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Stoelhorst, J.W.

Publication date

2007

Document Version

Author accepted manuscript

Published in

The evolution of economic institutions: a critical reader

[Link to publication](#)

Citation for published version (APA):

Stoelhorst, J. W. (2007). The naturalist view of Universal Darwinism: an application to the evolutionary theory of the firm. In G. M. Hodgson (Ed.), *The evolution of economic institutions: a critical reader* (pp. 233-251). Edward Elgar.

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**The Naturalist View of Universal Darwinism:
An Application to the Evolutionary Theory of the Firm**

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Published in:

-Stoelhorst, J.W. (2005), The Naturalist View of Universal Darwinism: An Application to the Evolutionary Theory of the Firm, In: J. Finch and M. Orillard (eds.), Complexity and the Economy, Cheltenham: Edward Elgar, p.127-147.

Reprinted in:

-Stoelhorst, J.W. (2007). The Naturalist View of Universal Darwinism: An Application to the Evolutionary Theory of the Firm. In Hodgson, G.M., The Evolution of Economic Institutions: A Critical Reader. Cheltenham: Edward Elgar, p.233-251.

The Naturalist View of Universal Darwinism: An Application to the Evolutionary Theory of the Firm

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The purpose of this paper is to contribute to recent efforts to ground evolutionary theory in economics in the principles of Universal Darwinism. The paper contrasts two views of evolution, based on the Ultra-Darwinian and Naturalist theory of biological evolution, both of which are consistent with Darwinian principles. It is argued that the specific characteristics of the Naturalist view make it the better starting point for developing an evolutionary theory of the firm. This claim is substantiated empirically by analysing a crucial episode in the history of the semiconductor firm Intel. The paper concludes that an evolutionary theory of the firm should steer clear of analogies based on mechanisms of biological reproduction such as ‘routines as genes’.

1. Introduction

Nelson and Winter's *An Evolutionary Theory of Economic Change* (1982) is one of the seminal contributions to evolutionary theories in economics. However, as Hodgson (2003) has recently shown, questions may be raised about the way in which Nelson and Winter use evolutionary concepts. Is the use of concepts from the theory of biological evolution a matter of metaphor or analogy, or are there ontological commonalities between social and biological evolution (Hodgson 2002, 2003)? One of Nelson and Winter's achievements is that they ground their evolutionary theory more firmly in the three core Darwinian principles of variety, inheritance and selection than their predecessors in economics (Hodgson 1993, 2003). At the same time, however, they are reluctant to admit to more than the use of analogy. Hodgson argues that more than mere analogy is involved in applying evolutionary theory to economics, and that the Darwinian destiny of evolutionary theory in economics is yet to be realised (Hodgson 2001, 2002, 2003). This claim is based on the promise of Universal Darwinism, which holds that the development over time of any open, complex system can be understood in terms of variation, selection and retention (e.g. Campbell 1965, 1974; Lewontin 1970; Plotkin 1994; Cziko 1995; Dennett 1995).

The purpose of this paper is to contribute to the effort to ground evolutionary theory in economics in the principles of Universal Darwinism by viewing the firm as an open, complex system. Following Simon (1981[1962]), a complex system is seen as a system that is made up of a large number of parts that interact in a way that makes it difficult to

infer the properties of the whole from knowing the properties of the parts and the laws of their interaction. Evolutionary theory applies to open systems: systems that need to secure resources from their environment to maintain their functional integrity, and that may experience selection pressures to the degree that the resources they need to function are scarce. Following a distinction introduced by Eldredge (1995) and Gould (2002), the paper will contrast the ‘Ultra-Darwinian’ and the ‘Naturalist’ theory of biological evolution. While both of these theories are consistent with Darwinian principles, they differ in their outlook on some characteristics of biological evolution that are pertinent to theories of economic change. It will be shown that the Naturalist view captures the ontological commonalities between biological and economic change better than the Ultra-Darwinian view. This is illustrated empirically with an historical case study of semiconductor firm Intel. It will be argued that some of the problems that have emerged from the application of evolutionary reasoning to the theory of the firm originate from the emphasis on genetic reproduction in the Ultra-Darwinian view. The paper discusses how the Naturalist view may help solve these problems, and concludes with an outlook on the development of a theory of the firm on the basis of a Naturalist interpretation of Universal Darwinism.

2. Universal Darwinism

Economists have a tendency to use the term ‘evolution’ in a rather cavalier way, often merely equating it with change. More specific links to Darwinism in economic theory

come in two forms: the use of natural selection as a metaphor for competitive processes that results in the survival of the fitter, and the search for specific analogies to biological mechanisms in such competitive processes (Knudsen 2002). But there is both a need and a possibility to look for more substantive similarities between economic and biological change (Hodgson 2002; Knudsen 2002). Universal Darwinism can take us beyond metaphor and analogy and help elucidate the ontological commonalities between different types of evolutionary processes (Hodgson 2002).

