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Disruptive innovation can occur even if technology progresses gradually

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Abstract: Disruptive innovation is the phenomenon that products with inferior performance replace incumbent products with superior performance. We show the phenomena can happen without (1) competition between multiple firms, (2) rapid change of technology or (3) changes in customer preferences. The shape of customer utility function plays an important role. When the utility does not follow the law of diminishing marginal utility, discontinuous changes in customer behavior also occur under circumstances where the technology progress gradually. We demonstrate them by reproducible computer experiments. Our model helps to understand this phenomenon better. Our model can explain the other common customer behavior as well as destructive innovation. The only difference is the second derivative of the utility function. From the viewpoint that disruptive innovation can happen under a gradual situation, we point out the pitfalls when existing companies develop new products. Understanding these pitfalls is to help management decisions.

Keywords: disruptive innovation, characteristic space, the law of diminishing marginal utility, indifference curves, convexity, sigmoid, performance threshold, constrained utility maximization, second derivative

1 Introduction

Christensen (1997) reported the possibility that products with inferior performance can replace incumbent products with superior performance, and call the phenomena 'disruptive innovation.' We tend to think that better products deprive market share. However, he showed cases where inferior products robbed market share. It is because customers appreciate new performance other than well-known key performance.

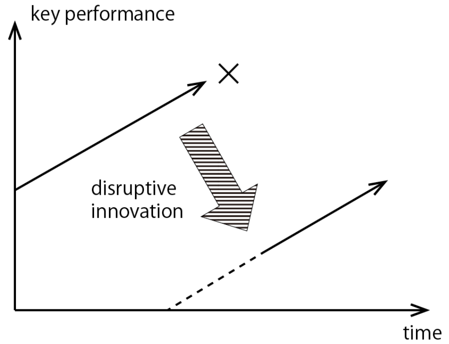

Figure 1 The concept of disruptive innovation

The concept became, but the reasons why it happens are unclear yet. Various explanations have been done in the past. Existing companies try to avoid issuing new products that may cause cannibalization with their products (Kamien and Schwartz, 1982). Organizations may have inertia trying to continue existing rules and ways. And various reasons including bureaucratization (Schumpeter, 1934) cause this. The inertia hinders decision-making to lower the key performance evaluated in existing products (Hannan and Freeman, 1977). Some companies do not have the necessary skills to understand new technology (Henderson and Clark, 1990).

Two aspects of disruptive innovation: supply-side and demand-side

The phenomenon called destructive innovation has two aspects. One aspect is competition between existing enterprises and new entrants. Why do newcomers beat existing companies? We call it a supply-side aspect. The other aspect is customer choice of products. Why do customers choose products with inferior performance? We call it a demand-side aspect.

This article focuses on the demand-side aspect. We are interested in customers' choice of products from many products, not a competition between the two products nor two firms. Adner (2002) also emphasized the importance of demand-based views.

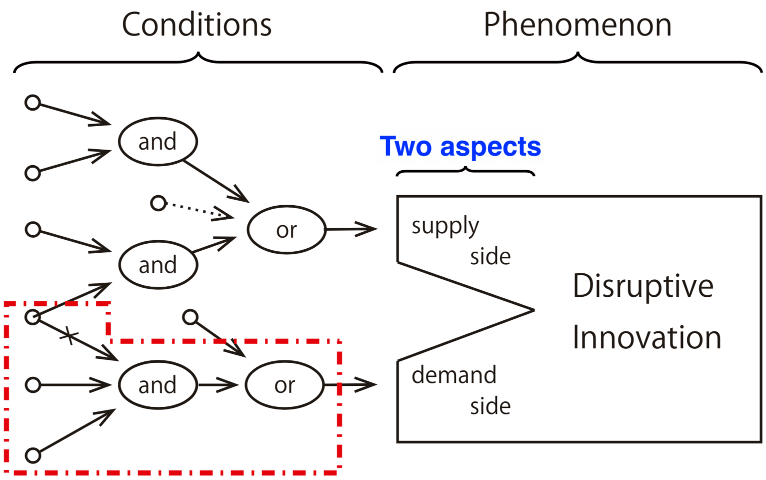

Figure 2 Two aspects of the disruptive innovation and their conditions

The concept of conditions we discuss

Many conditions under which destructive innovation happens have been proposed and discussed. Some of them are relations with high probability (solid arrow in the figure). Some of them are suggestions that there may be relevance (dotted arrow in the figure).

We are interested in building a theory that helps business decisions. For the purpose, it is useful to be able to foresee its occurrence with high probability before destructive innovation occurs. Therefore, we use computer experiments that can be repeatedly verified.

