The Internet as a Global Production Reorganizer: The Old Industry in the New Economy

Gunnar Eliasson

Abstract Globalization of production is breaking up the 200 year industrial knowledge monopoly and backbone of the wealthy Western economies; their engineering industries. Development is moved by a distributed manufacturing technology made possible by the integration of computing and communications (C&C). Previously internal value chains, now distributed over global *markets of specialized subcontractors*, have made smaller scale production relatively more profitable. As engineering firms are embracing the new technologies to take them into the New Economy, they are destroying the business platforms for laggard incumbent firms. As volume based strategies of the old actors clash in markets with new innovative producers, the dynamic and complex decision environment that characterizes an *Experimentally Organized Economy* (EOE) raises the business failure rate. The complexity of the situation makes the capturing of the new opportunities genuinely experimental and dependent on entrepreneurial capacities that are not universally available among the industrial economies. While some developing economies are successfully adopting the new technologies, entering

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The *Internet* is the ultimate manifestation of the integration of *Computer and Communications* (*C&C*) technologies, or the *fifth generation of computing*. This essay takes on the broader C&C perspective and addresses the introduction of fifth generation computing at all levels; Microchips integrated with sensors and mechanical devices minimize fuel consumption in car engines; Product life cycle planning (PLM) help visualize and monitor the entire design, manufacturing, use and servicing process of a product up to final scrapping, a C&C based technology that some visionaries say will help high wage Western firms beat low wage competitors.

The empirical background of this paper are the more than 200 interviews with Swedish and European industrial firms that I have conducted for various studies referred to in the text.

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G. Eliasson (✉)
The Royal Institute of Technology (KTH), Stockholm, Sweden
e-mail: gunnar.elias@telia.com

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onto faster growth paths, mature industrial economies experience difficulties of reorganizing for the same task. Some suffer more from the new competition than they benefit from the new opportunities. For the foreseeable future, however, engineering will continue to serve as the backbone of the rich industrial economies.

1 The Old Industry in the New Economy-Introducing an Opportunity

The principles behind my story of the ongoing industrial development were well understood already by Smith (1776), who was observing the spontaneous decentralization of the organization of production in the British economy. Change today, however, is considerably faster, and dramatically raised its pace around the mid 1990s when C&C technologies were finally integrated to become accessible for broad based commercial use. The outcome has been a considerably more dynamic and complex decision environment for businesses operating in the markets of the old industrial economies.

Computing and communications (C&C) technologies have revolutionized production in three ways; by (1) making the design and manufacturing of radically new, innovative and higher quality products possible, notably within engineering industry, by (2) changing the ways hierarchies are organized and managed, and by (3) creating economic incentives for a global distribution of production. This essay is about all three, and therefore addresses an eminently complex problem, the analytical solution to which will depend on how we cut it down to size by prior assumptions. Combining the three ways in my analysis, however, will allow me to relate both to standard economic theory, and popular business management models that have their origin in the same theories.

The new C&C technologies suddenly established the *Internet*, broadly defined, around the mid 1990s, as the perhaps most disruptive platform for global economic, industrial and social change ever. The Internet is the unexpected evolutionary outcome of the more general integration of computing and communications (C&C) technologies.[1] The stage was set for a future production organization of not only extreme global complexity, but also of constant experimental change. One question is in what shape the currently leading industrial economies will eventually emerge. How will the old engineering industry, for a couple of 100 years the

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[1] For decades the large computer and (tele) communications companies had been unsuccessfully attempting to integrate computing and communications without coming up with a universal commercial solution until the mid 1990s, when the Internet became a viable commercial technology, created by outsider new business start ups, notably Mosaic Corporation in 1994 (rechristened Netscape in 1995). Eliasson (1996a) tells the story, and notably in the appended Chronicle (Eliasson and Eliasson 1996). I will use "the Internet" as a model term to represent the more general C&C technologies.

industrial backbone of the industrialized economies, look in the New Economy? A consequent question therefore is if the new C&C technologies are taking the world through an even greater period of economic experimentation, creative destruction and increasing income diversity than was the case during the first industrial revolution, that began in the late eighteenth century.

The ongoing C&C based industrial revolution has meant a renaissance for engineering. The consequences are visible in the form of both great new business opportunities, and new market risks. *First*, the need for large volumes over which to distribute the increasing costs for investments in product platform development has been reduced through more efficient innovation by actors that have been capable of capturing the opportunities. This is a concrete illustration of the increasing returns in "ideas production" theorized about in the "new growth models" (Jones and Williams 1998, 1999).

Second, increasing returns in innovation, combined with new C&C technology allow the distribution of production over *markets for specialist subcontractors*, raising the flexibility of manufacturing and allowing smaller producers to enjoy significant positive networking externalities of the kind suggested already by Marshall (1890, 1919) as a property of his industrial district, in the macro economic model of Romer's (1986) version of new growth theory, and again later as an aspect of the spillover proposition.[2] But this *macro dynamics can only be understood by taking the analysis down to the micro level* (Eliasson 2003). It is nice *to place the increasing importance for macro economic development of broad based markets for specialized subcontractor services in the context of the Marshallian industrial district*, that is further illuminated in a parallel paper on the European automotive industry (Eliasson 2011a).

Third, the consequences for industrial development of these two technology shifts have not all been assimilated by the business community in which the new production organization techniques are yet to be learned, and a remaining volume mentality in strategic business models derived from standard micro production theory, blocks their introduction. *When volume based and small scale flexible manufacturing strategies clash in markets complex*, *unpredictable and interesting dynamics is generated of the kind typical of an Experimentally Organized Economy*

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[2] My Marshall/Schumpeter inspired quantitative analysis of what I call an *experimentally organized economy* (EOE) is therefore principally interesting since it is based on a method of simulating macro outcomes from micro cases over markets with the simultaneous endogenous determination of quantities and prices (see Eliasson 2009). The Appendix brings the principles together, and indicates with references to experiments on the Swedish micro to macro model MOSES, that significant, even revolutionary change may be involved. Both new growth theory and Marshall's theory of an industrial district were attempts to correct for a deficiency of the neoclassical model through endogenizing spillovers into a theory of economic growth. But that same "new" theory is still only a variation of an old theme that rests squarely on a traditional neoclassical static equilibrium footing that has been elaborated for decades by Dale Jorgenson and his research group, beginning with Jorgenson and Griliches (1967).

(EOE, Eliasson 2005b, 2007, 2009). Complexity theory here takes on new intriguing dimensions for business analysts and economic observers alike to consider (Frenken 2006; Hanusch and Pyka 2007. Again see Appendix).

In the 1980s, and before, three different ways of capturing economies of scale practiced frequently were to (1) raise volumes to reduce unit costs, often neglecting product innovation, (2) develop a complete product range for the market and to (3) engage in non core activities to spread risks. Automotive industry was, and still is, the outstanding example. Particularly interesting from an academic point of view, therefore, is that this volume mentality of the past has been coded into "modern" Enterprise Resource Planning (ERP), or company wide business planning systems, practiced top down in today's dynamic global market environments. Some of these planning systems have taken on gigantic proportions. They embody a top down mentality and ambitions to integrate everything through immensely complex accounting systems in ways that remind of old soviet planning. These systems not only involve principally impossible updating of accounting systems in a dynamic business environment that requires constant organizational change, but also, as a consequence, foster a conservative business mentality (Eliasson 1996a: CH5), that prevents large corporations from breaking up and distribute their value chains to capture the benefits of smaller scale and more flexible distributed manufacturing over markets of more innovative and efficient specialist subcontractors. Econometric evidence (e.g. Okamuro et al. 2011) also suggests that an industry structure dominated by large scale manufacturing and big business makes the business climate less entrepreneurial.

