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The Evolution of Technology

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The Evolution of Technology. Memetics: A Literature Review

Kelly Cooper, Honors Thesis

Does the evolution of technology follow the same model as evolutionary biology? On the surface level, they do appear to be analogous, as the variation, selection and retention processes seem relatively similar. Additionally, both models utilize the concept of adaptation through a changing environment. While there are a wide range of biological analogies that can be seen throughout the rich history of technological evolution, most notably, speciation, convergence and drift, likewise, there are also a wide range of disanalogies, highlighting fundamental differences between the two. This literature review will present arguments from various scholars spanning the past few decades, then based on presented evidence, draw a conclusion about the likelihood of the evolution of technology following the same model as evolutionary biology.

Before presenting the evidence, it is important to define the slightly convoluted terminology used while discussing the evolution of technology. Genes are the “replicators” in biological evolution, that is, the entity that is copied over time. Genes are constructed of DNA, a long strand of nucleic acids that code for mRNA (messenger RNA). mRNA is eventually translated into proteins, which makes up the phenotype, or the actual physical characteristics of an organism, such as hair color or height. According to Ziman (2000) the genotype – the genetic makeup of an organism - essentially contains the instructions for how to build an organism, but it only has meaning if the DNA is read correctly and through its interaction with its environment, a process known as phenotypic manifestation. Variation occurs through mutations in the DNA sequence, ranging from a single base difference to insertions and/or deletions. Different DNA coding corresponds to different instructions, and therefore, a different organism. Following the theory of evolution, certain organisms with particular instruction sets will prevail given the

selective advantages they have, such as a bacteria with an antibiotic resistance. These variants will then pass on that particular portion of the instructions, with the corresponding advantage, to their offspring, a concept known as retention.

Cultural evolution can be seen as a bridge between biological and technological evolution. Dawkins (1976), a pioneer in the broad discipline of "memology" coined the term "meme" to describe the replicator of cultural evolution (as genes are the replicating units in biological evolution). Memes can be anything from a simple idea, to a song, to ways of building things. Dawkins (1976) contends that just as genes replicate within organisms via sperm and egg, cultural memes propagate in the meme pool by leaping from brain to brain, in a process called imitation. Once in a new brain, the brain acts as a vehicle for further propagation. This can occur in a number of ways, such as a song being played on the radio, a professor giving a lecture, or a scientist writing in an academic journal. The most important difference when comparing a meme to a gene resides in a concept called copy-fidelity, or the accuracy of transfer. Aside from a few random mutations, DNA replication is considered high copy-fidelity. However, when you think about the children's game *Telephone*, every time an idea is passed between people, it changes a little bit. Dawkins posits Darwin's theory of survival of the fittest to illustrate this point: while most scientists understand the theory, very few recite Darwin's original words written centuries ago. But all scientists have a similar enough idea that the theory still prevails. This is a prime example of concept-fidelity. Dawkins believes that those small and insignificant alterations of the theory are not included in the "meme." Memes do not transfer with 100% accuracy in the meme pool; instead, they transfer with just enough accuracy that the *general idea* of the meme persists.

The replicator of technological evolution is the artifact, a tangible cultural object. Ziman (2000) contends that the evolution of technology is not just limited to material objects, but rather includes technical procedures related to the material objects (such as a farming routine, where the procedure is just as important as the artifact). Hence, he believes a thorough model of technological evolution would have to include all of cultural (social) evolution as well. However, for simplicity, Ziman believes the artifacts co-evolve within their changing social contexts, so he writes solely on the evolution of material objects.

More specifically, Fleck (2000), Ziman's co-author, believes the unit of technological evolution is the artifact-activity couple. Both the artifact and human agents (the activity) are required for an effective replication of technology. Memes (ideas) are broad and elementary, but they replicate and shape the actual artifacts. For example, the idea of successful hunting and gathering facilitated the production of a hunting spear, an artifact. Together, memes and artifacts represent knowledge. The *replicator* (the artifact) passes its intact structure through a series of replications, and an *interactor* (the activity, or human agents) interacts with both its environment and the artifact in a way that causes said replication. The interactor is required for successful replication of the artifact, and Fleck (2000) claims neither one of those individual entities are sufficient units of replication on their own. It is the combination of the artifact elements and human activities in which elements are utilized (the couple) that is the key to successful replication.