The term Universal Darwinism was coined by Dawkins (1983), and has since been used as a label for the idea that the development over time of any open complex systems can be understood in terms of the same principles that are at the core of Darwin's theory of natural selection (Plotkin 1994; Cziko 1995; Dennett 1995). This use of the term incorporates earlier work by Campbell (1965; 1974) and Lewontin (1970), who suggested that a few general principles of evolution could be derived to explain evolution *regardless* of the specific mechanisms involved.

The 'variation-selection-retention' algorithm captures these principles.¹ Universal Darwinism holds that evolution will occur in a population of entities if there are mechanisms for introducing variation, a consistent selection process, and mechanisms for preserving and/or propagating the selected variants. Note that neither the nature of the selection process, nor the mechanisms to introduce variation or retain selected variants are specified. Herein lies the universality of Universal Darwinism: it presents a generic formulation of evolution that is applicable to any domain.

The implications of this view for the development of economic theory are clear. There is more than biological analogy involved in developing an evolutionary theory of economic change. If the evolution of any complex open system can be understood in terms of variation, selection and retention, then so can firms, economies, and indeed societies. Evolutionary theory in economics should thus uncover the specific nature of economic selection processes, and the specific mechanisms of variation and retention on which they operate.

This view of the role of Darwinism in economics should in principle rid us of discussions about the value of biological analogies in economics. The ontological claim that Universal Darwinism captures the commonalities in the way complex open systems change over time cannot be dismissed by casting doubt on the value of biological analogy. It would in fact be entirely compatible with the notion of Universal Darwinism to accept its principles and not to give biological evolution another thought when exploring the specific nature of variation, selection and retention in the economic realm. However, much of the theorising in evolutionary economics continues to make use of biological analogy.

3. Some problems in applying Universal Darwinism to the evolution of firms

There is some obvious sense in the use of biology in the search for the specific mechanisms of variation, selection and retention in the economic realm. Metaphor and analogy have always played an important role in developing theory, and given the advanced state of development of evolutionary theory in biology, it would be foolish not to use it for inspiration. But whereas the *generic* scheme of variation-selection-retention of Universal Darwinism presents an *ontological* claim with respect to the evolution of all complex, open systems, the use of concepts from biology to illuminate the *specifics* of how variation, selection and retention work in an economic system, brings us back to biological *analogy*.

The use of biological analogy is an important reason for the objections that have been raised against employing Darwinian principles in economic theory. It has been argued that whereas variation in biology is blind to the nature of selection, economic change is driven by intentionality and design, so that (suitable) variations can occur in response to specific environmental pressure (e.g. Penrose 1952). The resulting acquired characteristics, moreover, can be passed on through social learning, so that evolution in the economic sphere has often been seen as Lamarckian. But these differences between biological and social evolution do not contradict that economic evolution takes place through variation, selection and retention. A recent argument about the evolution of human knowledge by Loasby illustrates this point: human behaviour is neither a result of optimal ex-ante choices from known opportunity sets (the neoclassical economic view of human problem solving) because no novelty would then arise. Nor is it a matter of ex-post selection of random trails (the Neo-Darwinian view of biological evolution) because

there is purposeful pre-selection of actions. Yet the growth of human knowledge can be understood as an evolutionary process that combines the generation of novelty and the selective retention of some of the novelties generated (Loasby 2002). In fact, as Hodgson (2001, 2003) and Knudsen (2001) have shown, Lamarckian mechanisms are entirely compatible with the explanatory structure of Universal Darwinism.

Although this conclusion invalidates the most widespread objection to using Darwinian principles within economics, a number of problems remain. Consider the application of Universal Darwinism to the theory of the firm. To understand firms in Darwinian terms, we should specify the specific mechanisms of variation, selection and retention by which firms adapt to their environments. But what is the unit of selection? Is it the firms themselves, is it their products, or is it their routines? And what are the sources of variation and retention? Is there something equivalent to genes in organisations? Something that mutates and is passed on to future generations? Is that what Nelson and Winter (1982) had in mind when they coined the concept of routines? If so, their use of the term to also indicate actual behaviour is confusing (Hodgson 2003), and the notion of routines does not explain why they are persistent (Becker and Lazaric 2002).

Such questions point to the biggest problem in developing an evolutionary theory of the firm on the basis of biological analogy: there are no readily identifiable equivalents of generations and species in the world of firms. The Neo-Darwinian theory of biological evolution hinges on these two concepts, but it seems rather far-fetched to think of firms in terms of generations that pass on their routines. Even if it would make sense to think of

firms in terms of genealogical lineages, an essential part of the explanatory value of the concept of generations in biology is that mutations can only occur between generations, and that genetic information can only be passed down to the next generation. That is, adaptations can only occur as a result of reproduction, and the arrow of adaptation runs in one direction only: from parent to offspring. It is hard to see how this would apply to firms. This leads to a fundamental problem: Why bother to identify the equivalent of genes in firms when there is no offspring to pass them onto? Second, the concept of a species is derived from the inability of a species' members to successfully reproduce with members of another species. Such exclusive reproductive communities do not exist in the economic world. Firms exchange information, employees, assets and routines all the time. They do so by way of different kinds of communication, through hiring practices, mergers and acquisitions, and different types of corporation such as alliances and joint ventures. Again, the analogy breaks down in an obvious way.