By our experiments, we can see that some conditions are not necessary that are often thought to be a prerequisite for destructive innovation (arrow with a cross-mark in the figure). If a model has less necessary conditions, it can apply the more situations. So it is useful to know what conditions are necessary.

What we call here a necessary condition is the arrow that enters the "and" node. The phenomenon called disruptive innovation can occur in multiple paths. In this paper, we concentrate on a path. So, when we call something a necessary condition, it is not an assertion that it is necessary on all other paths. Also, when we say "a condition is not necessary," it is not an assertion that it is not necessary for all other paths. We show that combining several conditions results in destructive innovation sufficiently.

The conditions which are not necessary

We show three conditions which tend to be considered necessary is not necessary. The phenomena that customers choose products with inferior performance can happen without (1) competition between multiple firms, (2) rapid change of technology or (3) changes in customer preferences.

First, multiple firms and competition between them are not necessary. There is not a requirement that there are multiple companies and the knowledge they have is different. There is no requirement that there are multiple companies and the production possibility they have is different. There is no requirement that there are multiple companies, one with strong inertia and the other with weak inertia. Even in the condition that one company produces a plurality of products, a phenomenon occurs in which the customer selects products with inferior performance.

Second, no rapid change in technology is necessary. No discontinuous technology change is necessary. We show that the phenomenon occurs even if the technology develops gradually over time.

Third, no changes in customer preferences are necessary. No changes in lifestyle are necessary. No changes in demand are necessary. We show that the phenomenon occurs even if the utility of the customer does not change.

Experiments

We carry out these demonstrations by reproducible computer experiments. We propose a model for those computer experiments. The model shows the sufficient conditions to the phenomenon that the customers choose products with inferior performance. You can test and verify my results. You can also do different experiments with different conditions. We plan to release source code and execution environment. It promotes research on the cause of destructive innovation.

We also provide knowledge that helps enterprises develop new products. We point out that there are pitfalls in the development of new products by companies. It gives a business suggestion.

2 Model structure

I focus on the customer choices, not the competition between companies. Regarding customer's choice, the model proposed by Lancaster (1966) is famous. This section first explains this model. Also, we will explain some concepts of economics which are necessary to describe our research.

Lancaster's new approach

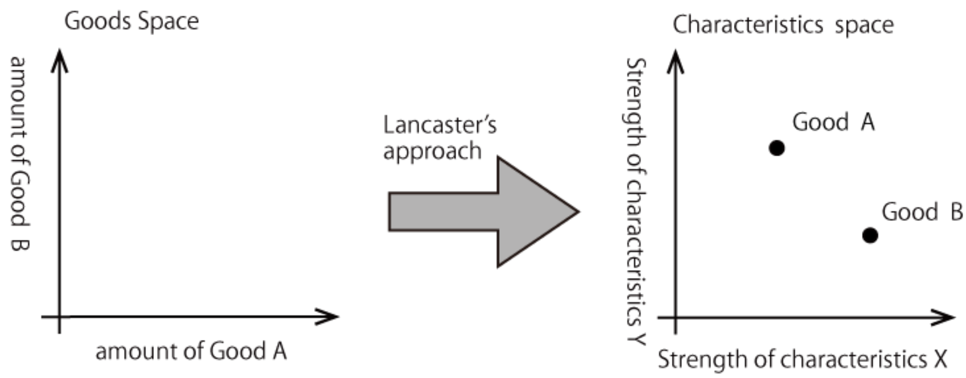

Figure 3 Lancaster's approach: from Goods space to Characteristics space

Before Lancaster

The figure with the amount of goods on the vertical axis and the horizontal axis often appears in economics textbooks. However, Lancaster pointed out that there is a problem in this figure. Let's consider a red Chevrolet and a black Chevrolet as an example.

In the model where the axis is goods, there are only two ways of considering these two goods as the same goods or as different goods. When considering these are the same goods, we ignore color information that may affect customer's choice. If we think that these are different goods, we ignore that these two goods have many characteristics in common. In this model, we can not handle the information that they are similar.

From Goods space to Characteristic space

So Lancaster introduced the concept of Characteristics space. We took the amount of goods on each axis in the traditional model. It is called Goods space (G-space). We took the amount of goods on each axis in the traditional model. Lancaster called it Goods space (G-space). Lancaster, on the other hand, took the strength if characteristics on each axis. He called it Characteristics space (C-space).

A good corresponds to a point in the Characteristic space. Similar goods correspond to near points. Even though we think only two characteristics, there are many goods. It is convenient because we want to think about customers' choices among many goods.

The number of characteristics is not limited to two. We write a two-dimensional figure for the sake of paper space, but in general, it is a higher dimension. In this paper, the discussion is made only in the case of two dimensions, but we confirmed that the same holds even at higher dimensions.