Although these replicators are quite fluid, the artifact is static, and by itself lacks the vitality for successful replication. Human intermediaries (the interactors who contain the knowledge, skills, resources and organizational systems) are the entities which actually select artifacts for replication, and they only survive within the system of human practices. Thus, Fleck

(2000) maintains that artifacts are not self-contained, but rather exist within the system of human practices. As the artifact cannot replicate without the interactor, Fleck argues that casting artifacts into the role of "genes" does not suffice. Genes and artifacts do not form a 1:1 analogy.

Along similar lines, Fleck (2000) argues that memes, like artifacts, cannot be synonymous with genes (which are self-replicating because they do not require human intermediaries for successful replication.) Furthermore, memes rely purely on ideas, and those ideas are only one part of the "technology complex." This complex includes all elements that encompass the core purpose of the technology, such as how to build, use, maintain and replicate. However, the mere *idea* of a new technology does not equate with that idea's execution in the real world, something vital when studying the evolution of technology. Ideas alone do not replicate if there is no effective action in the real world. Like artifacts, ideas are static and rely on human practices for expression; the idea of a beautiful piano concerto means nothing without a composer and an orchestra to bring the music to life. Consequently, knowledge by itself, as the replicator, is insufficient. This is further evidence to support the artifact-activity couple: memes, like artifacts, are non-self-replicating and rely on human interactions to be replicated. This is why memes and artifacts cannot be synonymous with genes (which *are* self-replicating) when comparing the two distinct classes of evolution.

To illustrate the artifact-activity couple, Fleck (2000) discusses the evolution of a basic hand tool. While the physical tool constitutes the artifact, the knowledge of how to operate and maintain the tool constitutes the activity. Without these activities, there could be no replication of current designs or development of new ones. The artifact-activity couple is indeed self-replicating, as it contains the raw material as well as the human cognition to replicate it.

It is also important to discuss the selection process. In both biological and technological evolution, selection occurs via the environment. According to Mokyr (2000), selection must always exist as part of a Darwinian system. Only a certain number of organisms can survive in an environment, and there will always be more organisms produced than can survive. As noted before, in biological evolution, the genotype (genetic code) constrains the phenotype (physical characteristics), but does not completely dictate it, as the phenotype interacts with the environment. Hence, the environment selects the phenotype with the best chance of survival. The environment does not physically select a phenotype; rather, certain characteristics of the environment, such as food sources, temperature or hiding places, are more accessible to certain phenotypes. Those phenotypes will flourish and pass on their characteristics to the next generation. If the environment greatly changes, a different phenotype might be better adapted, slightly altering which genes are passed on, as it selects a different phenotype.

How does this relate to the evolution of technology? Mokyr (2000) postulates that the store of useful knowledge regarding an artifact (i.e., a hand tool) dictates the set of useful techniques to produce the artifact, much like the genotype and phenotype relationship. In Mokyr's analogy, the "phenotype" is the technique, or a set of instructions involving production. Changes in the technique lead to changes in the artifact. The technique contains characteristics that can be selected for or against depending on the environment. Different environments may require different instructions on how to create a product (i.e., the artifact). Mokyr further posits that in biological evolution, mutations in genes (or changes in the DNA code) are parallel to changes in knowledge in the context of technological evolution. Similarly, in both forms of evolution, most of these mutations, or knowledge changes, are not seen in the phenotype. That is, most mutations that arise are deleterious and new knowledge will most likely not produce a new

technique. But, in response to a changing environment, those mutations could prove useful. Likewise, new knowledge can be utilized to change a technique if it is useful in a given situation. To further explain techniques, Mokyr (2000) uses the example of methods of skinning a cat. If there exists more techniques than cats, there is a clear selection process that will occur based on efficiency, cost, etc. Because the environment constantly changes, there must be continuous adaptations (variations) in the technique to assure suitability to various environments. As in organisms adapting to their environment, technology must also adapt to a similar, ever-changing environment, which includes social, economic and historical factors. For the purpose of this paper, the “environment” will indicate the consumer market. The consumers, as part of the consumer market, consciously choose which products are produced and how, simply by where they choose to spend their money. Companies are constantly trying to alter their technique for producing goods to balance both consumer happiness and company profit. If a technique does not produce a product with an acceptable cost/benefit profile, it will not prosper in the consumer market. Furthermore, a new product will be selected for that can accommodate the needs of the current consumer environment. This parallels to how a new trait will be selected for that better fits the environment in the context of biological evolution.