Note that both the concept of generations and the concept of species are grounded in the specifics of biological reproduction. The conclusion must be that we should steer clear of analogies based on the genetic mechanisms of biological reproduction. The notion of routines as the economic equivalent to genes, or of industries as the equivalent of species, is metaphorical at best. Given the importance of genetic mechanisms to the modern Neo-Darwinian theory of evolution, one might conclude that it would be wise to abandon biological analogy altogether. But this is not necessarily the case.

4. Ultra-Darwinian and Naturalist views of evolution

Before discarding the theory of biological evolution as a source of inspiration, we should be aware of some of the bones of contention within biology. The problems in applying evolutionary reasoning to the evolution of firms outlined above are mirrored in discussions about the value of alternative views of biological evolution. We will here differentiate between the so-called Ultra-Darwinian and Naturalist views of evolution.

These labels were coined by Eldredge (1995), whose admittedly partisan summary of the two views is that Ultra-Darwinian theory offers ‘a gene centred and essentially reductionist approach to evolutionary explanation’ (p.4), while ‘Naturalists, in contrast, are attuned to the hierarchical structure of biological systems’ (p.6). These different views originate in different professional backgrounds: geneticists and molecular biologists tend to take an Ultra-Darwinian view of evolution, while paleontologists and ecologists typically take a Naturalist view. Of the two, the Ultra-Darwinian view represents the more orthodox and mainstream approach to biological evolution, to which the Naturalists take exception.ⁱⁱ

Although the Naturalist approach to biological evolution is here discussed as an alternative to the orthodox view, it is nevertheless Darwinian. As recently formulated by Gould (2002), it retains the core of Darwin’s theory of natural selection. The issue is *not* with the principles of variation, selection and retention, and the Naturalist view is therefore entirely compatible with the premises of Universal Darwinism. However, it

does take issue with a number of specific points that are central to the Ultra-Darwinian approach to biological evolution. We can summarize the differences between the two views as expressed in Eldredge (1995; 1997) and Gould (2002) in four basic controversies.

1. Smooth, gradual, and cumulative change versus a pattern of punctuation

The controversies between Naturalists and Ultra-Darwinians originate in a debate about the nature of evolutionary change. Ever since Darwin, the orthodox view of evolution has been of a smooth and gradual process driven by the continuous accumulation of small changes at the level of the organism. The Ultra-Darwinian view is that this process can explain all evolution. In 1972, Eldredge and Gould proposed a different view (Eldredge and Gould 1972). It had long been known that fossils did not support the view of evolution as a process of continuous adaptation. Once a species appears in the geological record, it tends not to change much at all. In other words, empirical evidence of the importance of slow, continuous change was lacking. The traditional explanation for this anomaly was that it was the result of imperfections in the fossil record. Eldredge and Gould argued that imperfect as the fossil record may be, the fact that it shows species to exist in largely unchanged form reflects a true phenomenon in nature. They called this phenomenon 'stasis', and went on to propose an alternative theory of evolution to explain it. Dubbed 'punctuated equilibria', this theory holds that an important part of the evolutionary process occurs in relatively short periods of rapid change.

2. Single level versus hierarchical theory

A second, and related, difference in the views of biological evolution concerns the units of natural selection. Darwin's view was that all biological evolution could be explained by natural selection acting on organisms (Gould 2002). His was a single-level theory, in which all higher level order in nature could be explained by natural selection acting on organisms pursuing their own self-interest. Ultra-Darwinians still embrace this view, while Naturalists stress the hierarchical nature of biological evolution.ⁱⁱⁱ The Ultra-Darwinian view of evolution is that the micro-evolutionary mechanisms of organismal selection can be extrapolated to explain all phenomena in life's history. The Naturalist view is that selection acts simultaneously on several levels in nature, and that nature's units of selection include genes, organisms, and species. Moreover, macro-evolutionary patterns may require additional explanations of how selection operates at higher levels of the hierarchy and over longer periods of time. Among such macro-evolutionary patterns is the pattern of punctuated equilibria.

3. Natural selection versus structural constraints

Darwin's theory postulates that natural selection is the sole and sufficient cause of all adaptation (Gould 2002). The fit of organisms, including such intricate structures as the eye, can be entirely explained by how natural selection slowly accumulates the positive effects of favourable variations between organisms over many generations. Gould (2002) believes that there are additional mechanisms at work and calls for the recognition of the importance of structural, historical and developmental constraints in channelling the pathways of evolution. He argues that what he calls 'formalist' thinking in terms of a systems internal architecture should complement the pure functionalism of a strictly

Darwinian and externalist approach. Specific past histories and timeless structural principles can play strong, interesting and indeed 'positive' roles in fashioning certain adaptations. An example of this is 'exaptation', a term devised for the phenomenon whereby existing structures are co-opted for functions for which they weren't originally evolved (Gould and Vbra 1982). Gould (2002) proposes a triangular model to explain adaptive structures, which includes not only the functional forces of natural selection, but also structural forces that arise from principles of good design, and historical forces that originate in past adaptations that now constrain and (positively) direct further adaptation.

