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Entrepreneurship: An analytical thermodynamic theory

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Entrepreneurschip: An analytical thermodynamic theory

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Abstract:

In this paper, we present a newly developed analytical thermodynamic theory and show that it offers a simple understanding of entrepreneurship. The approach we present in the paper is different from previous work on the subject in that we not only borrow the mathematical tools from, and the analogy to thermodynamic but treat economics in general and entrepreneurship in particular as a thermodynamic process. Entrepreneurship as a thermodynamic process can be represented by lognormal process, which contains a growth term and a dissipation term. The lognormal process in turn can be mapped into a thermodynamic equation. The thermodynamic equation is solved to derive an analytic function that explicitly represents the relation among fixed costs, variable costs, uncertainty of the environment and the duration of a production system. Our analysis shows that entrepreneurial ventures and established firms have different kinds of competitiveness in different kinds of market environments. Even if equilibrium states are reached, introduction of innovation by entrepreneurial venture changes the market and will disrupt the balance in old systems. Furthermore we use information theory to show that when environment changes suddenly, novice entrants as the entrepreneurs are, actually perform better than experts whose prior knowledge often cause severe biases in prediction, in terms of recognizing and acting upon opportunities.

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1. Introduction

Entrepreneurship is known to play a critical role in the economy, leaving economists concerned whether it fits into the theory (Boumol 2005). In his 1968 article "Entrepreneurship in Economic Theory" in the American Economic review, Baumol urged the economists to start paying attention to the role of entrepreneurship in economic development. Yet, entrepreneurship remains absent in mainstream theory.

In mainstream economics, the constructs are generally equilibrium models in which structurally nothing is changing. But, this very attribute excludes the entrepreneur by definition. Schumpeter and Kirzner have argued that sustained equilibrium is something that the entrepreneur does not tolerate, any more than he tolerates sustained disequilibrium. According to Baumol (2005), this is exactly why neoclassical theory is not wrong in excluding the entrepreneur. It does so, because it is dealing with subjects for which the entrepreneur is irrelevant. Bianchi and Henrekson (2005) come to a similar conclusion: Entrepreneurship presupposes calculable outcomes. Entrepreneurship is a process of discovery where one thing leads to another, and the discovery and exploitation of opportunities in turn create previously unknown opportunities. In this sense, the mainstream theory's entrepreneur is not entrepreneurial. The entrepreneur they argue, even though probably of critical importance for innovation and growth, lacks operational definition and is too elusive a concept to ever fit into the neoclassical model.

We use Schumpeterian definition of entrepreneurship - a disequilibrium process driven by radical innovation, a process of creative destruction by which young entrepreneurial firms grow and replace the established dominant firms thereby reducing the role of these firms and at time causing their collapse. At the industry level the role the young entrepreneurial ventures is that of 'creative destruction' by which their innovative technology results in the collapse of established firms with old technology and services. The unit of analysis is the economy in which entrepreneurship is (one of the) disequilibrium processes.

In this paper, we present a newly developed analytical thermodynamic theory and show that it offers a simple understanding of entrepreneurship. Moreover, it sets entrepreneurship in a broad background of evolutionary biology. Previous work on evolutionary model of entrepreneurship include (Grebel et al 2001) who discussed a model of entrepreneurial behavior as an evolutionary process.

Economic and biological systems need to extract low entropy from the environment to compensate for continuous dissipation. This process is the most fundamental property of life (Schrodinger, 1944; Georgescu-Roegen, 1971; Prigogine, 1980), and indeed of economic system. According to (Jenkins

2005) the application of principles of thermodynamics like maximum entropy production (MEP), that has been used to model complex physical systems like fluid turbulence and the climate of the Earth, may be applied to human economic activity. The approach we present in the paper is different from previous work on the subject in that we not only borrow the mathematical tools from, and the analogy to thermodynamic but treat economics in general and entrepreneurship in particular as a thermodynamic process. Economic goods are low entropy products. The purpose of economic activities in general, and entrepreneurship in particular, is to extract low entropy from the environment. The entrepreneurial process uses innovation to achieve that. Innovation in this context is utilizing un-used energy or finding ways in which less energy is used for the production of the same goods (Vogel …).