Throughout the rest of this literature review, I will discuss further similarities and differences between the processes of biological and technological evolution, and in the end, decide if there is enough evidence to conclude if they both follow a similar Darwinian system of evolution. I will present the arguments from scholars on both sides of the aisle.

The beauty of comparing a complex process, such as technological evolution, to a different, equally complex process, such as biological evolution, is that the latter has been studied for centuries, well before Darwin. With that comes the vast processes and well-studied

models that have been tested both via simulation and through real-world observation for many years. Kirsh (2010) believes that the evolution of artifacts can be explained by natural selection through comparison with similar processes outlined in Optimal Foraging Theory. This theory states there are optimal behavioral strategies that allow an organism the best chance of survival given all factors within its environment.

To lay the groundwork for this comparison, Kirsh (2010) posits that artifacts evolve to attend human need. When incompatibilities arise in the environment, humans are prompted to adjust their practices to fix the issue. Furthermore, latent, or unforeseen, uses of these artifacts drive new or adjusted practices. Along the same lines, humans acquiring new skills stimulate the evolution of better designed products. Kirsh's idea is based on the concept of "Artifact Optimality" in which artifacts are designed to fix a specific problem, in such a way that the best suited, or optimal artifact prevails. In sum, Kirsh is trying to explain how artifacts evolve such that they are the most optimally designed in a consumer market.

Much the way organisms live and thrive in their ecosystem, Kirsh (2010) believes that there are many components to the "artifact ecosystem," including tasks, practices, users, and the environment. These components interact and co-evolve in the process of artifact evolution. All of these components constrain each other, and eventually dictate how an artifact is to be used and in which conditions it has the best chance of survival. Kirsh also noted that the optimal, or absolute best, artifact is not necessarily the most prevalent, illustrating the complex interactions of all components of the ecosystem. This boils down to the users being the ultimate selectors for the artifacts; they may select one that does not address the problem as well, but offers some other advantage the user finds appealing. The artifact ecosystem is less clear-cut than the biological

ecosystem; there are more interacting forces, one of which is human cognition, an ever-changing selector that has multiple social and economic influences.

In the biological ecosystem, organisms must interact with members of the same species, different species (e.g., predators), their abiotic environment, as well as many other entities in order to find food and shelter and eventually successfully reproduce. Optimal Foraging Theory states that given all the factors the organism must interact with, there are optimal behavioral strategies that will allow the best chance of survival. Kirsh (2010) explains this by using a "model" organism: there is a certain amount of time this animal must sleep and eat to be able to maintain its metabolic rate. There are very particular strategies this animal can employ to optimize this process and obtain the largest surplus of energy. That energy surplus gives the animal the highest chance of reproducing and passing on its genes, as it gives the animal an advantage in any number of adverse conditions. The energy surplus is used as a metric to compare the optimality of an animal in their ecosystem.

To continue exploring his hypothesis in artifact evolution, Kirsh (2010) contends there must be a similar metric to dictate if potential design A is more optimal than potential design B. He believes there are many metrics consumers take into account, such as cost, quality, or appearance. At any given time, consumers dictate what is optimal. As better products are introduced, consumers may change the core values that interest them, leading to new products becoming optimal in that market. Alternately, the producers of the artifact could alter the design to better fit current consumer values, thus, designing it to be more optimal. Theoretically, a company could produce a product maximizing all the previously stated metrics (e.g., a product could be made with the best quality material, best design, best performance, ideal size, etc.) but, because the cost to the producer is significantly increased, the cost of that product to the

consumer could be maximized as well. That product would not survive well in the market for the average consumer as it does a poor job at optimizing the cost/ benefit profile. The cost/benefit profile, like its name states, seeks to maximize benefits while minimizing cost, a strategic balancing act between consumers and producers. Likewise, the animal from the previous paragraph could potentially optimize every aspect, such as sleeping, traveling and foraging, but a similar balancing act must occur which conserves the most energy while maintaining a livable energy expenditure. Kirsh (2010) contends this idea is enshrined in basic economic theory. At the end of the day, consumers will ultimately decide what product best fits their idea of the cost-benefit profile based on what metrics are most important to them.