4. Reproductive versus economic behaviour

Eldredge (1995) best articulates the last difference between the two camps. He points out that biological evolution needs to be understood in terms of two distinct hierarchical systems. These are the 'genealogical' and 'ecological' system. Organisms basically do two kinds of things: they engage in matter-energy transfer processes to survive, and they reproduce. Eldredge calls the behaviour of organisms related to matter-energy transfer 'economic'. Economic behaviour to secure and process the resources necessary for survival takes place within the 'ecological hierarchy' of proteins-organisms-ecosystems. Relative economic success is a measure of how well an organism copes with its environment – the physical habitat plus the other organisms with which it competes for resources. The 'genealogical hierarchy', which includes genes, organisms and species, is the result of reproductive behaviour. The genealogical and ecological hierarchies are linked through the individual organism, which competes for resources from the

environment in the economic system, and for opportunities to pass on its genes in the reproductive system.

It follows that evolution is essentially the result of differential success in two separate, if ultimately related, biological realms. Where Ultra-Darwinians and Naturalists differ is in the importance they accord to each of them. The Ultra-Darwinian view is that evolution is primarily about success in a reproductive game of passing on genes to the next generation. All competition, including competition for food and other economic resources, is seen to take place in service of reproductive success. In contrast, the Naturalist view is that evolution is primarily about success in the economic game of securing enough energy from the environment. Eldredge points out that most adaptations are in fact economic in nature. Following this view, natural selection is a matter of differential economic success biasing reproductive success.

To Ultra-Darwinians, competition for reproductive success is the driving force of evolution, and not only the genealogical hierarchy, but also the organization of ecological systems can be explained by extrapolating its effects. Naturalists see evolution as primarily driven by economic competition. The structure and organization of ecological systems follows directly from economic behaviour. The economic system depends on the genealogical system only as a constant supplier of players in the ecological arena. What happens in the ecological arena determines the fate of genetic information as it is passed on from generation to generation in the genealogical system. Stasis and change –the fate of that genetic information- is what is appropriately called evolution. Evolution is a

historical process, a record of the changing state of living things. To the Naturalists, the genealogical hierarchy is but a passive reflector of what worked in the ecological arena. Evolution is, in a very literal sense, just history.

It should be noted that the objective of the overview above is not to take sides in the debate that continues to rage within biology. The validity of the Ultra-Darwinian and Naturalist views of biological evolution is not the issue here. What is of concern is how these views can inform economic theory. If the principles of Universal Darwinism hold promise for the further development of evolutionary economics, and if both the Ultra-Darwinian and Naturalist view of evolution are consistent with these principles, then we would do well to ask which view to adopt when drawing on biological analogy. To answer this question we have to move beyond metaphor and analogy, and confront the two theories with empirical data.

5. The case of Intel^{iv}

The name of Intel is now inextricably linked to the microprocessor, a product the company introduced to the world in 1971 and that became the source of its remarkable profitability in the 1990s. But Intel was originally founded as a semiconductor memory company. In 1968, Bob Noyce and Gordon Moore left Fairchild, arguably the most successful semiconductor manufacturer of the 1960s, to start a company to build semiconductor memory products. These products would compete with core magnetic

memory, then the leading technology to store data, for a share of the mainframe computer market. Intel's original mission was to 'design, develop, manufacture, and market advanced memory circuits for digital equipment'. In 1969, Intel established itself as a leader in semiconductor memory by pioneering MOS process technology and producing the world's first SRAM. This memory product was followed in 1970 by a 1K DRAM, and in 1971 Intel introduced the first EPROM.^v Of these three semiconductor memory devices, DRAMs were to become the best selling product. While other firms had also been able to design working DRAMs, Intel's advances in process technology pushed manufacturing yields to where DRAMs became a viable alternative to core magnetic memory. In 1972, Intel's original DRAM was the world's largest selling semiconductor product and over the next three years, DRAMs replaced magnetic cores as the standard in the computer industry, creating a new market for semiconductor products that would quickly outgrow all others.

In 1972, DRAM products accounted for over 90% of Intel's sales revenues, and they remained Intel's core business throughout the 1970s and early 1980s. But in 1988, it was microprocessors and other so-called logic products, not memory, which accounted for approximately 90% of sales. The pivotal event in the company's transformation from Intel 'the memory company' to Intel 'the microprocessor company' was a major crisis in the mid-1980s, which led to the decision to exit the DRAM business in 1985. This crisis had been some time in the making.