Entrepreneurship as a thermodynamic process can be represented by lognormal process, which contains a *growth* term and a *dissipation* term. The lognormal process in turn can be mapped into a thermodynamic equation. From the entropy law, the thermodynamic diffusion of an organic or economic system is spontaneous. The extraction of low entropy from the environment, however, depends on specific (or biological) institutional structures that incur fixed or maintenance costs. Higher fixed cost systems, such as large established firms, generally have lower variable costs. The thermodynamic equation can be solved to derive an analytic formula that explicitly represents the relation among fixed costs, variable costs, uncertainty of the environment and the duration of a production system, which is the core concern in most economic decisions (Chen, 2005). This analytical representation of various factors in production processes presents a greatly simplified understanding of economic activities in general and entrepreneurial activities in particular.

From the analytical thermodynamic theory, it can be derived that in a stable environment, as fixed cost of an economic entity increases, variable costs dropped sharply. Therefore, a stable, mature industry favors established businesses. However, in a highly uncertain environment as entrepreneurial, innovation driven environment is, investment in fixed assets has little influence on variable costs. Since higher fixed cost systems need large output to break even, they often face difficulty in working in a new market, where uncertainty is high and market size is small. Large established firms consider such market niche market and tend to avoid them. In such niche markets entrepreneurs with low fixed costs have advantages over large established firms, although these large established firms are heavily endowed with financial and technical resources. In his study of Inc. 500 companies Bhide (2000) concludes that successful new venture target niche markets in which they expect less competition from the market leaders. Our theory shows that entrepreneurship thrives in highly uncertain environment, niche markets, which is consistent with the experience.

In general, any economic or biological system, as a dissipative system, is only meta-stable instead of absolutely stable. This is why most businesses fail in the end as demonstrated by study of the companies that make the NYSE and NASDAQ lists. (Ormerod, 2005). From the analytical theory, it can be derived that the main theme of economic and biological evolution is the tradeoff between competitiveness of high fixed cost systems in a stable environment and flexibility of low fixed cost systems in a volatile environment. Since there is no dominant strategy in all environments, judgmental decision which according to Casson is the entrepreneurial function, based on opportunity recognition will drive new ventures creation based on low fixed costs in the market.

From a thermodynamic perspective there is a natural link between information, which represents opportunity in the context of entrepreneurship, and entropy. In this paper, we apply a newly developed generalized entropy theory of information to understand entrepreneurial activities.

2. Production, competition and entrepreneurship

A basic property in economic activities is uncertainty, which according to Knight (1921) is central to entrepreneurship: Entrepreneurs, according to Knight, attempt to predict and act upon change within markets. Knight emphasizes the entrepreneur's role in bearing the uncertainty of market dynamics. While a business may face many different kinds of uncertainty, most of the uncertainties are reflected in the price uncertainty of the product, which was the early definition of entrepreneurship (Cantillon), and which according to Kirzner represents the entrepreneurial opportunity.

Suppose S represents economic value of a commodity, r the expected rate of change of value and σ, the rate of uncertainty. Then the process of S can be represented by the lognormal process

$$\frac{dS}{S} = rdt + \sigma dz \,. \qquad (1)$$

where

$dz = \varepsilon\sqrt{dt}, \quad \varepsilon \in N(0,1)$ is a random varaible with standard Gaussian distribution

The production of the commodity involves fixed cost and variable cost. Firms can adjust their level of fixed and variable costs to achieve high level of return on their investment. Intuitively, in a large and stable market, firms will invest heavily in fixed cost to reduce variable cost, thus achieving efficiency

and higher level of economy of scale. In a small or volatile market, firms will invest less in fixed cost to maintain high level of flexibility. New venture are an example of the later.
In the following section, we will derive a formal analytical theory.