As discussed previously, in the complex interactions within the artifact ecosystem, the most prevalent design may not be the most optimal. This is also true in biological evolution, as it may take many generations to select a trait better suited to the current environment; thus at any given time, there may be a sub-optimal trait in use. Kirsh (2010), the theory of economics, and biological evolution all posit that over time the optimal design will prevail if the entity continues to persist in its given environment. Producers and consumers will both interact within the consumer market to eventually settle on a product with the most optimal cost-benefit profile.

To summarize, Kirsh (2010) explains how the evolution of artifacts follows the mechanism of natural selection, as artifacts are optimally designed. Changes to the design are driven by changes in consumer value and practices as well as alterations to the cost-benefit profile. New artifacts could be selected if they have a lower cost or better benefit than their predecessor. Likewise, animals change their behaviors to minimize energy expenditure or maximize energy gain in certain situations. I believe Kirsh (2010) did an excellent job in his analysis and comparison. Furthermore, I feel this is a strong line of evidence supporting the idea

that technological and biological evolution follow similar models, as both utilize a process of optimizing the cost-benefit profile to prevail.

There has been an uptick in research surrounding the optimization of the cost-benefit profile. Yoon (2019) proposed an agent-based simulation which can predict technological change by employing themes seen in biological evolution. This simulation seeks to predict the evolution of an artifact based on the interactions and decisions between producers and consumers (the "agents"). Yoon (2019) and Kirsh (2010) support the same thesis: products evolve in their environments through interactions with consumers, producers and the economy. This research is significant as it utilizes a computer model, rather than only theory and logic, to apply the theory of evolution to technological change. Statistics and computer models allow one to generate tangible data. Additionally, this proves valuable to the economy and producers, as different market scenarios can be simulated to see the trajectory of a potential product or industry. More specifically, this paper explores the many similarities in the selection process between biological and technological evolution.

As discussed previously, Mokyr (2000) postulated that the store of useful knowledge constrains the set of useful techniques, much like the genotype and phenotype relationship in biology. In his analogy, the phenotype is the technique, or a set of instructions involving production. Yoon (2019) utilized the analogy of Nelson and Winter (1982), which contends the genotype is the decision-making power of producers and consumers, and the phenotype is the artifact itself. Nonetheless, the particular definition does not matter because both posit that the decision-making power by consumers and producers will alter the set of instructions, which directly change a product (thereby producing artifact variation). More specifically, Yoon (2019) maintains producers gather information regarding consumers' purchases, which the producers

then utilize to generate a new product. To summarize Yoon's definition: changes in phenotype (i.e., products) are due to alterations in the genotype which is directly related to decisions of consumers and producers.

In biological evolution, the selection process is divided into both internal and external selection (Whyte 1964). After a mutation in the DNA, internal selection dictates if this mutation survives, as the majority of mutations are significantly less fit (less likely to survive and reproduce) than the previous iteration. If the mutation is stable enough, the organism's corresponding features will be altered, and it will encounter external selection in the environment. External selection refers to possible encountered adversity in the environment, as organisms with a beneficial mutation will be more likely to pass their genes to the next generation. Product evolution shares a similar model: internal selection begins with decision-making processes from a firm (another term for producer) which alters a product, much like a mutation alters an organism. Then external selection occurs when the product is in the consumer market and its survival in the "environment" is determined by consumers' purchasing decisions. According to Yoon (2019) the more a product is purchased, the higher fitness it has. Firms create variation by releasing a wide range of products; firms then retain only a certain number of those products based on consumer purchase decisions mediated through price and quality (or the cost-benefit profile). Essentially, the decision-making power of the consumer (purchasing) constrains the decision-making power of the firm (what new products are developed and released).

Yoon (2019), like Kirsh (2010), also discusses the interaction of the complex artifact ecosystem. Kirsh posits that artifact evolution is influenced by human cognition; Yoon goes one step further to suggest consumer interaction is an important factor as well. Consumer interaction, such as word-of-mouth and communication on social media platforms, is one of the most useful

tools to a firm; hence, marketing and advertisements are also part of the complex artifact ecosystem. The impact of the social interactions of humans as it relates to the consumer market will be discussed in more detail later in this review.

