not guarantee societal well-being. To the contrary, there is cause for concern that many current practices in the strategic use of advanced manufacturing technologies are unsustainable since they lead to increasing resource consumption in the aggregate by increasing market demand.

From industry, a consensus has emerged on what are the attributes of competitive products in today's markets, namely, cost, quality, time-to-
market, and performance based on distinctive product features. The technical means of manufacturing products with these attributes are well in hand: computer-based, flexible production technologies have come of age. Policies aimed at increasing competitiveness promote the adoption of the latest advanced manufacturing technologies. Yet, the use of these technologies is far more involved than the intent of the pursuit of economic growth, the 'reason why' of competition. Firms' operational strategies cause changes in their markets that rebound to affect decisions on how current generation technologies should be further developed to meet changing market demands. In effect, markets and technology systems co-evolve. This suggests that policies aimed at transforming consumption patterns must also pay heed to the direction of the dominant technological trajectories in production systems. One such trajectory, faster product cycles, has serious implications for achieving sustainability for the reason that firms with fast-to-market strategies must 'grow in order to compete', resulting in the need for ever larger effective market demand.

Proposed solutions to intensive resource consumption and the more general problem of how to decouple industrial activity from negative environmental impacts have largely focused on producing 'more with less' and integrating sustainability criteria into economic decision-making. While effective in limiting the environmental impact per unit of production activity, this approach essentially overlooks the issue of how growth in consumption is allied to increasing competition. The analysis in this paper differs by examining the interdependency between market demand and the competitive uses of advanced manufacturing technologies.

In the analysis that follows, I argue that production systems structure the formation and growth of product markets. To provide a theoretical context for this reasoning, the second section of the paper reprises relevant current thinking in evolutionary economics on path dependence, technological trajectories, and technological regimes, and relates this to the construction of sustainability and competitiveness policies. The paper's core theoretical exposition, Sections 3 and 4, traces the economic significance of shortened product cycles to its technological sources. (The term 'product cycle' is used here in keeping with industry terminology. It denotes the span of time from introduction of a product to the introduction of its replacement product. Often, the initiation of a replacement product's design is used to mark the onset of the cycle. This is different from how the term 'product life cycle', sometimes abbreviated to 'product cycle', is used in the environmental literature to denote the product's material cycle from resource extraction through waste disposal.) In the third section, I undertake an analysis of computer-based production innovations using a modification of Georgescu-Roegen's fund-flow model. The fourth section explains why firms, driven to stay competitive, are adopting operational strategies based on reducing the time it takes to develop and manufacture products and how such strategies promote consumption. In the final section of the paper, the contradictions between sustainability and competitiveness, as embodied in current generation production technologies, are exposed, but also, the potential of these same technologies for seeding a sustainable technological regime based on qualitative economic development, as opposed to quantitative growth, is considered.

2. Dominant production system trajectories

The tendency for technological innovation to occur along defined trajectories is described in the evolutionary economics literature as path dependence (Nelson and Winter, 1977; Dosi, 1982; Nelson and Winter, 1982; Rosenberg, 1994). A path, or trajectory, represents the economic and technological tradeoffs made with respect to the available opportunities for technological advance. These tradeoffs characterize technologies' functionality or performance, that is, the attributes that define the technologies' effective use. In evolutionary terms, a technology's performance characteristics convey its selective advantage.

From a supply-side, or technology-push, perspective, the envelope of technological opportunities corresponds to the degree of technical
challenge in realizing proposed innovations, the prospects for appropriating returns on innovation, the degree of technological ‘cumulativeness’ represented in past innovation and firms’ capabilities, and the nature of the knowledge base (Dosi, 1982; Malerba and Orsenigo, 1993). In the short term, these are likely to be limiting factors for technological choice, in the long term, only conditioning factors (Rosenberg, 1994; Kemp et al., 1997). Critical environmental pull factors in a technology's development include the distinctiveness of the selection environment — the domain of application — and the amount of resources available to foster development within that domain (Levinthal, 1998).