3. The model

In natural science, there is a long tradition to study stochastic processes with deterministic partial differential equations. For example, heat is a random movement of molecules. But the heat process is often studied by heat equation, a type of partial differential equations. In studying quantum electrodynamics, Richard Feynman (1948) developed a general method to study probability wave function with partial differential equations. Kac (1951) provided a more systematic exposition of this method, which was later known as Feynman-Kac formula. While this method is little known in social studies, its use is very common in natural sciences (Kac, 1985). Recently, Feynman-Kac formula has been widely used in finance. It was even suggested that, “Feynman could be claimed as the father of financial economics” (Dixit and Pindyck, 1994, p. 123)

Let *K* represents fixed cost and *C* represents variable cost, which is a function of *S*, the value of the commodity. If the discount rate of a firm is *r*, from the Feymann-Kac formula, (Øksendal, 1998, p. 135) the variable cost, *C*, as a function of *S*, satisfies the following equation

$$\frac{\partial C}{\partial t} = rS\frac{\partial C}{\partial S} + \frac{1}{2}\sigma^2 S^2 \frac{\partial^2 C}{\partial S^2} - rC \qquad (2)$$

with the initial condition

$$C(S,0) = f(S) \qquad (3)$$

To determine *f(S),* we perform a thought experiment about a project with a duration that is infinitesimally small. When the duration of a project is sufficiently small, it has only enough time to produce one unit of product. In this situation, if the fixed cost is lower than the value of the product, the variable cost should be the difference between the value of the product and the fixed cost to avoid arbitrage opportunity. This does not contradict Kirzner’s definition of entrepreneurs’ role as the agent who takes the arbitrage role if we consider Kirzner’s entrepreneurial alertness as a component of the fixed asset of the entrepreneur.
If the fixed cost is higher than the value of the product, there should be no extra variable cost needed for this product. Mathematically, the initial condition for the variable cost is the following:

$$C(S,0) = \max(S - K, 0) \qquad (4)$$

where *S* is the value of the commodity and *K* is the fixed cost of a project. When the duration of a project is *T*, solving equation (2) with the initial condition (4) yields the following solution

$$C = SN(d_1) - Ke^{-rT}N(d_2) \qquad (5)$$

where

$$d_1 = \frac{\ln(S/K) + (r + \sigma^2/2)T}{\sigma\sqrt{T}}$$
$$d_2 = \frac{\ln(S/K) + (r - \sigma^2/2)T}{\sigma\sqrt{T}} = d_1 - \sigma\sqrt{T}$$

The function *N(x)* is the cumulative probability distribution function for a standardized normal random variable. Formula (5) takes the same form as the well-known Black-Scholes (1973) formula for European call options.

Suppose the volume of output during the project life is *Q*, which is bound by production capacity or market size. We assume the present value of the product to be *S* and variable cost to be *C* during the project life. Then the total present value of the product and the total cost of production are

$$SQ \text{ and } CQ + K \qquad (6)$$

respectively. The return of this project can be represented by

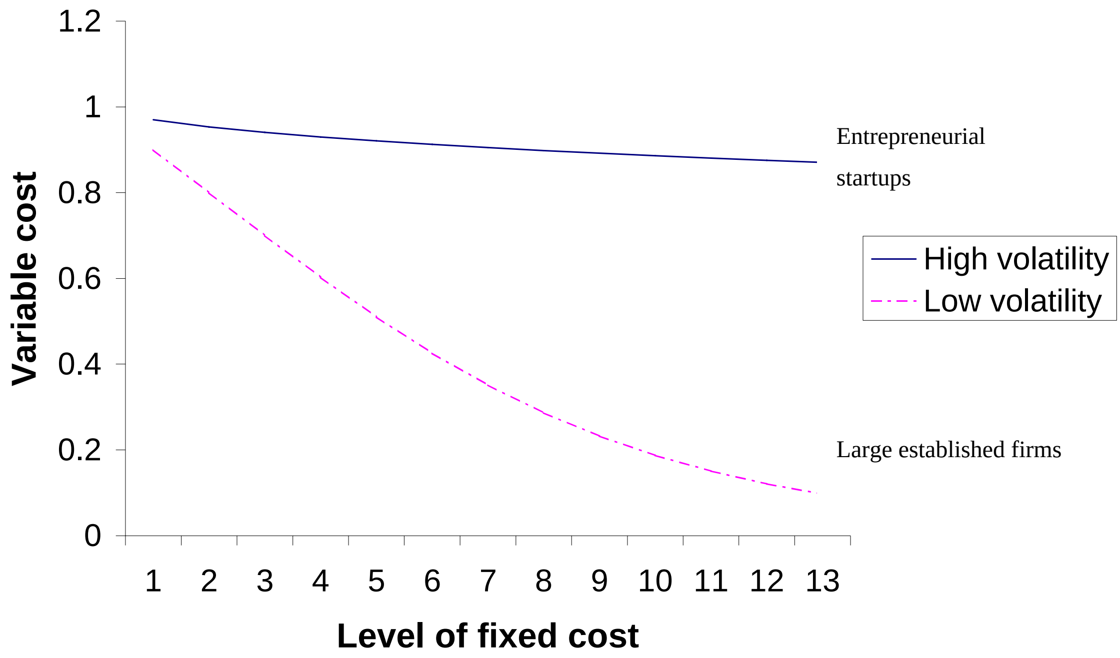
$$\ln\left(\frac{SQ}{CQ+K}\right) \qquad (7)$$