Fourth, and finally, the shift in the nature of the increasing returns concept is reflected in new work place competence requirements. Productivity of workers along the manufacturing line is no longer determined by the machines, irrespective of worker quality. Instead the workers, or rather engineers, are increasingly defining their own job specifications and their own productivities. There is a potential to significantly raise business performance and *an increasing demand for entrepreneurial qualities of "workers"*. This development is illustrated by the large and growing part of design and engineering in modern production, and the diminishing cost share of physical manufacturing (Eliasson 2006a, b). (Thus, for instance, ASEA (now ABB) in my hometown Västerås in Sweden has been thoroughly transformed from a blue collar to a white collar work place dominated by specialist workers, engineers and managers and with practically no low skill jobs. Similarly, product development at Ericsson is 95 % software development, the productivity of which is directly dependent on engineer ingenuity (Eliasson 2010).) This outcome is again reflecting back on the idea of so called new growth theory (Jones and Williams 1998). Even more telling is the fact that engineering industry of today is supported by an equally large and rapidly growing consultancy industry, sometimes internalized within the contractor firm, but increasingly composed of external innovative service providers.[3] These subcontractors are extremely important for the development of modern manufacturing firms. Key to understanding the story to be told therefore are the two sides of resource allocation and production; the information processing and the communications side, on the one hand, and the coordination of production activities on the other, knowledge based communication being needed to coordinate physical production.[4] *The globalization of previously internalized value chains over markets for specialized subcontractors therefore has made small scale production based on positive networking externalities not only profitable, but also flexible, and caused an increased interest in the role of small and medium sized firms (SMEs) in local, regional, national and global economic growth*. This is not a new phenomenon, but new C&C technologies dramatically raised the pace of change from the mid 1990s and on, prompting premature visions of an entirely New Economy.

Another consequence, slowly learned among the students of industrial economics, is that information processing and communication use up the bulk of resources in an advanced industrial economy, probably much more than 50 % (Eliasson 1986, 1990a, b; Wallis and North 1986).[5] A large and growing part of industrial output therefore consists of information and communications services embedded in physical products. Productivity change in this service production therefore today dominates productivity change of the entire industry. Mechanical devices, sensors and electronics are integrated in increasingly complex products, often making software services the largest cost component in advanced engineering products. Transactions within hierarchies and over markets, furthermore, not only use up large resources. They also fundamentally influence how resources are allocated, making the standard (static) I/O model a less than useful instrument to understand and influence what is going on (Eliasson 2009).

In the early 1990s economists worried about the absence of visible manifestations of the enormous investments in information technologies in US industry over the previous two decades. Had large investment resources been

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[3] This is a fact that has made industrial statistics increasingly misleading for years. We observed already in Eliasson (1990b:51ff, 79)that the size statistically occupied by manufacturing in the NA statistics had been on a steady decline since the early 1950s. When corrected for external, outsourced service inputs the revised extended manufacturing industry had, however, remained constant, or even slightly increasing at around 50 % of GNP. The even more interesting observation is that the mistaken idea of "deindustrialization" still keeps coming up in even serious policy debate, with reference to the misleading NA statistics.

[4] In what follows I will use the term *production* to cover all value added creation over the entire value chain, including product design and development, engineering, manufacturing, marketing and distribution to the final user. The term *manufacturing* will be reserved for the physical side of production.

[5] The two volume *Handbook of Industrial Organization* edited by Schmalensee and Willig (1989) refers to the principal existence of transactions costs, notably in Williamsson's chapter, but the consequences of a dominant information and transactions cost element in the total cost structure of the economy for the standard I/O model on which so many policy conclusion have been based, are carefully avoided in the 1555 page discourse. See Eliasson 2009.

wasted? Robert Solow coined the widely used term *the productivity paradox* (Solow 1987; Brynjolfsen 1993; Berndt and Malone 1995). This discussion was however worded in the physical productivity terms of modern neoclassical macro production theory. The dynamics I am referring to, however, took place within the aggregates, and "invisibly" for those studying reality through the wrong theoretical glasses. So when during the second half of the 1990s the US economy suddenly and unexpectedly surged ahead, and the largest economy in the world, believed for many years to suffer from overage and chronic stagnation, was now leading the growth league, the economics profession was again caught off guard and coined the term the *New Economy* to "explain" what was going on, as the economies of previous winners, such as *Japan* (*As Number 1*, Vogel 1979) were stagnating. From 1980 to 2000 practically all industrial economies had lagged behind US GNP per capita growth, excepting *at that time* Ireland, and perhaps Portugal (Hämäläinen and Heiskala 2007:18f).

The New and superior Economy had been ushered into the US on the back of C&C technologies. Röller and Waverman (2001) estimated the diffusion of land-based communications networks in 21 industrial economies had accounted for one-third of output growth between 1970 and 1990. Greenstein and Spiller (1996), Lichtenberg (1993) and Mun and Nadiri (2002) also observed that new technology spillovers were particularly large in industries that were intensive in their use of C&C technologies.[6]

Then came a sudden reversal in the IT industry around the turn of the millennium. Still Chun et al. (2004) observed that "stock returns and fundamental performance measures were significantly higher in industries that had a history of more investment in information technology". Radically new methods of organizing production, made possible by new integrated computing & communications (C&C) technology and the Internet, were said to be the mainstay of the New Economy, and explained the unprecedented growth cycle of the US economy over more than a decade (Jorgenson and Wessner 2006, 2007).

(There is an even longer term policy issue. The 1990s saw a surge in spillover[7] econometrics, and the observation that social rates of return were above, or far above, private rates of return on R&D. Nadiri (1993), Jones and Williams (1998, 1999), and others concluded that the rich industrial economies were *underinvesting in private R&D* and argued that a great policy opportunity to do something about that underinvestment was presenting itself. The numbers were such that the low wage competition from China, and similar industrially developing economies challenging Western engineering industries, should be considered too small to worry about. The real economic problem, however, is different and has to do with (1) the incentives to invest sufficiently in private R&D to generate the spillovers needed to overcome the underinvestment, and (2) the commercializing competences needed to profitably exploit the spillovers. The spillover values seem

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[6] See further Eliasson (2010:41).

[7] The term first appears to have been used by Nadiri (1978).

to be largely captured by others than those creating them, notably by consumers in the form of lower prices (Nordhaus 2004), and society at large, while the profitability of the spillover generating firms is too low to make them invest in R&D and grow at a rate sufficient to overcome the underinvestment. Defense products are one case, notably military aircraft. Such products distinguish themselves by carrying with them a large "cloud of technologies", available for free to everyone capable of commercializing them, and sufficient to name Swedish Saab military aircraft a technical university diffusing new technologies and workers with experience from the most advanced manufacturing techniques to engineering industry in particular. I have therefore (Eliasson 2010:239ff) ventured the suggestion that a *new demand based innovation policy* in the form of *public procurement of privately demanded advanced public goods and services* should help overcome the underinvestment, without most of the misallocation and dead weight problems associated with traditional short term Keynesian demand stimulus.)