Given relatively stable trends in environmental conditions, technological change will, more than likely, lengthen the trajectories inscribed by past innovations. The propensity is to refine existing technology, to build on previous investments, to copy success. Rosenberg (1994) calls this ‘soft determinism’ where the outcomes of the innovation process are not prescribed, but improvements in one direction are made easier, cheaper, and more probable.

Research into the sources of path dependence has emphasized the cumulative nature of the innovation process. Incumbent technologies have been refined (‘optimized’) through the process of learning by using, thereby realizing relative cost and performance advantages over newly commercialized technologies whatever their longer term promise. Established technologies represent investment in a set of capabilities; innovating from an as-yet-to-be-acquired knowledge (and skill) base is comparatively costly. Likewise, the cumulative learning process affects the strategic choices of technology suppliers and users since articulated market needs reflect experience with existing technologies (Mazzoleni, 1997).

The evolutionary economists’ view of firm behavior as a set of routines in an unpredictable world (Nelson and Winter, 1982) is constructive here in illuminating the role of firm strategy in the rise of dominant trajectories. An industry’s choices regarding the direction of technological change are guided by a ‘rule set’ that derives from its prevailing socio-techno-economic complex, or technological regime (Kemp et al., 1997). This complex/regime circumscribes both the technological choices to be made and how such choices will be made. Strategy, as the framework for firm decision-making, is embodied in structure and practices for translating the firm’s cumulative knowledge into selective advantage (Metcalf, 1997). The objective of strategy formulation is to couple the organization’s capabilities to opportunities present in the environment to achieve long-term objectives (Saren, 1990). Strategy represents the firm’s best guess (albeit, an educated guess for firms that do their homework) as to how to deploy resources in response to changing market and industry conditions. Since the past success of particular strategies for appropriating and managing resources in large part decides current strategy — in as much as current strategy is the outcome of both cumulative learning and investment processes — an industry’s dominant technological trajectories will mirror the course of dominant strategy. In this regard, operational choices concerning technology use may be as important as product development decisions in creating technological momentum.

Certainly, the strategic use of production technologies is a dominant factor in the rate of change and size of product markets. Reciprocally, shifts in the social, economic or technical conditions of a market/regime affect the success of current manufacturing strategies. Thus, the emergence of a new technological trajectory signals a change in regime conditions.

A widely recognized historical instance of a dominant regime is the exploitation of economies of scale (Dosi, 1988; Freeman and Perez, 1988; Chandler, 1990) embodied in mass production technologies. Furthermore, the imprint of these technologies on socioeconomic organization is no less conclusive (Piore and Sabel, 1984; Harvey, 1990). The historical inference is that an industry’s dominant production technology trajectories provide a basis for the prevailing regime, demarcating the span and depth of the possible socio-technological configurations. In the case of mass production technologies, increasing material consumption was propelled by ever cheaper goods obtained through economies of scale.
To illustrate further the interaction of markets and production technology systems, it is worth recounting the beginnings of flexible manufacturing, which can be traced to a then novel means of reducing production cycle time (Womack et al., 1990). (In this paper, the umbrella terms ‘flexible technologies’ and ‘flexible production’ cover the broad spectrum of computer-based manufacturing technologies and practices, including, for example, lean and agile manufacturing.)

Following World War II, the Toyota company of Japan, then a small craft-methods producer of trucks, laid out a strategy for entering the world car markets with a full-range product line. Having studied Ford’s mass manufacturing methods in detail, Toyota’s genius production manager, Taichi Ohno, determined that Toyota would not be able to successfully copy them. By the 1950s, when Ohno began experimenting with new techniques, mass manufacturing had reached its prime. Toyota, for all its ambitions of challenging the American hegemony in automobiles, did not have the capital, or the access to capital, to finance a mass production facility. Only through reordering the production processes to allow for greater equipment utilization, thereby substantively reducing the amount of equipment needed, could Toyota hope to achieve the necessary economies.