Intel's success with the early generations of DRAM devices was based upon its technology development (TD) competence. There are three major types of technological competence involved in producing semiconductor products: technology development, circuit design, and manufacturing engineering. Technology development is concerned with developing the production process. It is a silicon-based competence that involves materials science and device physics, and the sequence of physical steps necessary to put circuit patterns onto silicon. Circuit design is a non-silicon based competence that involves the ability to define circuit patterns on different mask layers, so that the resulting product has a specific functionality. Technology development can roughly be seen as process innovation, and circuit design as product innovation. The third area of technological competence, manufacturing engineering, focuses on achieving high yields of functioning chips. It involves characterizing the production process and learning how to set certain parameters so that a stable process results.

Because it had made the difference in its initial success, Intel naturally viewed TD as its distinctive competence. Moreover, in DRAMs, process technology development was initially clearly the linking pin between the other two competencies. DRAMs require a very tight relationship between circuit design and TD. Unlike logic chips like microprocessors, the design and the process are developed together. Moreover, in the early stages of the DRAM industry, when production volumes and minimum acceptable yields were relatively low, the differences between the activities and concerns of TD and manufacturing engineering were not that salient. As a result, Intel could develop a distinct way of integrating the two by keeping them together in the production facility

and by performing all process technology research directly on the production line. This approach emerged from the previous experience of Intel's founders at Fairchild. They felt that one of the biggest problems at Fairchild had been to transfer technology developed in a research lab to the operating organization.

Intel's approach of letting new process development take place on running production lines initially resulted in the ability to make rapid process changes that helped Intel stay ahead of its competitors. By thus exploiting its TD competence, Intel's strategy could emphasize being first to market with premium-priced products and quickly moving into new markets as existing ones matured. In light of this strategy it was a source of pride to Intel's manufacturing engineers that they were able to run manufacturing processes that were not entirely stable and still achieve acceptable yields.

Throughout the 1970s, Intel's competitive strategy kept successfully emphasizing innovative TD efforts, and even in the early 1980s, the company introduced a number of innovative memory products. But at the same time, its position in DRAMs, the main memory market that it had dominated in the early 1970s, was rapidly eroding. Intel's market share fell from 20% in 1976, to 3% in 1980, to a little over 1% in 1984.

As the DRAM technology had matured and the market had grown, the basis of competition had slowly shifted to the ability to rapidly move into volume production and achieve very high yields of each new generation of DRAMs as quickly as possible. The changing rules of the game put a strain on the integration between Intel's TD and manufacturing groups and called into question the way Intel had chosen to innovate.

TD's scientists, Intel's early technical heroes, continued to see their task in terms of introducing process innovations, revolutionary change, and technical elegance, whereas manufacturing engineers became increasingly aware of the importance of stability in their processes, incremental change, and technical simplicity. It became increasingly disruptive to carry out process technology development on the production lines, and process yields would often dip after the introduction of a new technology, an effect that was internally known as the Intel 'U'.

In the mean time, another important development had taken place. As semiconductor memory was becoming a viable alternative to magnetic core memory, Ted Hoff, one of Intel's new recruits, invented the microprocessor. In 1969, Hoff was given the assignment to design a chip set for a new line of desktop printer-calculators for a Japanese firm called Busicom. Busicom chose Intel, at the time no more than a small components manufacturer, because of Intel's advanced MOS process technology, the fruits of its early TD efforts. The work on what would become the first microprocessor began as a typical custom design job, but one with a complication. As the project got underway it became clear that what Busicom really wanted was a number of different calculators, one for scientific, one for business, and one for general applications. This meant that a large number of chips had to be developed and Intel simply did not have enough MOS engineering staff to handle the job. Moreover, Hoff, who had a background in minicomputers, became convinced that Busicom's approach, which needed at least five chips for each calculator, was too complex to be cost effective. He thought that the number of chips could be reduced by implementing the more complicated logic steps as a

program in memory, as opposed to designing them into the hardware. While Busicom was, at least initially, not very enthused by Hoff's idea, he did get the support of Intel's management, and was able to further develop the concept. Hoff's idea was to combine supporting memory devices containing special purpose instructions with a general purpose logic device. After nine months, a four-chip design, consisting of a central processing unit (the actual microprocessor), two memory chips and an input-output device was ready.

The successful completion of the project was cause for much debate within the company. In fact, there was strong pressure to drop the thing. Wasn't Intel a circuit maker concentrating on memory chips? Here, in contrast, was a whole system, and who would want to buy it except for maybe some minicomputer firms? Gordon Moore, Intel's CEO, was among those who did not immediately see a use for the product. Ed Gelbach, a newly hired marketing director from Texas Instruments, was one of those who understood that the application of this innovation would be in entirely new markets and could be pervasive. He later commented that the company initially saw the product as a way to sell more memories. Hoff's design, after all, replaced logic with memory. However, soon after Intel launched its first microprocessor in 1971, the product became recognized as a useful addition to Intel's product line and was actively marketed. By 1980, Intel had moved on to the third generation of microprocessors, the 16-bit version. Facing stiff competition from Motorola and Zilog, the company made what would later prove to be the most important sale in the company's history when it convinced IBM to choose an Intel processor as the heart of its personal computer.