The integration of mechanical devices and electronics through software in products has created entirely new industrial opportunities for the mature engineering industry, the industrial backbone of Western economies. But this is also the industry that is being subjected to the most dramatic change as concentrated production sites based on volume manufacturing are giving way to *new distributed forms of flexible production*, the complexity of which make them analytically intractable and *available only as the outcome of an experimental process fraught with management mistakes*. Not all local or national industrial economies will therefore make the transition, since not only are the organizational competences to do it right often lacking. *The new organizational practices to cope are also resisted politically since they affect the distribution*, *composition and compensation of jobs*.

It may be true that the global diffusion of spillovers explains most of economic growth among the rich industrial economies (Klenow and Rodriguez- Clare 2004; Keller 2001),[8] but not all rich industrial economies will therefore make it successfully into the New Economy, because they lack the necessary entrepreneurial *receiver competences* (Eliasson 1986:46f, 57f, 1990a; Cohen and Levinthal 1990). *Failing economies will then suffer more from the increased global competition than they will benefit from the new opportunities*. The roads to successful globalization of production in an experimentally organized economy are therefore lined with business mistakes and occasional successes. As in the first industrial revolution beginning in the late eighteenth century (Pritchnett 1997) diversity will probably increase (Eliasson 2007). Now, as well as then, inabilities to receive, adjust to and commercialize the new technologies will be the reason (Eliasson 2000, 2003; Parente and Prescott 2004).

I therefore go on (in Sect. 2) comparing the engineering industry, as the initiator and mover of the industrial revolution, with what is currently going on with product technology development and the organization of firm hierarchies and the

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[8] For a somewhat contrary view, see Branstetter (1996).

globalization of their value chains. My story is about the renaissance of engineering. I continue (Sect. 3) with a stylized presentation of the C&C technologies, notably the Internet, as a global production flow reorganizer, placing special emphasis on the security issue and on what is yet to become established industrial practice; integrated production based on virtual and flexible design. This frames my concluding (in Sect. 4) discussion of *the new balance between volume and smaller scale production*, that will save the capable high wage economies of the Western world from the onslaught of low wage competition from industrializing economies and re-establish engineering as the industrial back bone of the "New Economies".

2 The Renaissance of Engineering

When the machine tools had been developed into reliable machines for routine factory use by the beginning of the nineteenth century, decentralized industrialized structures of specialist producers began to evolve very much as Smith (1776) had described it, while it was happening, and compete the then dominant handicraft industry out of business. The modern engineering industry had been born. But not all economies succeeded in reorganizing themselves for that transition. Massive global diversity was one consequence (Pritchnett 1997).

A similar industrial revolution of the engineering industry, made possible by new Computing and Communications (C&C) technology is currently in progress. Its potential leverage on productivity advance is huge, but the entrepreneurial capacities of the producers of the old industrial nations to reorganize production around the new engineering technology may not be sufficient to carry them further into the New Economy. If the transition of the industrialized world succeeds, it may, however, be possible in principle for the already rich industrial nations to beat imitator economies attempting to catch up, and to keep the distance to the industrially less developed economies. But this will require a new combination of technical and entrepreneurial competences, radical industrial reorganization and a political willingness to cope with the consequent social adjustments. I take note of the Patel and Pavitt (1994) observation of the continued, widespread and neglected importance of mechanical technologies. Are we witnessing the demise, or the renaissance of engineering industry?

2.1 A Brief History of Engineering Technology

The "new" machine tool technology was revolutionary. It represented a generic technology that could be used in practically all metal manufacturing, and it made specialized and decentralized production ("outsourcing") possible. From the beginning such specialization and geographical decentralization offered great advantages over the earlier craft industry where the entire product was manufactured in one workshop. O*rganization*, hence, became an integral part of engineering technology, or the fourth production factor recognized by Alfred Marshall. England's growing industrial heartland developed around this technology. To be noted is that the workshops in Lancashire had more machine tools in operation at the beginning of the nineteenth century than all the world taken together (Carlsson 1986; Woodbury 1972, *FT*, May 27–28, 2000).

Sweden, since its period of military imperialism during the seventeenth century had experienced an acute need to develop and manufacture more sophisticated weaponry than its enemies. At the time Sweden therefore developed a tradition to import whatever skills and industrial competencies that were needed to achieve those objectives through active promotion of the immigration and permanent settlement of skilled workers and industrialists. Thus public procurement to satisfy advanced military needs defined a Swedish platform for further indigenous industrial development. What began as an iron based cannon industry gradually evolved into a sophisticated engineering industry (Eliasson 2011b).

The world was eager to learn, and Swedes were outstanding learners. The Swedish economist Westerman (1768) travelled to, and learned from what was going on in England, and observed that the new machines from England of course were good to have, but they did not help much if there were too few people who knew how to operate them, and above all, if an understanding of how to organize manufacturing around them was lacking. The economic importance of the industrial revolution under way in England was soon understood, and industrial espionage became common. Linnaeus' student Daniel Solander, who worked in England most of his life, was instructed by authorities close to the Swedish king to persuade skilled English workers to emigrate to Sweden. He even tried to convince James Watt to move to Sweden with his impressive "fire machine" (*Populär Historia* Nr. 1, 2003, p. 31 ff).

Improved steel quality (not least because of the first industrial implementation of the Bessemer method at the Edskens factory in Gästrikland in Sweden 1853)[9] made the machine tools more precise and more reliable. This technology was further improved in the US during the second industrial revolution (1860–1920)[10] as measurement technology (refined by the gauge blocks from Johansson's factory in Eskilstuna, patented 1901) made it possible to manufacture standardized and exchangeable components very precisely. Swedish industry had already then become a great innovative player in global markets.

2.2 New Digital Technology Revolutionizes Engineering

Among the "old industries", engineering was best suited for exploiting the new digital technology; (1) because the *digital technology* is excellent replacement for many mechanical solutions in engineering products, and (2) because its basic technology potential is decentralized and distributed production. Enormous

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[9] By the founder of Sandvik, Göran Fredrik Göransson.

[10] And notably through the development, and effective use of guns with exchangeable components during the US civil war.

systemic productivity gains could be achieved and Swedish manufacturing firms were pioneers in the 1970s in using electronic devices in their products (Eliasson 1980, 1981). The micro-processor—or the fourth generation of computers—took engineering technology one great step forward. Today *the functionalities of advanced mechanical products depend entirely on how mechanical devices and electronics have been integrated through software* (Eliasson 2010).

The decentralized organization of casting, sheet metal forming, machining,[11] welding, heat treatment of components, etc., previously carried out within one factory, defines the next phase in the digital revolution. The geographical distribution of the production of components and subsystems over markets for specialized subcontractors to be brought together (systems integration) for final assembly into a complete product is another equally revolutionary characteristic of engineering production, still being moved at a rapid pace by the continuing integration of computer and communications technologies.

I therefore ask, in this essay, what the fifth generation of computers—the merge of computing and communications (C&C) technology and the Internet, its ultimate manifestation—will mean for traditional manufacturing, and engineering in particular. With specialization and outsourcing increasing, and with product development, manufacturing, distribution and marketing merging on a global scale, industrial actors with the right competence have discovered great business opportunities.