Ohno began with developing quick-change tooling that could be used to produce a greater variety of products in smaller lot sizes. The key was reducing the set-up time, which gave the equipment much greater flexibility. Greater flexibility meant less equipment could be used to manufacture a greater number of parts. With these tooling innovations (and subsequent decades of refinement), the cost for Toyota to produce a small-lot part approached that of a mass-produced part. This new production scheme challenged one of the central tenets of mass manufacturing, namely, the need for dedicated equipment. In essence, Ohno had substituted economies of scope for economies of scale. The significance of Toyota’s advance is that economies of scope were being reaped for the first time in a discrete parts industry.

The conception of the Toyota system, which later came to be known as lean manufacturing, signaled a radical shift in the modes of production, the ‘seeding’ of a new technological regime. But it was through the application of computerized information technologies that the market significance of product differentiation and accelerated product cycles fully began to be realized. It is these new trajectories and their market significance which are the subjects of the next sections, but first, a brief synopsis of the line of argument and a few preliminary policy implications.

The evolutionary process works to channel technological change along developed pathways according to past success in adapting to market needs, even as markets are shaped by technological change — that is, markets and technology systems co-evolve. In particular, we are concerned that firms’ operational strategies cause changes in their markets that rebound to affect decisions on how current generation production technologies should be further developed to meet changing market demands. The development of the Toyota system marked the transition from one dominant manufacturing trajectory, economies of scale, to new trajectories based on flexible technologies. As experience in the use of flexible technologies has accumulated, distinctive patterns in market organization have emerged, which, in turn, cause more firms to adopt flexible technologies.

This interdependency of market needs and the strategic use of manufacturing technologies has significance for drafting sustainable development policy. A central focus of competitiveness policy is promoting the adoption of advanced manufacturing technologies, or movement along the current trajectories, whereas, an economy based on sustainable development will likely require changes in manufacturing that would alter the direction of existing trajectories. A policy thrust in the advanced industrialized countries towards ‘sufficiency’ — limiting consumption to what is enough to secure collective well-being — would advance slowly, if at all, within a techno-economic regime that necessarily reinforces quantitative growth.
Currently, the predominant focus of sustainable production policy is limiting the environmental damage per unit of industrial activity by integrating sustainability criteria into firm decision-making (as examples, see (Williams et al., 1993; Hart, 1997) for a policy-takes on corporate environmental strategies). However, it is not certain that such practices as clean production and eco-efficiency will prove adequate to realizing sustainable policy goals if growth in product consumption continues. Even with considerable progress in recent years in reducing production waste and increasing efficiency, resource consumption per capita continues to grow. The World Resources Institute (1997) reports that the rate of dematerialization in industrialized societies has not yet offset growth in resource use. Studies of individual consumer goods also show negative trends in aggregate consumption even when the individual gains in efficiency are high. For example, there was a 3.5 factor increase in the energy efficiency of television sets over 25 years (from 1970 to 1995); during the same time, the aggregate energy consumption of televisions rose by a factor of two (Hirschl, 1998). The World Business Council for Sustainable Development (WBCSD) does include extending product durability (lengthening product life) and intensifying the service content of goods on their list of eco-efficient practices. Such measures could reduce aggregate consumption, not just resource intensity levels. But the economic implications are duly noted: ‘Durability is not likely to commend itself immediately to all manufacturers, some of whom believe that the health of their bottom line depends on the regular ‘repeat’ purchase of their products’. (DiSimone et al., 1997, p. 74). In short, to be effective, policy must address both consumption behavior and production practices simultaneously.

I would also maintain that what is needed in the construction of viable sustainability policy must go beyond the standard consideration of ‘barriers’ and ‘opportunities’. Such analyses often leave open the question of what conditions undergird said barriers or opportunities. On the other hand, an analysis of regime conditions can elucidate the social and economic embeddedness of the prevailing technological forms, provide insights into the competitive behavior of firms, and reframe policy issues to greater effectiveness. For example, the reluctance of manufacturers to convert to the use of recycled materials in their products has more to do with the reliability of supply, both in terms of quantity and quality, than the technical difficulty of substituting one material for another or the problem of market acceptance of recycled-content products. In this context, the problem of establishing use of recycled materials then becomes one of creating market demand in tandem with building supply systems that can compete with those of virgin materials, a problem of considerably different scope than overcoming the barriers of getting manufacturers to test new materials or getting information before consumers.