Before discussing agent-based simulation, Yoon (2019) compares various evolutionary models and explains them in terms of product evolution. Exaptation is a phenomenon seen in both biological and technological evolution. Exaptation is the process by which traits, originally designed for one use, get co-opted for a completely different use as they were found to also perform that second job well. The classic exaptation example in biology includes the feathers of early dinosaurs. While early dinosaurs did not fly, many evolutionary biologists speculate these feathers originally served to attract a mate, but over time, they became essential to the process of flight. Eventually, selection for better flight capabilities began to take place and dinosaurs with the optimum feather profile were selected for. There are also plenty of examples of exaptation in technological evolution: Mokyr (2000) illustrates that the gramophone was originally intended to be a Dictaphone. Yoon (2019) discusses that the technology in a microwave was originally intended to serve as a radar. Exaptation, or the process by which intended uses for an artifact (or animal trait) are co-opted for a latent, unintended use, if it proves advantageous in that new role, is one specific example of how selection is similar between biological and technological evolution.

Yoon's (2019) agent-based simulation model seeks to predict the evolution of an artifact based on the interactions and decisions between firms and consumers (i.e., agents). In Yoon's simulation, the product is the Korean Mobile phone. Yoon analyzed the mobile phone as it is one of the fastest changing products over a short amount of time. Samsung and LG have used the Korean market as a testing ground, and thus have gathered copious amounts of consumer data.

This particular study gathered data that ranged from 2004 to 2013. This time range is excellent for illustrating the evolution of a portable telephone to the modern smart phone, which includes features such as Wi-Fi, GPS and Bluetooth.

Yoon (2019) devised multiple mathematical equations to quantitatively explain evolutionary principles, one of which measures the variable VIT_t, or vertical information transfer. VIT_t is a variable that correlates how a firm's price matches a consumer's preference. A VIT_t above 0.6 means the two variables are correlated, and a negative VIT_t indicates that transferred information does not reflect evolution via the selection and retention process. For example, if consumers have preferences that producers choose to ignore, the producers then generate versions of products outside of what was selected for. Yoon (2019) found two distinct phases along the timeline in this study, with corresponding VIT_ts. The first phase (2004-2011) included major changes, including the introduction of the first smart phones, which had a VIT_t of 0.84. In the second phase (2011-2013), it dropped to -0.98, meaning producers created mobile phones outside what the consumer selected. These maladaptive phones will not be selected by consumers. If producers do not manage to raise the VIT_t, they will eventually be forced to accommodate the decision-making power of consumers, who must remain satisfied in order to give producers their money.

Yoon (2019) suggests there are many ways products evolve, with new products leading to new industries, which then interact with the previous artifact environment. Furthermore, the potential for new industries has major implications for the economy and government. I believe this study was very well done, and clearly illustrated how the selection process leads to the evolution of products.

There is another Agent Based Modeling study that further illustrates the complex interactions between consumers and producers (Ma and Nakamori, 2004). In 2004, this simulation model was becoming a popular way to study macro-level complexities via micro-level interactions, or "from the bottom up." Like Yoon's (2019) model, Ma and Nakamori define the "agents" as producers and consumers. Producers design and release products for the consumers to evaluate and purchase.

Ma and Nakamori (2004) believe every product put out in the market contains both design and performance parameters. Furthermore, for consumers, performance parameters will always be more important than design parameters because consumers do not understand the majority of design decisions. Ma and Nakamori use the example of the digital camera to illustrate this point. Most consumers do not care if a camera has a serial or parallel interface (a design parameter), but most will care about compatibility or ease of use (performance parameter). However, it gets more complicated because the design parameters directly affect the performance parameter, another example of the genotype/phenotype relationship. Just as the long strands of nucleic acids (genotype) code for the physical characteristics of an organism (phenotype), the design parameters of an artifact code for how that artifact will perform in the hands of consumers. A small change in design has the potential to code for an entirely different version of the product, therefore, it is essential for firms to correctly assess the design of an artifact given the current consumer market. The camera interface affects the ease of use, even if the consumer does not realize it. Thus, this agent-based model illustrates a way to map the design parameter space (DPS) onto the performance parameter space (PPS) to correlate the two in different market scenarios.