Metal forming machine tools are still the backbone of modern engineering industry. Engineering has been given attributes such as "mature", "old" and "traditional", and automobiles are often quoted as a typical product of such a mature industry. The question, however, is how a production technology founded on "metal forming" could have been maintained for 150 years as, and still to a large extent defines, the industrial backbone, and the competence monopoly of the industrial world.

The question is how western producers will cope, when their engineering knowledge monopoly is being challenged from all ends by an industrially not yet developed world that is rapidly learning this technology, and at least to begin with operates at far lower wage levels. Literature offers a variety of answers. *First*, sufficient numbers of the highly diversified products of engineering industry are very sophisticated and are constantly changing in response to the constantly varying tastes of wealthy customers. They will be demanded "for ever" and it will be a competitive advantage to be close to those customers. So the industrially developing economies will not be capable of competing successfully in the upper end of these markets. *Second*, mechanical engineering in the industrial world uses very complicated technologies. Everything from military jet fighters to computers and simple metal components belong to the product mix. Swedish metal manufacturing was once (Pavitt 1979; Pavitt and Soete 1981) ranked as one of the most varied and technologically advanced industries in the world, just behind the US, Japan and

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[11] Using gear-cutting, grinding and milling machines.

Germany, and far ahead of all other economies, including England and France. Since then, however, the Swedish range of technologies has narrowed. The big firms have discontinued their production of peripheral products, shedded high risk experimental development projects and shut down non profitable production to focus on core competences. At the same time (*third*) Swedish engineering companies have developed from being small (by global standards) as financial organizations, but large as manufacturing units in the 1970s (Pratten 1976) to become, through internal growth, acquisitions and expansion abroad, a smaller number of very large firms. It is interesting to compare a list of the largest firms 50 years ago with the same list today (see Eliasson 1996a:49). Most of the firms at the head of the ranking have been replaced. (Today only ASEA (now ABB), Ericsson, Stora (now Stora Enso), SCA, Sandvik, SKF and Volvo remain among the largest 15, but both ABB and Ericsson were recently close to being toppled by internal mismanagement and external events (Eliasson 2005a). Volvo, Electrolux, Saab, Scania, Astra (Zeneca) and (temporarily) Pharmacia have moved up).

2.3 The Spontaneous and Unpredictable Emergence of the Internet Revolution

While economic analysts had been preoccupied with the particular technologies they had been used to be concerned with, an economic tsunami had been secretly gaining momentum during the last couple of decades of the twentieth century.

The transistor was the first step in the digital computing revolution. It was invented in Bell Labs 1947 and the second generation of computing had been initiated.[12] One of the inventors, William Shockley, took the principle with him to Palo Alto in California where he started Shockley Semiconductors. As talented employees jumped ship and started their own companies a close to explosive development was initiated. AMD was one spin off from Shockley's enterprise, and Intel another, within which the micro processor was invented 1971, and with that the PC made possible. The fourth generation of computing was born.

The origin of the Internet is sometimes dated to 1973 when Winston Cerf (at Harvard) and others formulated the so called Internet Transmission Protocol (TCP/IP). But very little occurred outside the university world until 1994 when Mosaic corporation (rechristened Netscape in 1995) introduced an easy to use graphical browser. Most computer companies had been aware of the industrial potential, and had been unsuccessfully attempting for years to integrate computing and communications (Eliasson 1996a), only to see Netscape's bright idea initiate a commercial revolution, and Internet use exploded. Before 1995 the Internet is more or less absent from the business journals, then suddenly to permeate them

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[12] After the vacuum tube. The third generation of computing was ushered in 1958, when Texas Instruments first introduced the integrated circuit.

(Eliasson and Eliasson 1996). If we are to discuss the intellectual origin of the Internet, furthermore, we should go back to 1957 when the US Defense Department founded Advanced Research Projects Agency (ARPA) and asked it to develop a method to keep communications open during a nuclear war. A computer network capable of exchanging information between any couple of computers was developed. In this sense the by far most important industrial technology of the twentieth century has a military origin. To capture such spillovers is, however, an entirely different story. Thus, for instance, the document on "Future Critical Technologies," delivered to the White House and the US President in 1995 failed to mention the Internet, and even worse, also the then ongoing rapid integration of Computing and Communications (C&C) technologies was not really part of the presentation. It is not the spectacular emergence of Silicon Valley that constitutes the new industrial revolution. It is the explosive, but unpredicted, commercialization of technologies developed there and diffused through the production system in extremely complex ways. The model capable of representing the dynamics of this process is based on micro economic phenomena, extremely complex and of the nonlinear type with no analytically determinate equilibrium outcome. The story is that of the unpredictability prevailing in what I call an Experimentally Organized Economy (EOE. See Eliasson 1987, and Appendix). A tsunami had been created that surfaced at the industrial level about the mid 1990s. The fifth generation of computing had been born and a new industrial revolution was on the way.

2.4 The Art of Distributed and Integrated Production: A Small Scale Revolution?

Decentralization and distribution of production over markets, was understood already by Smith (1776) to be the source of economic wealth of nations. Advanced engineering products of today are too complex and require too many specialized technologies to be developed and manufactured within one company. Product development and manufacturing, therefore, have to be distributed over *markets of specialist subcontractors*, and increasingly on a global scale. To organize such distributed and integrated production right is a difficult management art in itself. Even though this is where Swedish industry, and its aircraft industry in particular, was a pioneer and has excelled (Eliasson 2010), complexity is such that organizational failure is common. The market for specialist subcontractor services, however, is what makes it possible for the systems integrating firms to operate on a smaller scale than before, drawing on the networking externalities embodied in the system. C&C technologies make it possible to reorganize and *integrate* the different manufacturing methods in innovative new configurations, raising the *flexibility of production*. Individual technologies can also be subjected to both stepwise and radical change, the latter not rarely making the competence endowment of entire firms obsolete. Benkard (1999) emphasizes the need to "forget" in aircraft industry.

Networking externalities arise in different ways. First, one single producer can never be the most cost efficient in all operations. New C&C technologies have made it possible to shift production from concentrated internalized large volume manufacturing towards a more flexible, but also more complex distributed organization. With some production outsourced to more efficient subcontractors they can achieve optimum scale by also serving other customers (Eliasson 1986:82f). The distribution of production over many subcontractors also means increased efficiency since factors of production, notably labor, will be better utilized and compensated closer to their marginal productivities (Eliasson 2006a), and flexibility can be achieved more easily by changing delivery contracts than by laying off own workers. To get the new distributed organization right, however, is not easy. The distributed organization means that new *indirect* transactions costs are incurred through organizational mistakes, and larger *direct* transactions costs because of the increased market transactions. If done right, however, large systems productivity gains, and flexible product designs can be achieved. Second, part of the systems productivity gains originates in the possibilities to charge higher prices for flexibly redesigned products for markets where such products are demanded.[13] This is the normal situation in modern production subject to rapid technological change. A distributed (over markets of subcontractors) production organization is, therefore, also more flexible than a centralized internalized organization. This means that large systemic productivity effects can normally be achieved *in principle* from reorganizing a company towards distributed production.