Despite the fact that by the early 1980s Intel's market share in DRAMs had been decimated, and although the company found it increasingly difficult to compete in this maturing market, there were strong forces that kept Intel from exiting the business. There was, first of all, the emotional attachment to the product that had made Intel, 'the memory company', a success. Moreover, while in 1984 DRAMs accounted for no more than an estimated 3% of Intel's \$1.6 billion sales, they were still the largest volume product produced by the company, and CEO Gordon Moore supported the idea of DRAMs as the basis of the company's learning curve. In light of these concerns, R&D funds continued to be routinely allocated to the DRAM business. In fact, budgeted expenditures for R&D were evenly divided between DRAMs and Intel's two other businesses, EPROMs and microprocessors.

While official corporate strategy thus kept emphasizing the DRAM business, Intel's day-to-day decisions were being taken in an environment that favoured open debate, constructive confrontation, and the rule that knowledge of the issues at hand should never be overwhelmed by hierarchical position. This resulted in a number of incremental decisions by middle managers that were undermining the idea of Intel as a memory company. An important role in this process was played by a capacity allocation rule that was used to decide which of Intel's three product lines, DRAMs, EPROMs, or microprocessors, would be allocated maximum production capacity. Most production facilities could produce all these product lines, and production capacity allocation decisions were made every month. The criterion used was to maximize the so-called

‘margin-per-wafer-start’. Involving a complex calculation, this decision rule, consistent with Intel’s historical emphasis on premium-priced, leading-edge products, would systematically lead to the selection of niche products over commodity products. Reflecting Intel’s competitive advantage in microprocessors, the maximum margin rule led to a gradual change in favour of microprocessors over memory products in those production facilities that could produce both. By 1984, DRAM production had in actual fact been reduced to one plant out of a network of eight. While this situation was the result of the accumulation of a stream of incremental decisions with respect to the allocation of resources in manufacturing, in the same year, middle managers also made a key decision in R&D. This decision was to adopt new process technology that inherently favoured advances in logic over advances in memory. With this decision, resource allocation in favour of the microprocessor business by middle management went beyond manufacturing capacity and into the heart of the company’s TD efforts.

By the end of 1984, top management finally faced up to the changes in the competitive environment for DRAMs. To regain leadership with the next generation of DRAMs would require several hundred million dollars, and in November 1984, Intel management decided not to put the new DRAM product that was under development in production. In October 1985, the company decided to stop producing DRAMs altogether. An important moment leading up to these decisions was when Andy Grove, then COO, asked CEO Gordon Moore what new top management would do if he and Moore were replaced. The answer was clear: Get out of DRAMs. Grove then suggested to ‘go through the revolving door, and just do it ourselves’. However, to articulate a new strategy was one thing, to

realise it something else. Between November 1984 and October 1985, Intel's top management struggled with implementing the exit decision. The existing organization impeded implementation as those who were asked to make the changes were in fact being asked to make themselves less important. The general manager of the Components Division, for instance, who had joined Intel from Texas Instruments, a company known for its volume production orientation, had strong feelings about the importance of DRAMS as a commodity business for Intel. But in the summer of 1985, Grove prevailed and this manager stepped down as Grove imposed change by restructuring the organization and reassigning senior managers and R&D staff.

After a dismal 1986, Intel's turn-around started to pay off. By 1991, it had almost quadrupled its sales, doubled its profits, and enjoyed operating margins of 18% to 25%. The development of the personal computer market had led to an unexpected boom in microprocessor sales and the success of the IBM PC had made Intel's microprocessors a *de facto* industry standard. Andy Grove later commented that if Intel had foreseen the dramatic growth of the personal computer business, it might have been easier to exit the memory business. By 1992, Intel was the biggest semiconductor firm in the world.

6. An evolutionary interpretation of Intel's history

What does the Intel case tell us about the validity of the Ultra-Darwinian and Naturalist views of evolution in the economic realm? Which of the views best corresponds to the

empirical data? To differentiate between them, we need to ask what Intel's history tells us about the pattern of change, the unit of selection, the sources of adaptation, and the role of competition for economic resources versus competition for reproductive success in the evolution of a firm.

The pattern of change

Intel's history shows how the company evolved through a period of incremental change that lasted some 14 years, followed by a compact period of two years, in which a wholesale strategic reorientation took place. The pattern of organisational change at Intel was one in which its early innovative behaviour provided the basis for a relatively long period of success, lasting some seven years, followed by an equally long period of mounting performance pressure on its memory product line, the original mainstay of the firm. Organizational change during these periods was largely of an incremental nature. As the basis of competition in the market for DRAMs was changing, inertial forces in the company hindered adaptation. Eventually, however, the performance pressures on Intel's DRAM products threatened the survival of the entire firm, and the company went through a period of radical change. In a relatively compact period of two years, Intel was able to overcome the inertial forces within the firm and transform itself from a fledgling memory company to a leading microprocessor firm. Intel did not adapt to changing environmental pressures through a continuous, smooth and gradual process of change, but through a process of incremental change punctuated by a major reorientation.