Before discussing the findings of the simulation, it is important to discuss some similar themes seen in the papers discussed so far. Like Yoon (2019), Ma and Nakamori (2004) see consumer purchasing behavior as consumers evaluating metrics and choosing the product that provides the greatest utility (the cost-benefit profile). Ma and Nakamori discuss many different evaluation methods consumers can utilize. This, like Kirsh's (2010) example of human cognition interacting in the artifact ecosystem, will be discussed as part of the opposing viewpoint illustrating that many factors weigh on consumer decision. Additionally, Ma and Nakamori (2004; pg. 747) propose that the environment is analogous to the consumer market, and there are many factors including "cultural backgrounds, income, age, sex" which influence consumer purchases. In order for producers to survive, they must generate new products (variants) that have changed to meet the needs of the consumers.

The Agent Based model (Ma and Nakamori, 2004) includes five distinct simulations that indicate two factors that prevent producers from monopolizing the market: consumers' incomplete knowledge of the market (i.e., consumers do not evaluate all products) and diversity of consumer needs (no one producer can produce enough variety to satisfy all consumers - at least not in a cost-effective way). Notably, in simulation five, the model found that producers who expanded and changed their DPS profile midway through the simulation did remarkably better than the competition. The simulation found that in the beginning, if a particular producer was not succeeding in the market, upon altering the design, they could become an excellent producer in the market. Ma and Nakamori (2004) believe that most of the new designs released will not serve a purpose, and are filtered out during a test period, so only advantageous changes will succeed in the market.

Ma and Nakamori's 2004 study provides another illustration of how the variation, selection and retention aspects of a Darwinian system can be found in technological evolution. As producers generate variation in products, that variation will lead to consumers choosing a product with an appealing performance parameter space given that product's design parameters. Variation leads to selection, and only the most optimal products will be retained.

The main difference identified between biological and technological evolution includes the directionality in the selection and variation processes. As Kirsh (2010) stated clearly, artifacts evolve to attend human need. Similarly, Ziman (2000) posits that unlike random mutations in genetic variation, artifact evolution is not random, but rather, variation occurs due to conscious design. For example, if firms gather data that consumers dislike a feature of their latest car model, the next design the firm releases is going to address that feature. Human cognition allows firms to adapt as they release products into the environment and make adjustments accordingly. Many scholars, including Zimon, believe technological evolution shares characteristics with Lamarckian Evolution, which is a concept that posits that organisms evolve to suit their environment (a giraffe evolves a longer neck to better reach the tall trees). This presumes evolution is directional and working toward an end goal, which is a theory not supported in biology.

Lee (2013) took this concept one step further by discussing how artifacts evolve based on societies' perception and relationship with the artifacts. Artifacts evolve in a direction based on many different interacting characteristics. Like Kirsh's (2010) notion of human cognition and Yoon's (2019) of consumer interaction, Lee has a similar outlook that states artifact evolution is directly related to human perception. Lee (2013) contends artifact evolution occurs to both increase artifact performance and consumer satisfaction. If consumers can no longer see

improvements in an artifact, they will no longer select the “improved” artifact because the cost outweighs the benefits. Then producers will no longer want to keep producing that artifact because it is costly to produce, and they are receiving less money from consumers. Unlike random mutations that arise in nature and then are subject to the environment, this system of technological innovation allows for a fine-tuned mechanism for generating the optimal artifact. On the contrary, organisms do not evolve to fit their environment, rather, mutations occur randomly, and only the fittest mutations will propagate in the environment. Organisms exist to survive in their environment; technology exists to be the best through interactions between producers and consumer.

Devezas (2005) discussed some of the main points that are still missing from the Evolutionary Theory of Technological Change (ETTC), which states biological and technological evolution follow the same model. Devezas (2005) postulates that biological analogies are merely the foundation to be able to describe technological evolution, but, as previously discussed, the technological system is far more complex, and there is no corresponding analogy to account for human cognition. Likewise, he believes instead of diving into the realm of biological evolution, one should instead look to the diverse discipline of “Evolutionary Epistemology,” which studies the development of cognition in humans and includes all aspects of human social, cognitive and material evolution. Evolutionary Epistemology takes biological evolution one step further and seeks to discover the development of theories, cultures and the broad evolution of ideas. Nelson (2003) posits evolutionary epistemologists believe evolution is about finding a solution between ideas and reality. Devezas sees this as a better starting point for ETTC as there are underlying factors (directionality) in the

evolution of technology. Essentially, Evolutionary Epistemology involves factors that account for the human cognition aspect seen in the evolution of technology.