3 The Internet as a Global Production Reorganizer

The industrial potential of the "Internet", broadly defined, completely unforeseen some 20 years ago, appears to be enormous and originates in the simultaneous reorganization and coordination of information and "production" flows (Item 5 in Table 1). A production organization distributed over markets of specialized subcontractors makes it possible both to capture systemic productivity gains and to raise flexibility in production for those capable and creative enough to manage the complexity involved. The deep information and communications structure superimposed on the distributed physical production structure is reflected in significant transactions costs. That transactions draw large direct and indirect resources (More than 50 %, Eliasson 1986, 1990b; Wallis and North 1986) was long an unknown or ignored fact among economists and still is, in much contemporary economic theorizing. The direct transactions costs are incurred in both internal and external markets. The indirect transactions costs are however much larger and are incurred in the form of business mistakes and lost profits (Eliasson and Eliasson

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[13] Cf Nilsson's 1981 study of the diseconomies of the inflexible automated ASEA electrical motor manufacturing line.

Table 1 Systems effect categories at different levels of aggregation in knowledge based information economy

1. Speed up info flows over given structures (rationalization)
2. Speed up physical flows over given structures (rationalization)
3. Reorganize info flows
4. Reorganize physical flows
5. Do all simultaneously (*integrated production*)

Source: Eliasson (1998b). Information efficiency, production organization and systems productivity—quantifying the effects of EDI investments; in Macdonald and Madden (1998)

2005). They constitute a standard cost for economic development and are key characteristics of an experimentally organized economy within which their size is not analytically determinate (see Appendix).

3.1 E-Business and Internet Security

Internet based electronic business is the perhaps most commonly referred to use of C&C technology in the old production organizations. To begin with physical transactions ("paper flows") were supposed to be replaced by digital flows. Attempts to replace the book by a digitally sourced screen have long been discussed, but perhaps Apple's new Ipad will do it. US *Amazon* has come to symbolize this development, but the principles date further back. The paperless office was an early indicator of the idea that did not take hold in the 1970s because the technology was not ready. Electronic Data Interchange (EDI), a precursor of the Internet, was introduced by many large companies in the 1990s to help organize their purchasing, production and distribution flows. Most of these systems were proprietary to the company which limited the possibilities to communicate over external markets and to achieve desired systems externalities (Eliasson 1998). This, however, all changed dramatically with the rapid introduction of the Internet standard in the late 1990s.

Early applications of C&C technology in industry and business, however, simply meant speeding up either information or manufacturing flows without changing the organization of the same flows (Items 1 and 2 in Table 1). Limited organizational competence and innovative capacities held back development. Security is another concern. As long as trade secrets and other sensitive information and large economic values transacted over the Internet can be pirated by skilled hackers the full potential of the new technology will not be realized. On this McKnight and Bailey (1997:19) and McKnight et al. (1997) observed that security is the "enabler for electronic markets".

While most speculation on, and around E-trade has been about its impact on distribution to consumers (B2C), the revolution has taken place in business to business (B2B) trade, a development closely related to the expansion of distributed production and the need to coordinate flexible information and production flows over subcontractors. The initiation of that development does not date back much more than a decade or two.

General Electric (GE) was a pioneer in developing advanced and efficient Internet based purchasing. Already in 1998 GE expected to save almost half a billion dollars by shifting the purchasing of five billion dollars to the Internet (DI April 17. 1998). *Dell* was early in selling its PCs over the Internet. It began its second revolution already in 2000 (*BW*, July 18, 2000) by using the Internet to integrate its assembly and subcontractor system over its entire value chain up to the customer, using enterprise resource planning (ERP) technology. This meant (*BW*, June 18, 2001, FT July 19. 2000) that Dell only had 5 days of inventory, while competitors were carrying 30, 45 and even 90 days of inventory. *IBM* took similar steps early, and announced in 1999 that 25 % of its income had been generated by e-trade (BW May 28. 2001). The theoretical principles behind this capital saving potential had been taught in economics since the 1960s. Only now, however, was the instrumentation there to allow the principles to be realized in practice.

Swedish *Sandvik* introduced IT already in the 1970s in its global customer relations using a proprietary system. Early in the new millennium it shifted its global marketing and distribution system over to the Internet (*Sv.D.*, February 8, 2002).[14] Swedish and Swiss ABB announced in 2000 that it was reorganizing itself away from being a hardware manufacturer to become an information and knowledge ("Brain power" based) business, using the Internet to integrate customers, product development and a distributed (over the market) manufacturing organization (DI February 14. And 21. 2002, Eliasson 2002:101), production automation being one of its strategic growth areas. It did not help, however, at least not in the short run, and ABB was in serious trouble by the turn of the millennium, being forced to shed almost all its non core businesses (DI, February 22. 2005), often at the wrong time and at bargain prices.

Reorganizing itself into something entirely different all the way through Table 1 is not easy. While one of ABBs specialties still is factory automation, ABB limits its ambitions to engage only in certain industry applications where it has learned the process technology, and never reorganizes the information and process flows of an established company completely to take full advantage of the possible systemic potential (Item 5 in Table 1). This is simply too difficult, and the risks of getting the flows organization seriously wrong are too high.

It is generally so that the new high tech electronics devices, sensors etc. may give the early developer and user a temporary advantage in partial applications. Over some "run", however, the new devices have been learned by competitors. They are available in the market, and the longer term industrial success and staying power rest on understanding the business to be automated. WoodEye, a Swedish Saab related company used early sensor and electronic devices, originally developed to represent, and analyze in flight behavior of supersonic missiles in real time, to automate the diagnosis and sorting of timber logs in a sawmill by quality, also in real time (Eliasson 2011b). The economics of this new technology was tremendous since sorting was reliable, rapid and labor saving. The long run business outcome,

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[14] Also cf case study of the earlier system in Fries (1984).

however, did not depend on the sensors and electronics equipment, components that soon became standard and generic, but on understanding and reorganizing the saw mill process to make full use of the new information technology.

Within automotive manufacturing *Covisint* (founded by GM, Ford and Daimler Chrysler 2000) has developed into the world's largest Internet market in the industry. One ambition was to cut prices for components through competitive purchasing in more transparent markets, but the official rationale for this trading place was to facilitate the development of new organizational solutions for production over the markets of subcontractors.

The new production organization of the *Boeing* company, however, illustrates the advantage of an Internet based information system. The ambition has been to raise the speed of the moving line of one of the world's most complicated manufacturing processes in its Renton (Washington) factory. The entire assembly line is integrated (over the Internet) with all subcontractors and all modifications of designs and construction blueprints being simultaneously updated at all locations where they are used. When developing, manufacturing and assembling the 250 seat 787 Dreamliner in the world's largest building in Everett, Washington 17 companies from 10 countries have been involved (*BW*, June 11, 2001, *Time* Sept. 17. 2007, DI March 26. 2010). The complexity has reached such proportions that Boeing fell 2 years behind schedule in flying its new Dreamliner. The Dreamliner business plan represented a dramatic paradigm shift compared to the previous 777 model. Still, time to market for the two models has been roughly the same. An additional comfort for Boeing is that its main competitor Airbus, with its giant 380 model for 555 passengers based on a conventional, but scaled up concept,[15] was even more late, because of organizational problems, and the awkward rules imposed on the sharing of management authority and job locations between the nations involved in the project, notably France and Germany.