and the net present value of the project is

$$QS - (QC + K) = Q(S - C) - K \qquad (8)$$

The above analytical model enables us to make quantitative calculation of returns of different projects under different kinds of environments. First, we examine the relation between fixed cost and variable cost at different levels of market uncertainty. Calculating variable costs from (5), we find that, as fixed costs are increased, variable costs decrease rapidly in a market with low uncertainty in which large established firm operate, and change very little in a market with high uncertainty in which entrepreneurs and new ventures operate. Put it in another way, high fixed cost systems are very sensitive to the change of market uncertainty level while low fixed cost systems are not. Change in market uncertainty can take place by introduction of innovation, new technology that changes the market. This is illustrated in Figure 1.

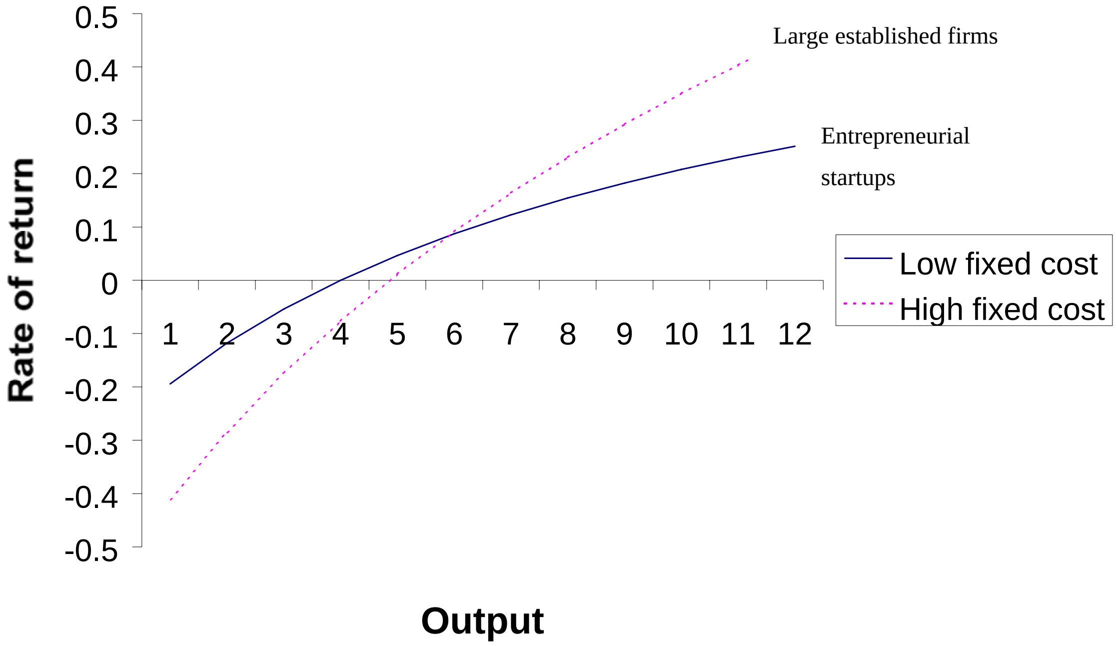
Figure 1. Level of Uncertainty and Variable Cost



Next we discuss the returns of investment on different projects with respect to the volume of output. Figure 2 is the graphic representation of (7) for different levels of fixed costs. In general, higher fixed cost projects need higher output volume to breakeven. At the same time, higher fixed cost projects, which have lower variable costs in production, earn higher rates of return in large markets.

From the above discussion the level of fixed investment in a project depends on the expectation of the level of uncertainty of production technology and the size of the market. When the outlook is stable and market size is large, projects with high fixed investment earn higher rates of return. When the outlook is uncertain or market size is small, projects with low fixed cost breakeven easier.