The unit of selection

The Intel case shows how a variety of selection processes interacted to produce the punctuated pattern of change outlined above. There were performance pressures on both the firm's individual product lines and the firm as a whole. It was the selection pressure on the firm as a whole that triggered the major strategic reorientation of the mid-1980s, but most of the firm's history can be understood in terms of a struggle for resources at the level of product lines. Product lines obviously competed in product markets, and it was the lack of profitability of DRAMs that put pressure on the firm as a whole. But product lines also competed for resources *within* the firm. Such competition for resources included competition for managerial attention, production capacity, R&D funds, marketing budgets, and the attention of the sales force.

This brings us to an important point. The Intel case shows that the competition for resources that needs to be taken into account to understand the company's evolution is not limited to competition in the market. There is competition for resources within the firm as well. At this level of analysis, the selection pressure is not exerted by the market, but by managerial beliefs, the firm's stated strategy, and routines such as the decision rules to allocate R&D funds and production capacity. Routines, beliefs, and strategies are thus a source of selection pressure. But the history of Intel also shows that these same routines, beliefs and strategies can change because they are themselves subject to selection. This is what happened when competitive pressures on one of the company's product lines called into question the firm's entire strategy and the strategic reorientation resulted in a new set of routines and beliefs. We may conclude that there are different units of selection, with recursive relationships between them. In keeping with the

Naturalist view, the Intel case shows that only a hierarchical theory can hope to capture the ways in which selection works to produce organizational change.

The sources of adaptation

Intel's history shows that both external and internal factors fashioned the firm's specific adaptations to its environment. External market pressure eventually weeded out beliefs, strategies and routines that, although initially adaptive, had, under changing competitive conditions, become detrimental to the firm's existence. Examples are the organizational arrangement to undertake technology development on the production line, the stated strategy of 'Intel the memory company', and the belief in DRAMs as the driver of the learning curve. These examples show how internal factors can be inertial forces that can only be overcome by strong selection pressure, and thus corroborate the importance of the functional forces of natural selection emphasized by the Ultra-Darwinian view.

But there is also clear evidence of internal factors acting as positive pathways to adaptation. A case in point was Intel's MOS knowledge. It was the company's lead in MOS process technology that led to the microprocessor that would be the pivot of its later turnaround. It not only attracted the Busicom project, but also made the circuit density required for the first microprocessor possible. Another example is the rule for allocating production capacity, which moved Intel away from producing DRAMs when its officially stated strategy still focused on memory products, and thus helped prepare the way for the transition from 'Intel the memory company' to 'Intel the microprocessor

company'. These historical and structural forces are a necessary component of an explanation of how Intel eventually adapted to changes in its environment.

The nature of competition

The history of Intel is rife with the sort of economic competition for resources that the Naturalists see as the main force of evolution. But what was the role of competition for reproductive success, the driver of evolution in the Ultra-Darwinian view? We would be hard pressed to find an analogue of this type of competition in the Intel case. Intel did not compete to pass on its routines to a next generation. Adaptation did not take place by accumulating favourable variations along a genealogical lineage. It was the firm itself that adapted. Over time, Intel continuously incorporated different kinds of knowledge and beliefs into the organization. Its founders started the company on the basis of their experience at Fairchild. Ted Hoff, with his background in minicomputers, was hired and invented the microprocessor, and Gelbach, hired from Texas Instruments, helped convince Intel's top management of the market potential of this new product. The company also changed its routines. The organizational arrangement of doing process development on the production line was eventually abandoned, and when performance pressures mounted, the firm even changed its strategy. Variations thus occurred during Intel's lifetime, rather than between generations. And the company evolved as some of those variations, sometimes under pressure from the market, took hold in the firm's internal selection environment.

7. A prospective outlook for an evolutionary theory of the firm

The Intel case suggests that the Naturalist view captures the nature of economic evolution better than the Ultra-Darwinian view. The Ultra-Darwinian view of evolution as a smooth process of single-level selection for reproductive fitness does not correspond to the historical data. The Naturalist view does. The history of Intel can be understood as a multi-level selection process for economic fitness that results in a punctuated pattern of change. This leads to three suggestions for an evolutionary theory of the firm.

An evolutionary theory of the firm should steer clear of genetic analogies

Following the Naturalist's recognition of the central role of economic competition in explaining evolution, the evolution of the firm is best seen as driven by the competition for scarce resources. There is indeed a close analogy between natural selection in biological evolution and competition between firms. But while *selection* may be seen as operating in a similar manner as in biology, *variation* and *retention* are the result of very different mechanisms than those that govern biological evolution. The fact that there are no generations and species in the economic realm has been recognized (e.g. Nelson 1995; Witt 1999; Nooteboom 2000), yet the notion of 'routines as genes' (Nelson and Winter 1982, 2002) lingers. This is an unfortunate analogy because there is no equivalent to biological reproduction in the world of firms. The search for a firm's 'genes' is therefore bound to lead to confusion.