In a high dimensional space, contrary to intuition in low dimensions, the proportion of points far from the axis increases. It provides useful suggestions which related to the discussion in this paper, but we omit it in this paper.

Utility

The concept of utility is an essential element of economics. The utility is the desirability of goods the customer feels.

In the Lancaster model, the customer does not judge the desirability of the product. The customer judges the desirability of the characteristics of the product. Before Lancaster, a utility is a function on goods space, but Lancaster redefined that a utility is a function on characteristics space. Customer choice is a utility maximization on the Characteristic space.

Law of diminishing marginal utility

Regarding the utility, there is a well-known concept of "law of diminishing marginal utility." Marginal utility is the increment of utility when the consumer gets one more unit of a good. This law is that the marginal utility decreases as the quantity of goods increases.

The subjective value of 100 dollars is different for those who have only 10 dollars and those who have 1 million dollars. Most people feel more happiness in the former case than the latter case.

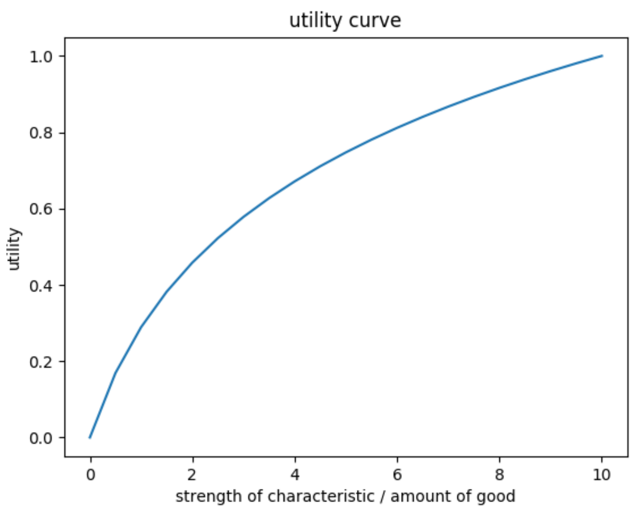

Figure 4 Utility curve which obeys the law of diminishing marginal utility

However, this is a discussion about the utility defined in the goods space. There is no guarantee that it also holds for the utility on the characteristics space. It is an essential point in this paper.

Indifference curves and their convexity

The concept of indifference curves is also familiar in economics. The indifference curves are sets of points whose utility is constant. It is a concept similar to contour lines in maps. Contour lines are sets of points having a constant height. There are many indifference curves like contour lines. When we focus on one indifference curve, the customers like the two goods on the indifference curve to the same extent.

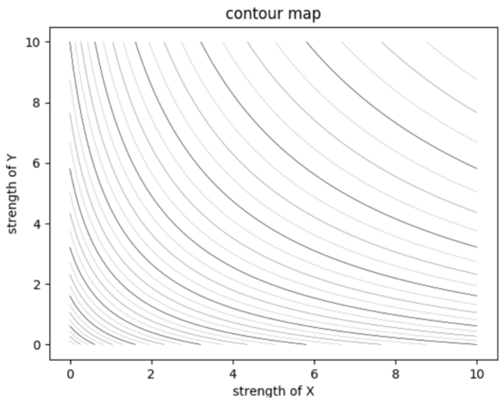

Figure 5 Indifference curves

Generally, the indifference curve is said to be convex to the origin. Also in the figure, they are convex to the origin. However, this is a case where the utility function follows the law of diminishing marginal utility.

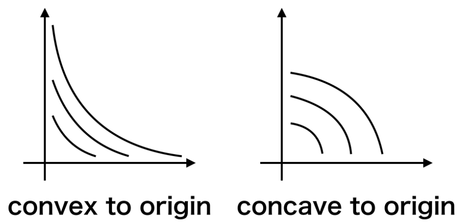

Figure 6 Convexity of indifference curves: convex and concave

S-curved utility function

In this paper, we discuss the case where the utility function is an S-shaped curve. The idea that the development of technology follows the S-curve is popular (Foster 1986). We also think that the utility function follows S-curve as well.

The phenomenon that the slope of utility becomes gentle when the feature is too small or too large is popular. For example, it is useless if the resolution of the camera is too low. So even if it improves a little, the utility rarely increases. On the other hand, if the resolution of the camera is too high, it is already sufficient for customers. So, even if it improves a little, the utility of the customer does not increase much.

We use sigmoid as a smooth S-shaped curve. We also use the utility function proposed by Adner (2004). His utility curve roughly follows the law of diminishing marginal utility. However, he introduced the concept of the performance threshold. If the performance is below the threshold, consumer's willingness to pay for the technology is zero.