Another significant benefit of using the evolutionary economics framework for policy-making is that it takes us out of the realm of technological determinism into that of technological choice. In contrast to analyses premised on autonomous technological development, the evolutionary perspective opens the possibility of purposively ‘seeding’ alternative technological structures. Kemp et al. (1997) in their work on strategic niche management (SNM) suggest that such restructuring can be done through modulating the dynamics of technological change by a process of selecting the socioeconomic environment in which technological innovation occurs or by managing the process of change so as to increase the chance of desired outcomes. Paramount in the SNM approach is the nurturing of learning processes in order to facilitate the diffusion of alternative, in our case, more sustainable technologies. This approach is being tried in the transportation sector to speed the adoption of electric vehicles through experiments in their use (Weber and Dorda, 1999).

To be effective, then, policy aimed at transforming consumption patterns would best pay heed to the direction of the dominant technological trajectories in production systems. The subsequent analysis is an in-depth examination of one trajectory in the development of next generation technologies, that of faster product cycles. Other associated developments, for example, process integration, are under study, but do not appear to
have as direct an influence as faster product cycles on consumption levels. The intent of this larger study is to identify the major production trajectories and their significance for market formation and growth. In this research, cycle time plainly and emphatically emerges as a principal competitive factor in today’s firm strategies.

The primary source materials for the study are industry roadmaps focusing on manufacturing and the information technologies used in manufacturing. Roadmaps envision desirable futures according to industry’s interests and outline steps for getting there. The production of roadmaps almost always entails the impaneling of a host of experts. For example, the Next Generation Project in the U.S. involved the participation of individuals from over 100 companies, industry associations, government agencies, and academic institutions (Agility Forum, 1997). Industry roadmaps, then, represent consensus and often are intended to influence policy. (A list of the roadmaps used in the analysis is presented in Section 6)

3. Time in the production process

Nicholas Georgescu-Roegen, a near canonical reference for more than a few environmentalists, introduced his own profession, economics, to the second law of thermodynamics — the inexorable grinding of matter and energy from low entropy/high use-value (resources) to high entropy/low use-value (waste). He applied this law in the development of an economic representation of the production process, the fund-flow model (Georgescu-Roegen, 1970). In the model, flows represent the matter and energy entering and exiting the production system, while funds (principally equipment, human resources, and knowledge) represent elements performing a service within the system. The analysis that follows is further indebted to Morroni (1992) elaboration of the fund-flow model in which he integrates the dynamics of technological change.

One of the striking features of the fund-flow model is its use of time to measure productive capacity, owing to the fact that the expenditure of funds requires duration. This is highly consistent with engineering models of the production process. To quote, as an example Krupka (1992), head of the manufacturing system engineering department at AT&T Bell Laboratories, ‘Time — the interval from the start of manufacturing activity to its completion — is the single most useful and powerful metric any firm can use. [It is] a more useful and universal metric than cost and quality because it can be used to drive improvements in both.’ And the Consortium for Advanced Manufacturing-International (CAM-I) espouses time as the metric of choice for capacity management (Klammer, 1996).

Time appears in two guises as an element in the production process. Time is the measure of the use of funds in the manufacture of specific product, but also time marks the progression in the development of specific product/process/resource systems. Economic gains from time reductions occur when average unit costs fall as a function of a reduction in the time a given microeconomic unit takes to produce specified product.

Reducing time in the manufacture of product is achieved through technical innovations in speeding up the execution of production. The material transformations taking place in converting inputs to product remain the same, but occur at greater speeds. By increasing speed we increase productive capacity (the range of output levels over which a technically optimized unit produces), holding organizational structure and environmental conditions constant.