Figure 2. Output and return with different levels of fixed costs



Projects are undertaken by firms, which often utilize existing assets to help reduce costs in producing or marketing new products. For example, Microsoft often bundles its application software together with its Windows operating system. This effectively reduces the cost of marketing. In general, new products from large firms often enjoy the benefit of brand recognition, which reduces variable cost in marketing. At the same time, costs of projects are often affected by the characteristics of firms. In general, ownership and management are less integrated in large firm than in small firms. Therefore, large firms adopt more rigorous check and balance systems in corporate control than small firms. This added cost of monitoring often increases the cost of projects. Therefore higher fixed cost large firms generally concentrate on large and stable markets while lower fixed cost small firms thrive in uncertain niche markets. From figure 1 and 2 we can conclude that large established firms with high fixed costs do not have competitive advantage in small volatile niche markets, which help explain the tendency of entrepreneurial new ventures to seek opportunities in niche markets. (Bhide, 2000).

Why entrepreneurship is often linked to young and small firms? When an industry becomes mature and uncertainty decreases, from Figure 1, increases in fixed costs, *K*, (capital investments and accumulated human capital), drives down variable costs rapidly, which enables leading companies to dominate entire market. So, in a mature industry only very few big companies can stay in business. In fact, without anti-trust legislation, many industries with high capital intensity, or high fixed assets would probably end up with monopolies or regional monopolies (Acs and Audretsch, 1990; Mazzucato, 2000).

While large firms with high fixed cost are highly competitive in their own fields, they are less effective in entering new markets with high uncertainty. First, from Figure 2, high fixed cost systems need a large market size to break even. So they tend to hesitate in moving into new markets, which are typically of small size in their early stages. Second, the high concentration of wealth in large companies often attracts litigation and other attempts to extract wealth from them. So large companies often incur high legal costs and are cautious in pursuing new opportunities. Third, internal coordination in large companies is much more complex and difficult than in small companies. While it is relatively easy to incorporate innovative ideas by adjusting firm structures in simple and small companies, innovation is often very disruptive to a highly coordinated and efficient complex structure. Large companies often develop highly optimized structures to reduce uncertainty and bring down variable costs in producing particular products. This however often stifles the innovative spirit inside the companies and makes it difficult for them to adjust in a changing environment.

In general, large companies, which have invested a great amount in existing technologies, may be unwilling or unable in the short term to switch to new and potentially better technologies. Innovative, newly introduced technologies are often disruptive to large companies. The adoption of Internet in the early 90s is a good example. This opens opportunities for new and typically small companies when new industries emerge. Their low levels of fixed cost enable them to adapt to the changing environment easily. For example, the champions of the IT revolution, such as Microsoft, Intel, CISCO, Oracle, Netscape, Yahoo Google and Ebay are all relatively new companies led by visionary entrepreneurs that reaped tremendous profits by being able to quickly respond to and take advantage of newly emerging markets.

In changing environment, these small companies often grow rapidly to replace the existing dominant firms, causing the demise or greatly reduces role of once great companies. Hence Schumpeter's 'Creative Destruction'.

The proposed analytical model (theory) differs from general equilibrium theory. Equation (2) is of first order in temporal dimension. This indicates that economic systems are intrinsically evolutionary. This differs fundamentally from the general equilibrium framework. Our analysis shows that different systems have different kinds of competitiveness in different kinds of market environments. Even if equilibrium states are reached, introduction of innovation changes the market and will disrupt the balance in old systems. Hence equilibrium states are rarely attained and cannot last long. This is consistent with casual observation and Schumpeter's theory of creative destruction. On a more fundamental level, this is consistent with the fact that all living systems are non-equilibrium systems. (Prigogine, 1980)

4. Generalized entropy theory of information and entrepreneurship

Entrepreneurship is often linked to abilities in information processing in terms of opportunity (Shane) and alertness (Kirzner). Information regarding opportunity raised by new technology, about future direction of market development or about price differences in the market. To understand information processing and its relationship with entrepreneurial activities, we make use of information theory. After the entropy theory of information was developed by Shanon (1948) to better understand problems in communication, its technique has been applied to many different problems in economic and finance. (eg. Theil, 1967; Maasoumi and Racine, 2002). However, the standard economic theory of information, represented by Grossman and Stiglitz (1980) was not built on the foundation of entropy theory. Authorities in information theory generally discouraged the application of entropy theory to broader areas.