E-business can also be "internal" within distribution and supplier networks, and few paid attention to the Arkansas supermarket chain *Wal-Mart* which learned long before the New Economy hype how to use IT to distribute everything from clothes

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[15] While Airbus is heavily subsidized, Boeing has had to rely on private partners and on some state subsidies to finance, and to cover the technical and commercial risks on the Dreamliner. On this French Prime Minister Lionel Jospin once said that "We will give Airbus the means to win the battle against Boeing" (*Newsweek* Dec. 13. 2004). On this I say (Eliasson 2010) that the positive spillovers to (externalities for) the US economy of the Dreamliner will be much larger than the Airbus benefits to the European economy. It will therefore be interesting to see who wins the commercial battle. Rather than leaning on politicians, Boeing listened to its customers (the Airlines) which managed to steer Boeing away from its original product concept, that to begin with was similar to that of Airbus, towards a smaller aircraft for direct flights between cities, the Dreamliner. To counter Boeing's Dreamliner, Airbus has started development of the 270 seat 350 model, again with public subsidies as the bottomline.

Recently (FT Sept. 10/11. 2011:9), one of the commercial partners of EADS (that own Airbus), German Daimler has been trying to sell its share to a (on insistence of the German Government) German investor. French Government controlled Aerospatiale, and other French owners are not signaling a corresponding divestment.

to medicine. Wall-Mart established an entirely new, highly productive organization of retail trade with direct contact between producers (suppliers) and superstore shelves and practically no inventories beyond what is being on the move between factories and Wal-Mart stores. Wal-Mart tried to enter Europe on the basis of its superior IT-based distribution technology. It shook up the old fashioned low productive European retail industry, but met with unexpected resistance with European customers who did not like to wander around in enormous ware houses. Whatever the long run outcome it will leave unproductive European competitors dead in its wake (*BW*, June 28, 1999, *Newsweek*, May 20, 2002, *Sv.D. Näringsliv* January 24, 2003).

3.2 Mass Manufacturing vs. Smaller Scale Networking Externalities

C&C technology enters production through three different information channels where (Eliasson 1996a) (1) *information* systems make hierarchies more transparent, and improves access to information and people with competence, (2) *business systems*[16] monitor and run *operations* and (3) *accounting* systems are designed for economic measurement and *control*. The three different channels overlap, since both information and business systems are based on the accounting systems of the firm. There may, however, be several, each based on different taxonomies to serve different purposes. The information access system has openings for discrete human interfaces and human competence inputs,[17] that business systems attempt to minimize. Manufacturing automation is a special, and "relatively simple" special case of such efforts. Even so, complexity is such that failure is common. One illustration is that companies in the manufacturing automation market, such as ABB, rarely undertake complete reorganizations of the entire business, but rather modify existing processes in a piece meal fashion.[18] In the last couple of decades specialist companies such as German SAP, US Oracle and Lawson have developed extremely complex enterprise wide business or Enterprise Resource Planning (ERP) systems designed to integrate everything top down to make the business more transparent and efficient in reducing slack and cutting costs.

While new information technology may make giant and complex hierarchies more transparent, such systems also reduce organizational flexibility because of the difficulties associated with maintaining and updating the enormous and often fragmented databases with new activities. And worse, such systems influence the thinking of management, foster a preoccupation with costs and encourage

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[16] Including electronic trade.

[17] Of the Turing (1936) kind.

[18] Interview with ABB Sweden in 2002. ABB works according to a bottom up approach, while SAP starts from the financial control level and works itself down.

"gigantism". In fact, such systems are principally impossible business planning tools in a dynamic business management context because they make it impossible to add and remove activities without a major overhaul of databases, and hence also make it difficult for large businesses to adopt smaller scale and more flexible manufacturing distributed over markets of specialist subcontractors. To avoid organizational rigidification an extremely high resolution of internal statistical accounts and a preparedness for integrating accounts of comparable resolution and classification of new businesses to come is needed. Such, standardized, expensive to install[19] and inflexible, some would say unwieldy, business systems that attempt to integrate everything therefore not only create impossible data collection and updating problems, but also distorts organizational transparency (Eliasson 1976, 1996a:Ch 5, 2005b). They develop a preoccupation with costs, notably inventory minimization, and should rather be called "partial misinformation system", to quote Ackoff (1967), in markets dominated by innovative product competition and constant organizational change. In fact, the CEO of profitable Swedish truck producer Scania has called the SAP system costly and useless (Interview in separate advertizing section of DI, Sept. 29. 2004). Many companies have tried and failed, including the Swedish defense organization, that has invested 2.4 billion SEK in a SAP system that cannot even, it turned out, handle secret documents, and now, after a series of cost overruns and reduced ambitions is expected to save 270 million SEK per year from integrating its 1,500 different IT systems.[20] This is well within the error margin for such calculations on a 40 billion annual budget (*Computer Sweden* June.5.2009:4f, *Veckans Affärer*, 8 April 2010:20–24). On this I add that the savings calculated overemphasize improvements in cost rationalization, deemphasizing the costs of rigidity, notably losing winners, and takes management attention away from innovative product development. Much larger values are likely to be lost in the long term in the form of missed winners, a typical illness of the very large business organizations (Eliasson 1996a).

ERP systems had been largely developed for stable organizational hierarchies to achieve top down cost control, faster flows, and minimized inventories, thereby being inattentive to the organizational flexibility (Item 5 in Table 1) that the break up and market distribution of previously internal value chains has created. Managing unstable business organizations in the Internet world through rigid accounting systems is certainly not the best way for top management to be well informed (Eliasson 2005b). Static efficiency may have increased, but at the cost of inflexibility and doing the wrong thing. The risk with comprehensive business systems therefore is that their introduction and use breeds a hierarchical volume mentality that both closes management eyes to business opportunities and reduces flexibility

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[19] And not only that. The SAP system was designed and on the market "before Internet", and converting SAP software for Internet use has been both difficult and costly, not least for the customers (FT June 12. 2001).

[20] There is no way to calculate savings at that level of precision. And what one has calculated as a gain might very well already have been lost several times over in the form of lost investment opportunities that could not be fitted into the systems standard.

in both product design and manufacturing organization. Such streamlined production control systems may kill innovation, argued already Michael Cappelas, then CEO in (the earlier) Compaq (now within HP. *BW*, September 24, 2001). Econometric evidence (e.g. Okamuro et al. 2011) also suggests that industry structures dominated by large scale manufacturing and big business make the business climate less entrepreneurial. Advocates for Product Life cycle Management (PLM) systems are therefore critical of the preoccupation with cost minimization in ERP systems. Their argument is that ERP systems make managers "neglect" innovation and product development. Product Lifecycle Management (PLM) is a visualization technology that originated in aircraft industry. To begin with PLM methods were developed to compute service charges from rented products such as aircraft engines (Eliasson 1996b, 2010:157ff). The business concept was to remain the owner of the complex product, renting it as a user service to the customer. With time PLM has become a generic term for virtual production systems that make all information on the product available over its entire life cycle. When aircraft engines were rented to airlines and charged for engine services the design, engineering and life management of the engine were changed radically (Eliasson 2010). The same is happening in large and expensive investment equipment with a long life, such as trucks, and also in automotive rental business. The argument is that virtual production systems of the PLM type, contrary to cost focused ERP systems, pay attention to the product and the customer, and make firms, both small and large, more innovative (*Ny Teknik*, *Special Supplement* Sept. 28. 2005:2).