Reducing time in the development and implementation of product/process/resource systems is a matter of increasing the speed of production system planning and realization. The knowledge transformations are the same, but occur at greater speeds. By increasing speed we increase productive capacity, holding organizational structure and environmental conditions constant, but within wider parameters.

It is the second aspect of time, regarding the speed of adaptation of production systems to changes in environmental conditions, which veers from the standard economics notion of measuring productive capacity. In the real world, since environmental conditions are not static, there can be
no single fixed, technically optimal combination of system elements. Instead, there is the possibility of continuous reorganization of the production processes in response to a highly variable environment.

Changes in the relations among production system elements prefigure increasing productivity and cost savings. In Morroni (1992) words, 'The main economic problem in production [becomes] no longer a simple problem of optimal inputs combination, but involves choosing a combination of processes.' I would amend this to add, 'in the quickest way possible'.

Referring back to Georgescu-Roegen's application of the second law of thermodynamics, there is another sense in which the inclusion of time as a production element is antithetical to neo-classical economics, but conforms to evolutionary economics, which is that production outcomes are contingent on the irreversibility of the processes involved. This irreversibility comes into play because, by the nature of the cumulativeness of technological advance as encoded in the knowledge base a given system draws from, only certain complementary relationships among the production elements will find use. (This causality, of course, has strong implications for the seeding of alternate technoeconomic regimes.)

An analysis of the economics of cycle time centers on how specific reductions in time drive reorganization of the system elements, and what are the attendant benefits of compressing product cycles with respect to particular technoeconomic regimes. The results of this analysis are presented in Table 1 and discussed below in this and the next sections.

3.1. Equipment speed increases

Increasing equipment speed increases the relative quantities of flows to funds. This is true for information technologies as well as machine tools. While increasing speed is not necessarily scale-dependent, increases in speed often amplify economies of scale and, in this, are applicable to mass production as well as flexible production techniques. Increased speed can also be used to lower the minimum efficient scale of equipment, which benefits economies of scope.

3.2. Equipment flexibility

Reducing process set-up time is associated with positive economies of scope, that is, reducing the costs of manufacture of different products at varying production volume rates. Successive waves of flexible automation are bringing us ever closer to the goal of cost-effective one-off product customization. Multi-use equipment increases the possible number of relations among different system elements, lowering limitable flows.

3.3. Concurrent processing

The customary, iterative, serial techniques for developing and managing product/process/resource systems take more time than does parallel processing of system requirements. In turn, early product/process/resource definition allows narrower design margins. Substituting parallel for sequential processing reduces irreversibility in the linking of system elements, which enhances the possibility of realizing optimal system organization.

3.4. Learning by using

Information-based processes for predicting system performance, for example, computer models of manufacturing queues to identify manufacturing bottlenecks, reduce system element variability during the design phase of manufacturing. Simulated technology validation leads to better definition of boundary conditions and overall reduction in the technical transaction costs occurring at interfaces.