An evolutionary theory of the firm should recognize the hierarchical nature of selection

The Intel case suggests that the behaviour of individual employees, each with their own personal histories, knowledge and beliefs, is the source of variations that fuel the process of evolution. The case also suggests that retention works by way of institutionalising behaviour that works in decision rules, organizational arrangements, officially stated strategies, and other elements of the firm's internal organization. This leads to a hierarchical view of selection, in which the market puts selection pressure on the firm, and the firm's internal organization puts selection pressure on the behaviour of individual employees (cf. Burgelman 1991; Campbell 1994; Loasby 1998; Knudsen 2002). Intel's history suggests that a substantial amount of a company's evolution is fashioned by this internal selection environment. Competition for resources takes place at different levels of analysis. The firm and its products compete in external markets, but business units, product lines, and departments also compete in an internal selection environment where scarce resources such as investments, R&D funds, marketing budgets, production capacity, sales force efforts, and managerial attention are sources of selection pressure.

An evolutionary theory of the firm should be able to explain punctuated equilibria

Intel's history confirms the Naturalist's view of evolution as a process that leads to patterns of punctuated equilibria. This is consistent with patterns of change that have been documented in research on organisational change (Miller and Friessen 1980; Tushman and Romanelli 1985; Gersick 1991; Romanelli and Tushman 1994). The role of historical and structural constraints can help explain this. Firms need strategies, organisational arrangements and decision rules to coordinate the behaviour of their

employees. There are, to paraphrase Gould's (2002) 'formalist' view, timeless principles of good organisational design that cannot be ignored without jeopardising the functional integrity of a firm. However, organizational arrangements that were once adaptive can also become a source of inertia that stifles adaptation when external conditions change (cf. Leonard Barton 1992). Firms are likely to have vestiges of bureaucracy that are no longer adaptive, but structural constraints may limit the ways in which such historical constraints can be overcome. Small changes in any one of the elements of the firm's organisation may not be possible without affecting the firm's ability to function. Strategies, organisational arrangements and decision rules are interdependent, and adaptation to changing circumstances may well require a 'quantum change' in their configuration (Miller and Friessen 1982).

8. Conclusion

Evolutionary theory in economics can benefit from being grounded in Universal Darwinism. There are, however, different views of evolution that are consistent with Darwinian principles. Confrontation of these views with empirical data should decide if they can inform economic theory. The history of Intel suggests that the Naturalist view of Darwinism captures the ontological commonalities between biological and economic evolution better than the Ultra-Darwinian view. The Naturalist view suggests an evolutionary theory of the firm that recognizes punctuated patterns of change and the hierarchical nature of selection, but steers clear of analogies based on biological

reproduction such as ‘routines as genes’. We may conclude that the principles of Universal Darwinism offer a useful *ontological* claim about how complex open systems change over time, that the Naturalist view of biological evolution offers useful *analogies* in the search for the specific mechanisms of variation, selection in retention in the economic realm, but that the appropriate role for genetics in developing economic theory is *metaphorical* at best.

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ⁱ There are different versions of these general principles. Hodgson (2002, 2003) has embraced the formulation in terms of variation-selection-inheritance, which is closest to Lewontin's (1970) formulation. For reasons that will become clear below, I will here use variation-selection-retention, which is closest to Campbell's (1965, 1974) formulation and takes us further away from the genetic overtones of the term inheritance. A still more general formulation may be generate-test-retest (See Plotkin 1994, pp. 82-85).

ⁱⁱ Eldredge (1995) designates people like John Maynard Smith, Richard Dawkins and George Williams as typical Ultra-Darwinians, and Stephen Jay Gould, Elisabeth S. Vbra, and himself as typical Naturalists.

ⁱⁱⁱ Among the Ultra-Darwinians, Dawkins (1976) has developed a view of evolution in which selection operates on 'selfish genes' as opposed to organisms. Eldredge and Gould welcome his ideas as a contribution to unravelling evolution's hierarchy, but dismiss his reductionist claim that all of evolution can be extrapolated from the selection of genes.

^{iv} This narrative is based on a more detailed history of Intel in Stoelhorst (1997). The sources for that history include accounts of (former) Intel employees (Noyce and Hoff 1981; Davidow 1986; Grove 1996), case studies (Cogan and Burgelman 1994; Froot 1994; Laurie, Huston and Yoffie 1994), and two strands of academic research by Jelinek and Schoonhoven (1990) and Burgelman (Burgelman 1991, 1994; Burgelman and Grove 1996).

^v Semiconductor memory devices come in two basic varieties: volatile devices that lose their content when power is switched off, and non-volatile devices that hold pre-programmed content. Random access memories are volatile devices that can be further divided into DRAM (dynamic access memory) and SRAM (static random access memory). SRAMs are faster and easier to use than DRAMs, but DRAMs can

store more information. DRAMs are best known for their use as the internal working memory of personal computers. Read only memories (ROM) are non-volatile devices that are typically used to store fixed programs and instructions. Their memory content is usually programmed during manufacture of the chip. EPROMs (erasable programmable read only memory) are a type of ROM that offers the flexibility to change the stored program after the chip has been manufactured.