Scholars in other fields should realize that the basic results of the subject are aimed at a very specific direction, a direction that is not necessarily relevant to such fields as psychology, economics, and other social sciences. Indeed, the hard core of information theory is essentially, a branch of mathematics, a strictly deductive system. (Shannon, 1956).

However, the dissonance between entropy function as a mathematical representation of information in which information has no values, and the practical value of information has long puzzled many people and recent works have shown that our intuitive concept of information coincides with the mathematical definition of information as entropy (Bergstrom and Lachmann, 2004; Adami, 2004).

Recently, an entropy theory based economic theory of information has been proposed (Chen, 2005). It can be simply stated as:

Information is the reduction of entropy, not only in a mathematical sense, as in Shannon's theory, but also in a physical sense. The rules of information transmission developed in Shannon's theory, as mathematical rules, apply not only to communication systems, but also to all living organisms, social and economics systems.

Since this new information theory can be applied to much broader fields than Shannon's theory, it may be called the Generalized Entropy Theory of Information. In the following section, we will present basic properties of information theory and then discuss some distinct properties of this new information theory.

The value of information is a function of probability and must satisfy the following properties:

The information value of two events (eg. Innovation, opportunity) is higher than the value of each of them.
If two events (eg. Innovation, opportunity) are independent, the information value of the two events (eg. Innovation, opportunity) will be the sum of them.
The information value of any event (eg. Innovation, opportunity) is non-negative.

In the context of entrepreneurship we consider innovation or opportunity as an event and the information value associated with it is the entrepreneur's perception of the probability to realize the opportunity associated with the innovation that can turn the innovation into economic value

The only mathematical functions that satisfy all the above properties are of the form

$$H(P) = -\log_b P \qquad (1)$$

where H is the value of information (the economic value of innovation), P is the probability associated with a given event / (or innovation to be successful in the market) and b is a positive constant (Applebaum, 1996). Formula (1) represents the level of uncertainty that is associated with any entrepreneurial venture based on innovation. When a signal is received, there is a reduction of uncertainty, which is information.

Suppose a random event (innovation), X, has n discrete states, $x_1, x_2, \ldots, x_n$, each with probability $p_1, p_2, \ldots, p_n$. The information value of X is the average of information value of each state, that is

$$H(X) = -\sum_{j=1}^{n} p_j \log(p_j) \qquad (2)$$

The right hand side of (2) which is the entropy function first introduced by Boltzmann in the 1870s, and is also the general formula for information (Shannon, 1948).

The new information theory has several properties that are relevant to entrepreneurship. From the view point of entrepreneurship, information can be thought of as representation of opportunity. According to Shane (2003), the individual-opportunity nexus is central to entrepreneurship and represents the framework for a general theory of entrepreneurship. Information that is more valuable is in general more expensive to obtain. From the second law of thermodynamics, Maxwell (1871) concluded that information of higher value is of higher physical cost. Since economic cost is highly correlated to physical cost (Georgescu-Roegen, 1971; Chen, 2005), more valuable information is in general more expensive to obtain. Entrepreneurial activities are often limited by the high cost to obtain valuable information like for example extensive market research, feasibility study or elaborated financial analysis.

Second, the amount of information one can receive depends on the person's prior knowledge. The most important result from Shannon's entropy theory of information is the following formula

$$R = H(x) - H_y(x) \qquad (3)$$

where R is the amount of information one can receive, $H(x)$ is the amount of information a source sent and $H_y(x)$, the conditional entropy, is called equivocation. Formula (3) shows that the amount of information one can receive would be equal to the amount of information sent minus the average rate of conditional entropy. The level of conditional entropy $H_y(x)$ is determined by the correlation between senders and receivers. When x and y are independent, $H_y(x) = H(x)$ and $R = 0$. No information can be transmitted between two objects that are independent of each other. When the correlation of x and y is equal to one, $H_y(x) = 0$. No information loss occurs in transmission. In general, the amount of information one can receive from the source depends on the correlation between the two. The higher the correlation between the source and receiver, the more information can be transmitted.