A conclusion for the following therefore is that the common management preoccupation with volume manufacturing and cost minimization, for instance to counter import competition from low wage economies, now codified in rigid business systems, makes the business less well prepared in markets where product innovation and variation are demanded. With quality variation becoming an increasingly demanded product feature, *flexibility*, *and the supply of product variety* have to be made part of a relevant definition of productivity. The more distributed over markets of subcontractors production, the more flexibly product customisation can be combined with efficient supply chain management, and the more difficult it becomes to measure and control quality over the entire value chain. As a consequence, the more difficult and competence demanding, the more important it becomes to get the new complex organization of production right, and industrial experience demonstrates that this is not only difficult, but also failure prone.

3.3 The Important Markets for Specialized Subcontractors

Large scale systems integration means concentrating on product development, outsourcing non core physical manufacturing on specialized subcontractors, and then marketing and distributing the product, sometimes even taking over part of the maintenance and servicing of the product from the customer. This technology was developed in aircraft industry and Alan Mulally has made a point of having brought it with him to crisis stricken Ford from Boeing in 2006 (*Time* Sept. 6. 2010:30f).

Visualization is key to effective distribution and integration of production. Visualization in turn depends on standardization, modularization, precise definition, measurement and manufacturing of the modules. Modularization is no simple technique, even though it was first used a century and a half ago[21] with the development of precise measurement and machining techniques. This development was speeded up by the Swedish pioneer "Mått Johansson" in Eskilstuna (in the Lake Mälar region) who invented and patented his set of gauge blocks 1901, a measurement technology that rapidly diffused through the global engineering industry. The new CAD-CAM based visualization technology is of course immensely more demanding on measurement and precision. Crosby's (1997) point about the role of measurement in economic quantification in the early western industrialization, from the thirteenth century and on, apparently still carries a momentum.

(Swedish engineering firms were leaders in integrating microelectronics in their products during the1970s (Eliasson 1980, 1981). *Embedded systems*,or chips (electronic modules) embedded in small mechanical systems that guide the mechanical devices have become an important technology in the last decade. Such devices now appear everywhere in engineering industry and are increasingly developed into standardized functional modules developed by specialized subcontractors.)

The benefits of distributed and integrated production are illustrated in Table 1. To begin with the use of IT in production was limited to doing the same thing, but now with IT support (Items 1 and 2). With degrees the art of raising productivity by reorganizing process flows in ways IT made possible were introduced (Items 3 and 4). The very complex, difficult and potentially rewarding art of doing both simultaneously (Item 5) is what we are discussing. The potentially large economic gains from distributing production come from complete reorganization at both the physical and the information process flow levels, and this is where the markets for specialist subcontractors come into play, in ways that were not feasible before the commercialization of C&C and Internet technologies. Even the fairly well controlled internal environment of a manufacturing plant offers such enormous variety of possible production flow organization that automation, as I have mentioned, is always done through gradual modifications of exiting architectures to avoid costly mistakes. The art of complexity management is however not fully tested until distribution of production stretches over markets, and includes the whole value chain from product design, through manufacturing, distribution and, as well, servicing and use, and involves the constant change of product specifications. We are now talking about much more than outsourcing the low end of manufacturing, but of the fact that it is impossible to develop all specialized competencies of advanced production internally, and that the systems integrating firm can never be the most

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[21] During the US Civil War the life and performance of guns were radically extended through the use of interchangeable parts (Carlsson 1994).

efficient developer and manufacturer of all. Here standardized modular systems integrated through C&C based software have worked wonders for engineering product development. But also economic factors are at work. The carriers of specialized knowledge can never capture their full rent by being employed by the systems integrator. By taking on the higher private risks of being outsourced they can also offer their services to other buyers, and raise their returns (Eliasson 1986:82ff). Again, the existence of varied markets for specialized subcontractor services are instrumental for capturing the full benefits of distributed and integrated production. (Outcontracting over specialized and varied subcontractor markets is more flexible than internalized production, and a natural part of the flexible manufacturing systems, originally pioneered by Honda and Toyota in Japan, but later learned, and rapidly introduced, in the US and Europe and now being returned to stagnant Japanese businesses in upgraded form (*Ny Teknik* Nr 49. Dec.3. 2003:14f).) But again, distributing the value chain too widely over markets, notably over global markets, eventually leads to the loss of cost and quality control.[22] To get that compromise right is a difficult industrial art that managers often fail to learn.

4 The New Balance Between Small Scale and Volume Production

C&C technologies have influenced engineering in three ways; by making (1) the design of radically new products possible, (2) complex hierarchies more transparent and (3) incentives for globally distributed production stronger. The outcome has been a shift towards smaller scale.

When looked at from a national or global economic perspective the systemic productivity gains or networking externalities associated with distributed and integrated production have been found to be based not only on the information, communication and coordination potential of C&C technologies (shown in Table 1) but also on the development of broad based markets for specialized subcontractor services and—not least—functioning, high capacity transport networks that allow for stable, high speed, predictable and flexible flows of physical products, notably road transports.

While the benefits of (globally) distributed production, very much as Smith (1776) once described it, are large, many factors hold back the immediate exploitation of the industrial productivity potential of new C&C technology. Factors slowing the transition to a new global production organization in a particular region or economy are (1) lack of local competence on the part of business management,

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[22] A common experience from extensive outsourcing that has forced many firms to return outcontracted manufacturing from low wage economies. This is typically the experience from producers that change their product designs frequently and/or customize their products (Eliasson 2005c).

(2) the high risk of management failure in the now much more complex and unfamiliar business opportunities space, (3) an institutional environment in the industrial economies that discourages entrepreneurs to act on the opportunities, and, not least, (4) a general political aversion among the (still) rich industrial economies to absorb the unpredictable reshuffling of monetary wealth, employment, individual welfare and political power that accompanies a successful such transition. There is also the time perspective itself. Learning takes time as does the development of the supporting markets for specialized subcontractor markets. But economic incentives are so large that the experimental transition process will not stop. The total outcome is already statistically visible as production is distributed over markets of specialized subcontractors delivering a larger production value at a significantly smaller input of labour. A number of these production units have once been internal parts of a large firm that have now been separated as small autonomous firms/subcontractors that can access the entire global market, and benefit individually from larger economies of scale. A radically *different balance between small scale and large scale production* is developing. This global development *has exerted* an effective check on inflation, and pushed for a more effective labour market organization that has moved individual wages closer to their marginal productivities. The other side of this coin might have been a widening distribution of incomes. To understand what has happened to the global economy is simply impossible if the analysis is not taken down to the dynamics of micro market behaviour.

The complexity of the situation makes the capturing of the new business opportunities genuinely experimental and dependent on entrepreneurial capacities that are not universally available among the industrial economies. While some developing economies are successfully adopting the new technologies, entering onto rapid growth paths, other mature industrial economies experience great difficulties of reorganizing for the same task, and suffer more from the new competition than they benefit from the new opportunities. For those that succeed, however, engineering will continue to serve over the foreseeable future as the backbone of the rich industrial economies.