3.5. Knowledge codification

Information technologies allow higher level abstraction and support the appropriate reuse of knowledge, increasing the speed and quality of decision making. Information technologies facilitate, ‘... rational consideration of complex trade-offs among product performance goals, design alternatives, materials, process constraints, and finished goods packaging and distribution’ (Defense Science Board, 1993). Economies of scale
<table>
<thead>
<tr>
<th>Source</th>
<th>Time reduction in</th>
<th>Change in organization of system elements</th>
<th>Representative technologies and practices</th>
<th>Productivity improvements and cost savings</th>
<th>Competitive advantage-operational strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment speed increases</td>
<td>Machining or assembling a unit; information processing throughputspeed to customers</td>
<td>Changes proportions of flows to funds, reordering specific relations of complementarity</td>
<td>High-Speed Machining; faster spindles</td>
<td>Increased manufacturing throughput</td>
<td>Faster delivery of products to customers</td>
</tr>
<tr>
<td>Equipment flexibility</td>
<td>Resetting a process</td>
<td>Increases complementarity among elements through reducing specificity of equipment purpose</td>
<td>Cell Technology; FMS; CAM; rapid set tooling; open-architecture controllers; in-line cellular processes and equipment (flexible transfer lines)</td>
<td>Increased utilization of funds; reductions in work-in-progress and inventory</td>
<td>Rapid execution of customer orders</td>
</tr>
<tr>
<td>Concurrent processing</td>
<td>Linking processes</td>
<td>Accelerates system organization as effect of modified boundary conditions</td>
<td>Concurrent Engineering; process planning software; CIM; EDI; JIT; intelligent machining (intelligent closed loop processing)</td>
<td>Increased utilization of funds; decreased flows</td>
<td>Faster implementation of new concepts in products</td>
</tr>
<tr>
<td>Learning by using capability</td>
<td>Developing process capability</td>
<td>Increases predictability of element performance within system</td>
<td>Computer-modeling and simulation; Rapid Prototyping; process modeling</td>
<td>Improved utilization of funds</td>
<td>Faster implementation of new concepts in products</td>
</tr>
<tr>
<td>Knowledge codification</td>
<td>Organizing processes</td>
<td>Decreases variability of knowledge utilization</td>
<td>CAD; CAE; Knowledge-based systems, e.g. neural networks; Product Data Management</td>
<td>Increased utilization of knowledge</td>
<td>Faster response to evolving customer needs</td>
</tr>
<tr>
<td>Equipment modularity</td>
<td>Implementing a new shop floor process</td>
<td>Facilitates system reorganization through increased divisibility of funds</td>
<td>Modular, ‘plug and play’ machine tools and controls; micro- and nano-technologies</td>
<td>Decreased capital costs</td>
<td>Faster response to evolving customer needs</td>
</tr>
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pertain in standardizing processes for managing large systems of variables.

3.6. Equipment modularity

In the time frame of product/process/resource implementation, scale-dependent indivisibility in system elements exhibits diseconomies: ‘For many manufacturing jobs, manufacturing capability is needed for a period of time that is short in comparison to the life of the process equipment. In addition, manufacturing equipment is often sized and purchased, not for the current part being manufactured, but for the worst-case part that one can envision in the life of the process. Both of these practices tie up valuable capital in equipment that is not fully used’ (Technologies Enabling Agile Manufacturing, 1997). In the reconfigurable plant, modular, ‘plug and play’ equipment will radically increase the divisibility of funds, thereby increasing system complementarity, and, resultantly, equipment utilization. Large threshold costs for designing equipment will be averaged over multiple units, triggering economies of scale. Under these conditions, the plant itself could be mass-produced and plant economics will evolve from a fixed to a variable capital input basis.

4. The economic impetus

From time reductions in specific operations it is conceptually a short distance to specific cost savings. As the diffusion of new technology hinges on opportunities for appropriating returns, the strategic use of advanced manufacturing equipment dictates more than just productivity gains (Kakati, 1997). Going back to the requirements of today’s markets, cost is no longer the only, or even the principal, driver in market evolution. While accelerating product cycles supports cost reduction strategies, it is the strategic advantage of faster cycle times that has propelled firms along the trajectory of time reduction.

Product cycle times can be decomposed roughly into design and physical production turnover rates. Firm strategies can emphasize one or the other depending on their external conditions. A build-to-order operational strategy requires the process capability to rapidly execute customers’ orders, which has as its effect solidifying customers’ goodwill and bringing repeat business. Moreover, build-to-order capability works to eliminate over- and under-production, the bane of fluctuating markets. In comparison, the crux of a first-to-market strategy is the ability to anticipate and respond rapidly to customers’ evolving needs, which takes superior design capabilities. Success, measured in terms of market share, belongs to first entrants. As an appropriation means, lead time and learning curve advantages, coupled to marketing efforts, dominate in most industries.