“Universal Darwinism” is a concept that Darwinian principles can be utilized in many aspects other than biology, such as science, technology, business, culture and economics, as they are all “evolutionary”. Nelson (2006), a proponent of this theory, goes on to state that all these institutions have gotten to this point through the same principles of variation, selection and retention. Devezas (2005) contends that Universal Darwinism is not understood to such a degree that it could be applied to ETTC. Furthermore, he states economists object to the use of this theory in place of other models, and that objection has to be resolved before any progress can be made on ETTC. This is crucial as Darwinian principles are a key element to ETTC. Finally, Devezas believes there have not been enough statistical simulations (which provide valuable, tangible data, as well as the ability to test different market scenarios) that illustrate the theory of ETTC to accompany the vast logic theories (such as proposed by Kirsch in 2010). However, Devezas’s paper was published in 2005, and as discussed, simulation research (and new explanations about Universal Darwinism) are now more common, so the last two points of contention may be invalid.

Before I discuss my opinion regarding the similarity between biological and technological evolution, let us first summarize where these scholars stand regarding how the evolution of technology fits in with the Darwinian system of variation, selection, and retention.

To begin, it is important to view the genotype and phenotype analogies along a continuum. In classical biological evolution, genes are constructed of DNA, a long strand of nucleic acids which code for mRNA (messenger RNA). mRNA will eventually be translated into proteins, which make up the phenotype, or the actual physical characteristics of an organism.

Ziman (2000) proposes the genotype essentially contains the instructions for how to build an organism. Transitioning to the evolution of artifacts, or material objects, Mokyr (2000) believes that the set of useful knowledge (genotype) constrains the set of useful techniques (phenotype). The technique contains the instructions for an artifact, and changes to knowledge (genotype) may alter the technique (phenotype) which eventually changes a product. Yoon (2019) contends that the decision-making power of the producers and consumers will directly code for the artifact (the product). Changes in decision making power of producers or consumers will alter a product. Finally, the most in-depth analogy comes from Ma and Nakamori (2004), who believe design parameters (DPS), or how the artifact is designed, directly affect performance parameters (PPS), or, how it performs. How it performs then dictates how it is perceived by consumers. All of the above relationships share something in common: changes to the genotype (variation) will directly alter the phenotype. Continuous changes to the genotype/phenotype are what produce an organism suited for its environment, or a product well suited for the consumer market.

How do these changes in "genotype" occur? Alternatively, how does variation arise? In biological evolution, Zimon (2000) postulates variation occurs through mutations in the DNA sequence, ranging from a single base difference to insertions and/or deletions. It is important to note these mutations are completely random, and the majority of them are actually harmful. As such, only a small minority of them will actually be seen in the phenotype. Mokyr (2000) does not specifically discuss the mechanism behind changes in knowledge; however, as human beings, changes in knowledge occur every day. I believe the majority of these changes in knowledge happen by accident, or through the process of trial and error. Zimon (2000) believes variation of artifacts occurs through conscious design, and more specifically, Yoon (2019) maintains firms create variation by releasing a wide range of products. Ma and Nakamori (2004)

believe that variation is essential for producers to survive. They must produce new products (variants) that have changed to meet the needs of the consumers. Here, it is important to note that this variation is not random; rather, it is directional. Firms gather consumer data which they use to alter and curate a range of products which are then released into the consumer market.

Arguably, the most important aspect of a Darwinian system is selection. According to Mokyr (2000), selection must always exist as part of a Darwinian system because there will always be more entities produced than can "survive." In biology, the phenotype interacts with its environment, and certain characteristics of the environment, such as food sources, temperature or hiding places, are more accessible to certain phenotypes. Therefore, the phenotype is under selection by the environment. Selection occurs a similar way in the evolution of technology, and Kirsh (2010) maintains that the "environment" in technological evolution includes the "artifact ecosystem." The artifact ecosystem includes tasks, practices and users. All these components interact and co-evolve in the process of artifact evolution. In terms of product evolution, he believes that at any given time, consumers dictate what products are optimal. As better products are introduced, consumers may change their core values of interest based on their personal cost/benefit profile. Yoon (2019) posits survival in the consumer market is determined by consumer purchasing decisions: the more a product is purchased, the higher fitness it has. Lastly, Ma and Nakamori (2004) see consumer purchasing behavior as consumers evaluating metrics and choosing the product that provides the greatest utility (again, the cost-benefit profile).