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Appendix: Some Background on the Complex Dynamics of an Experimentally Organized Economy

This empirical paper has told the story of (1) faster endogenous industrial decentralization ("globalization") facilitated by the *entrepreneurial introduction* (commercialization) of new generic technologies, and the (2) endogenous development of markets for specialized subcontractors that raise flexibility of production through (3) decentralized, individual and often inconsistent ("experimental") decisions in markets. What is going on is not principally new, but faster than before. In this Appendix I therefore discuss the principal relationships between entrepreneurial action at the micro level, and macroeconomic growth in terms of the Swedish micro to macro model, approximating an experimentally organized economy (Eliasson 1991). There is already sufficient evidence from simulation experiments on that model to demonstrate how the three circumstances together can raise long term macro economic growth on an order of magnitude that may warrant the term a new industrial revolution. I have therefore also presented an exercise in quantitative evolutionary economics, or Schumpeterian dynamics governed by the entrepreneurial actions and reactions of large numbers of individuals and businesses with widely different views of what is going on that frequently lead to business failure, but also are needed to capture business opportunities that would otherwise go unexplored. In that sense business mistakes become a necessary standard (transactions) cost for economic development (Eliasson and Eliasson 2005) and policy makers had better learn how to cope with the consequent social change for society to enjoy the benefits of growth. On this I like to talk about a Smith—Schumpeter—Wicksell (SSW) connection (Eliasson 1992, 2009).

The origin of the limits of economic systems understanding and decision failure at all levels, including the policy level, has its roots in complexity, and complexity theory has become a growing field of economic analysis in the Schumpeterian tradition (Frenken 2006; Hanusch and Pyka 2007). Failure, however, at the micro market level in an experimentally organized economy is the mirror image of viable entrepreneurship. An increase in successful entrepreneurial inputs in an economy unavoidably is accompanied by an increase in the business failure rate and should be positively regarded (Eliasson 1992, 2009; Eliasson and Taymaz 2000). So the upshot of my analysis is that understanding and explaining economic growth requires that the analysis be taken down to the micro market level where entrepreneurial dynamics that moves economic growth takes place (Eliasson 2003). The complexity of modelling, however, now escalates out of all bounds.

Beginning from that end it is, however, no longer acceptable to do what is commonly done, namely to reduce theoretical complexity by prior simplifying assumption to come up with models that embody clear single valued conclusions, notably on policy. Such simplification always takes the form of reducing the state space of the mathematical model that controls ones analysis to full transparency. Linearization of the model is one example. The analysis of this paper of an Experimentally Organized Economy (EOE) takes the exact opposite position, namely to *allow a maximum of facts to be brought to bear on a problem by the minimum use of prior assumptions*. This is desired micro to macro complexity theorizing, and I will conclude this brief Appendix by explaining how.

Hume and Locke had loosely discussed the world in terms of *memory*, *logic* and *imagination*. Leibnitz, however, objected. He did not accept any imagination beyond all possible logical combinations of the facts that resided in the memory. Hence, everything according to Leibnitz could be explained through logical manipulation of facts in a defined memory. Kant, however, opened the door again for vision, or "imagination" to enter as a separate dimension of human awareness

(Eliasson 1996a:16f). I have followed Kant and (1) let the unpredictable entrepreneur into exact economic modelling through the imagination slot, and (2) added the possibility that the new technology created by the imagery of entrepreneurs can be learned and thereby expand the opportunities space that corresponds to Leibnitz memory in an economic model, and finally (3) link the entrepreneurial input to economic growth through total factor productivity increase (Eliasson 1992, 1996a:77–87, 114).

On model form an experimentally organized economy is best represented by a class of highly non linear micro (firm) based macro models that feature frequent phases of deterministic chaos, such that the structure of the model cannot be learned from analysing the process outcomes (Eliasson 1991:179; Ballot and Taymaz 1998). For that reason they correspond to the ultimate notion of complexity.

It was long believed that evolutionary processes were deterministic, well understood and predictable, or stochastic and not fully understood, but predictable in expectation (Puu 1989). The discovery of deterministic chaos (Schuster and Just 2005), and that fairly simple non linear deterministic models generated sequences of chaotic and unpredictable events (Day 1982, 1983; Ysander 1981) eliminated the foundation for such beliefs. The problem of determinism is that if we do not know the initial conditions infinitely exactly we cannot determine the orbit. The exactitude by which we can determine (measure) initial conditions therefore determines the nature of predictability, chaos[23] or complexity. A key concept in the analysis of an experimentally organized economy, and of complexity or chaos, therefore is what we assume about the opportunities space, or the space which includes not only all possible logical manipulations of the facts stored in the Leibnitz memory, but also Kant's imagined combinations, or in our terms, the entrepreneurial experimental outcomes.[24] The mathematical term is state space. One side of complexity economics therefore is the limits of measurement, or the exactness with which one can determine the initial conditions of a sequence of events. *Measurement therefore has to be made a key element of theoretical economics*. Limits of economic measurement also prevent us from understanding the dynamics of evolutionary development with sufficient precision to "police" the economy in directions we might want it to take. Seemingly insignificant disturbances today ("the fluttering of the wings of a butterfly in northern Sweden") may with time take the entire European economy in completely unexpected directions.

The increased rate of unpredictable organizational change in the production system of a modern industrial economy invalidates the standard I/O model as a tool of analysis in industrial economics. As the principal theoretical base for my reasoning about the micro foundation of macro economic change I have therefore used my own micro (firm) based macro model which approximates a theory of the EOE (Eliasson 1977, 1991; Eliasson et al. 2004, 2005; Ballot and Taymaz 1998). The endogeneity of growth in that model is defined by the Schumpeterian creative

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[23] Note the relationship between deterministic chaos and stochastic events in Carleson (1991).

[24] They have been entered into the model through genetic algorithms (Ballot and Taymaz 1998).

Table 2 The four mechanisms of Schumpeterian creative destruction and economic growth

1. Innovative entry enforces (through competition)
2. Reorganization
3. Rationalization
4. Exit (shut down)

Source: "Företagens, institutionernas och marknadernas roll i Sverige", Appendix 6 in Lindbeck A (ed) Nya villkor för ekonomi och politik (SOU 1993:16) and Eliasson (1996a: 45)

destruction process shown on "stylized form" in Table 2,in turn kept moving by endogenous competitive entry (Item 1), or the entrepreneurial "imagination" of an experimentally organized economy.

Key to understanding how entrepreneurship can be defined as imaginary inputs is the size (or transparency) of the memory, or the opportunities space of the model. Optimization requires that state space to be small and/or transparent, or be strictly convex with continuous derivaties. The intangible entrepreneur, to exist, requires a non linear model with an immense opportunities space. The large opportunities space furthermore has to stay large and largely unexplored for ever. This defines the origin of the complexity of the model of the experimentally organized economy. Such a model allows for business mistakes, that are by definition excluded from all variations of the I/O model, barring stochastic, insurable business mistakes, a reduced form Frank Knight (1921) called ridiculous (Eliasson 1992:256). The capacity of an experimentally organized economy to keep the full information situation for ever unattainable through economic systems learning I have called the *Särimner effect* in honour of the pig of the Viking sagas that was eaten for supper, only to come back alive next evening to be eaten again. The difference is that the state space of the experimentally organized economy (contrary to the pig) grows from being explored and learned, therefore defining a positive sum game (Eliasson 2005a:42). Antonov and Trofimov (1993) demonstrate on the same model that free experimentation with different, often inconsistent decision models, and flexible structural accommodation of business failure outcompete centrally directed policies, because such policies are always restrictive and tend to eliminate some entrepreneurial winners, which may make a large difference in the long run in non linear models. Eliasson and Taymaz (2000) and Eliasson et al. (2004) furthermore demonstrate that the magnitudes involved at the macro level may take on "revolutionary" dimensions.

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