A side from their competitive advantages, strategies that emphasize faster cycle times create their own vulnerabilities, a major dilemma being how to recover plant and equipment costs over abbreviated product and process lifetimes. The challenge is evident, as voiced in the Next Generation Project report: ‘Immediate sales growth is required for companies to justify the significant investments [in agile technologies] needed to sustain economic growth and future earnings’ (Agility Forum, 1997). In substance, fast-to-market strategies assume strong market growth.

And market growth coupled to faster product cycles presages new product variants and faster product obsolescence linked to intensified customers’ needs. The term ‘mass customization’ is being used to describe strategies that play to escalating customer demands. (Perforce, this discussion of consumption patterns is limited to where flexible technologies have found their greatest application — in the west and the north.) Consider that, in the case of an established, non-growth market, a strategy that halves cycle time will need a market size twice as big, ceteris paribus. The economic rationale underlying growing product diversification and market fragmentation suggests itself: evolving customer needs, expressed through faster product replacement or product use particularized to individual consumers, and even to differentiated ‘needs’ of single consumers, counteracts problems of market saturation and over-capacity.
What’s more, faster cycle times do have a cost impetus. While cost may not be the deciding factor shaping market demand, it is a logic that impels growth in output. The search for the optimal combination of production elements has as its motivation the necessity of competing on cost. The firm that produces less than at optimal productive capacity, at less than the most efficient scale and rate of production, pays a penalty. Enhanced speed of production, through its cost advantages stemming from increased productive capacity, and through its multiplier effects on economies of scope and scale, puts pressure on firms to grow through boosting output. To wit, firms must grow in order to compete.

Ayres (1996) has alerted us to the ‘deeper structural problem’ of materials goods production underlying environmental degradation: increased demand drives up production scales; larger scales drive down costs; lower prices up demand. The effect of faster product cycles also appears to cause demand to spiral upward (an observation that is in want of empirical verification), but in a different manner. Consumers demand more, but not just more of the same, the pace of product replacement speeds up, and people purchase more product variants with duplicative functions. Effectively, faster product cycles have the power to raise the ceiling on market saturation.

5. Towards a sustainable consumption regime

In many respects, sustainable consumption — the principle that there are necessary social, environmental, and, ultimately, economic limits to consumption — challenges current economic reasoning. Slowing down consumption has obvious negative implications for competitiveness and employment, the shibboleths of economic development. Nevertheless, growing awareness of the adverse consequences of unchecked consumerism has placed the issue of sustainable consumption squarely on the international policy agenda (OECD, 1997). The question being raised is whether growth, as measured by GDP, represents an increase in human welfare.

If the long term goal of sustainable consumption policy is to achieve a ‘steady state economy’, defined here as a non-growth economy in biophysical equilibrium (Daly, 1996; OECD, 1997), the market functioning of competitive production systems must be well understood and taken into account in policy formation. One concern should be the impact of faster product cycles on increasing consumption. What I have tried to show by the above analysis is that patterns of consumption are not easily divorced from the modes of production. Does this then imply that sustainability — in light of competitiveness — is not possible, if not probable, within the prevailing industrial technoeconomic regime?

In a steady state economy, service is maximized given a constant level of capital funds (usually determined as that amount necessary to sustain future ecological balance) and throughput is minimized (to preserve resources and limit environmental harm). Yet, consequent to the current trajectory in faster cycle times, the ability to meet rising consumer expectations is paramount to being competitive. Flexible technologies maximize service with constant (and even decreasing) levels of capital funds, but at the same time, they push quantitative growth in production. A sustainable consumption regime will require finding a better balance in favor of reducing materials consumption levels.

The tradeoffs implied by the current development of flexible automation along the trajectory of faster product cycles are troubling, but there is also the possibility of modulating further development of these technologies through policy. Such a policy would seek to amplify incentives for configuring the production system around qualitative development as opposed to quantitative growth. It would possibly entail support for a shift in strategic emphasis away from accelerating production turnover to value enhancement as the primary basis for industrial competition.