From the above discussion, the process of understanding valuable information is very slow and it is often the people with special background who can understand certain information earlier than others thereby recognize opportunity in the market. Those who do become entrepreneurs and act upon the opportunity.

Third, it is often thought that the accumulation of knowledge will make production more efficient. Will this reduce the need for entrepreneurship? The following result from statistical physics helps answer this question.

If $\{p_1, ...p_n\}$ and $\{q_1, ... q_n\}$ are two sets of probabilities, then

$$-\sum_{j=1}^{n} p_j \log(p_j) \leq -\sum_{j=1}^{n} p_j \log(q_j) \qquad (4)$$

with equality achieved if and only if each

$$q_j = p_j, \qquad 1 \leq j \leq n$$

This result is called Gibbs inequality (Isihara, 1971). In Gibbs inequality, p_j can be understood, as the probability of event *j,* or the probability of the opportunity in the context of entrepreneurship, and q_j is the subjective probability of our assessment of that opportunity. The left hand side of formula (4) is the average uncertainty of the opportunity /events and the right hand side is the uncertainty of our subjective assessment of those opportunities /events. In general, the difference between the left hand side and right hand side of (4) is smaller when q_j is closer to p_j. This means that information processing is more efficient when the subjective probabilities are closer to the objective probabilities. Such a conclusion both makes common sense and matches our intuition.

From Gibbs inequality, the level of uncertainty in understanding a type of events, or the level of uncertainty in assessing an opportunity (innovation, new technology, future market development) by entrepreneurs, is

$$-\sum_{j=1}^{n} p_j \log(q_j)$$

where p_i and q_i are objective and subjective probabilities respectively. Suppose this type of events / opportunity has two possible outcomes, state 1 and state 2. The probability of state 1 is 90% (objective probability) and the probability of state 2 is 10% (subjective probability). An expert on this type of opportunities/events may correctly estimate these probabilities and the uncertainty in prediction is

$$-0.9\ln 0.9 - 0.1\ln 0.1 = 0.33$$

A novice, who has no prior knowledge on these events, may assign 50%[1] probability to each outcome. For her the uncertainty in prediction is

$$-0.9\ln 0.5 - 0.1\ln 0.5 = 0.69$$

It is clearly that the expert, who has accumulated knowledge through long time experience, has better estimation than novice in a stable environment. This outcome corresponds with observations in markets that are dominated by large existing companies.

Now assume the environment experiences some fundamental change by the introduction of innovation, and the new probabilities of state 1 and state 2 become 10% and 90% respectively. This time, the uncertainty of the prediction by the expert, who still uses the same probability, is

$$-0.1\ln 0.9 - 0.9\ln 0.1 = 2.08$$

while the uncertainty of prediction by a novice using the same probability is

$$-0.1\ln 0.5 - 0.9\ln 0.5 = 0.69$$

This shows that when environment changes suddenly, novice entrants as the entrepreneurs are, actually perform better than experts whose prior knowledge often cause severe biases in prediction[2], in terms of recognizing and acting upon opportunities. This shows that the need for entrepreneurship will not decrease with the accumulation of knowledge. This also explains why entrepreneurs are often newcomers or outsiders (Kuhn, 1996; Stearns and Allan, 1996).

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[1] Entrepreneurs often refer to such probability as "Head I win, tail I loose nothing"

[2] Like the case of web browser market – Microsoft entered the market at late stage only after newcomer Netscape gained substantial market share

5. Conclusion

According to (Jenkins 2005) the application of principles of thermodynamics that have been used to model complex physical systems like fluid turbulence and the climate of the Earth may be applied to human economic activity. Using thermodynamic, and in particular entropy and information theory provide for an analytical analysis of the entrepreneurial process. Our analysis shows that different systems have different kinds of competitiveness in different kinds of market environments. Even if equilibrium states are reached, introduction of innovation changes the market and will disrupt the balance in old systems. Hence equilibrium states are rarely attained and cannot last long. This is consistent with casual observation and Schumpeter’s theory of creative destruction. Furthermore, our analysis helps understand why when environment changes suddenly as a result of introduction of an innovation, novice entrants as the entrepreneurs are, actually perform better than experts whose prior knowledge often cause severe biases in prediction, in terms of recognizing and acting upon opportunities. Therefore the needs for entrepreneurs will not decrease with more knowledge available.

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