The last component of any Darwinian system is retention, or the passing along of the selected entity. In biological evolution, Ziman (2000) discusses that only the advantageous phenotypes will survive and reproduce, passing on their characteristics to the next generation. Similarly, Yoon (2019) posits that firms retain only a certain number of released products based

on consumer purchase decisions mediated through price and quality. Consumers select the products, then firms retain them. Lee (2013) has a similar view, contending that if consumers can no longer see improvements in an artifact, they will no longer select for the "improved" artifact. Likewise, producers will not want to keep producing (and retaining) that artifact because it is costly to produce and they receive less money from consumers. Although the mechanisms of variation and selection differ between biological and technological evolution, I believe retention is quite similar, as only the most optimal characteristics/ products will be retained and reproduced.

Lastly, there should be a brief discussion regarding the directionality and consequence of human cognition on the variation and selection processes. Kirsh (2010) discusses human cognition as an ever-changing selector that has multiple social and economic influences. Unlike the selection of traits by the environment, which is relatively direct, selection of an artifact has a multitude of moving parts. One of those moving parts is consumer interaction (Yoon 2019). Consumer interaction involves both word of mouth and advertisements. A consumer may not know a particular product exists if not for discussion amongst peers or advertisements in their daily lives. Lastly, Lee (2013) has a similar outlook regarding how artifact evolution occurs based on societies' perception and relationship with the artifacts. Furthermore, he believes artifact evolution occurs to both increase artifact performance as well as consumer satisfaction. Lee's notion illustrates how the evolution of technology is directional, which is the main disanalogy between these two models. The system of technological innovation allows for a very fine-tuned mechanism for generating the optimal artifact, while the "optimal" organism occurs merely by random chance. The process of a single random mutation being internally selected, *then* proving advantageous in its environment is clearly much more subject to chance.

It is no surprise that the evolution of technology is a social construct, as this type of evolution is at the hands of humans. Human beings themselves are products of biological evolution. Biological evolution is responsible for the expansion of our forebrains which allowed the exceptional cognitive abilities of our species. That cognitive ability has allowed for the building of empires, collective societies, industrialization, medicine, sports and other aspects that make humans the most civilized species on the planet. We are not going to intentionally produce random artifacts that will not prove useful in our lives. Instead, we are going to utilize our cognitive ability to employ mathematics, physics and engineering to produce near optimal artifacts that allow for increased longevity, transportation, building, flying or happiness.

Ziman (2000) and other contributors believe the retention of selected traits is at the core of all evolution. Whether that retention is of a trait that arose from a random mutation, or the retention of a new model of car that addressed a previous design flaw, those selected traits are going to be seen in the next generation. Personally, I don't think it matters how selection occurs; all that matters is that it does happen and that the selected traits get passed on.

Regarding the evolution of technology, I believe the aspect of human cognition simply allows the process to happen faster compared to evolution in biology. The pure randomness of mutations makes the latter process incredibly slow. If one organism has a mutation that is advantageous, it would take generations before the *population* as a whole contained that trait. On the other hand, a car manufacturer gathering consumer data can immediately fix a problem and proceed to roll out the entire next generation of cars with that aspect fixed. Instead of waiting generations for the *population* to get the trait, it is done in a single generation. This also allows for faster adaptation to a changing environment. Within one to two generations, that car manufacturer can alter the design to accommodate for the changing consumer market.

In conclusion, I believe that evolution of technology follows the same Darwinian model as evolutionary biology. It is important to establish they simply cannot be identical as human cognition leads to directionality (towards a “better” product) within the selection and variation process. However, at the end of the day, the core evolutionary element of retention of selected traits is shared between the two. Therefore, only those selected traits will be passed to the next generation, or from Darwin’s evolutionary theory (1859): survival of the fittest.

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