A few technical suppositions supporting these propositions are offered. Necessarily, this list is only suggestive, still, it serves to demonstrate the possibilities for seeding a sustainable consumption regime.
(1) Technologies such as computer-modeling, simulation, and rapid prototyping that aid learning by using can be directly applied as cost-effective means for experimenting in the production and use of alternative, greener product technologies. For example, they might be used to accelerate consumer acceptance of housing made from non-traditional materials. Similarly, knowledge codification technologies can be used to speed the replication of successful experiments.

(2) In general, knowledge-based manufacturing technologies that enable the integration of more detailed understanding of customer needs into product can facilitate a transition to competitively-priced higher value-added products, including higher use-intensity and longer life products. (Two examples of high use intensity products are: a multi-functional networked printer, copier, scanner and paperless fax machine, and a heat pump that provides both refrigeration and hot water.) Such technologies are the foundation of build-to-order strategies. It is interesting to speculate under what conditions a manufacturing capability that truly satisfies customer needs in a timely manner would lead to a decrease in product consumption.

(3) One significant driver of the move to lean manufacturing has been the reduction in input costs (time and materials) through the elimination of waste during processing. (In fact, lean manufacturing may be a major contributor the recent trends in dematerialization.) This technology is working its way back up the supply chains to the materials processors, where the incentive is to obtain the maximum value from material inputs in the face of diminishing resource supplies. An example is the growing use in the forest products industry of yield optimizers, computerized laser saws that maximize the product cut from each workpiece (say, a log) by adjusting the cut for each piece's material variability. Policy could stimulate a more rapid diffusion of this technology.

(4) Increasing manufacturing capability to reorganize production system elements in response to a constantly evolving environment holds substantial promise for orders-of-magnitude dematerialization through increasing capital utilization. Equipment modularity means that next generation plant can largely be constructed from current equipment, establishing variable capital.

(5) Lower limits to the range of output levels at which profitable operations are possible could enhance the viability of manufacturing strategies stressing value-added operations for smaller markets. In fact, the historical development of flexible production accelerated when Japanese machine tool builders, in order to expand their markets, designed equipment for smaller firms (Mazzoleni, 1997). A trajectory shift towards commercializing cost-effective small-scale systems could dampen the need of growing in order to compete.

All things considered, sustainability is at odds with competitive strategies dependent on the continuous expansion of consumer demand to succeed. Advanced manufacturing technologies, by reducing the time it takes to develop and manufacture product, enable competition based on fast-to-market strategies. Such strategies seemingly demand growth in manufacturing output because the technologies on which they rely amplify economies of scale and scope. These economies are realized in product markets through faster product replacement and increasing consumption of product designed for ever more particularized consumer needs. The competitive success of fast-to-market strategies, in turn, strengthens the demand for even faster technologies. Thus, current practices in the strategic use of advanced manufacturing technologies reflect and magnify the dominant direction of their development. For new, more sustainable directions in production system technology development to occur, manufacturers will need to turn the technical advantages of these technologies into strategies stressing more intensive product use, not more product consumption. Policy can encourage this shift by modulating the conditions of technology development.

One lesson of evolutionary economics with immediacy for sustainable policy-making is that adaptation is a dynamic process where technologies and their environments exert a reciprocal influence. This makes predicting the impact of new technologies on socioeconomic organization difficult and argues for increasing experimentation.
in the use of technologies in order to observe the resultant dynamic with the objective of balancing the various social, economic, and technological tradeoffs entailed in technology development. This approach fosters choice instead of taking technological determinism and autonomy in the development process for granted.

Policy is about choosing the world we live in — still, it does not negate the forces of technical and economic change. The laws of economics are clear in that decisions on what quantities to produce and when to produce must, more or less, balance with consumption or unleash undesirable economic consequences. More and more, these decisions are executed through the selection of production technologies. This is why it matters for sustainability policy to heed the direction in the development of production systems.

6. Industry roadmaps


National Center for Manufacturing Sciences, 1996. NCMS Collaborative Manufacturing Agenda. NCMS, Ann Arbor, MI.


References