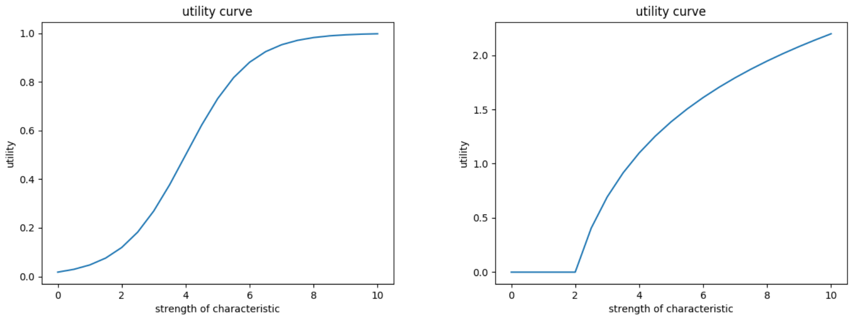

Figure 7 Sigmoid (left) and Diminishing marginal utility with a threshold (right)

The utility function on the characteristics space does not necessarily follow the law of diminishing marginal utility. If the utility does not follow the law, it changes the convexity of the indifference curve. In this paper, we show that this the change of convexity causes disruptive innovation sufficiently.

Budget constraint line and Technology constraint line

In the discussion on G-space, the concept of the budget constraint line is popular. In the case where the budget is limited, there are restrictions on the combination of goods that customer can buy with the budget. In other words, when expressing behaviors that customers can take in one point in goods space, there is a limit to the extent that the point can exist.

We discuss on C-space. We can think of a concept similar to the budget constraint line even on C-space. In one technology level, there are limitations on manufacturable products. For example, for a hard disk, if the technique of recording density is constant, increasing the recording capacity increases the size. Usually, the characteristics possessed by the product are not independent. Having a trade-off relationship between characteristics is common.

We call a line on this C-space expressing the constraint of productivity according to the technology level as "technology constraint line." The budget constraint line is considered to be a straight line. It is an assumption that the price per unit amount of each good is constant. The technology constraint line is not necessarily a straight line, but in this paper, we discuss only the case of a straight line because of the simplicity of discussion.

Also, we do not think about budget constraints in this paper. We think the price of a product is one of the characteristics of the product.

Technology constraint line moves gradually

The set of producible products expands according to the development of technology. That is, the technology constraint line is a function of the technical level t.

In this paper, to show that destructive innovation occurs even without rapid or discontinuous changes in technology, the technical level t increases gradually with time. In other words, in this paper, t is both the time and the technology level.

A simple mathematical expression can represent this expanding technology constraint line: $x + y \leqq t$.

Customer choice is the maximization of utility under technology constraints

The point that satisfies the constraint is a product that a company can produce. The utility shows how customers prefer the product. Therefore, the point where the utility becomes maximum under the constraint is the customer's most favorable among producible products. The computer can calculate the constrained maximization.

Experiments and result

In this paper, we use computer simulation so that we can repeat experiments with different conditions. We plan to release the source code in an executable state. The reader can verify our results and also can carry another experiment with different conditions.

Utility curves which follow the law of diminishing marginal utility

First, we explain the experiment by taking the case of utility functions with diminishing marginal utility. It is easy to understand since no surprising results occur.

Figure 8 is the utility function of each of the characteristics X and Y. Y is slightly smaller than X, but this is to make the figure easy to read and to promote understanding of the reader, and it has no deep meaning. In reality, it is rare that the utility functions of multiple characteristics match perfectly, so it is natural that there is a difference.

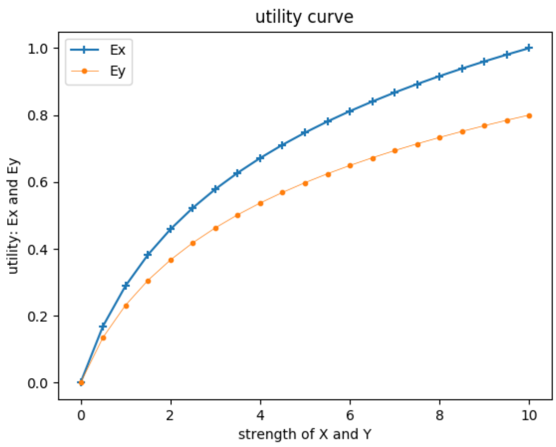

Figure 8 Utility curves which follow the law of diminishing marginal utility

In this case, the indifference curve is as follows. It turns out that curves are convex toward the origin. For example, the producible product at t = 8 is in the triangular area in figure 8, and the product with the highest utility within this area is the point of a star mark.

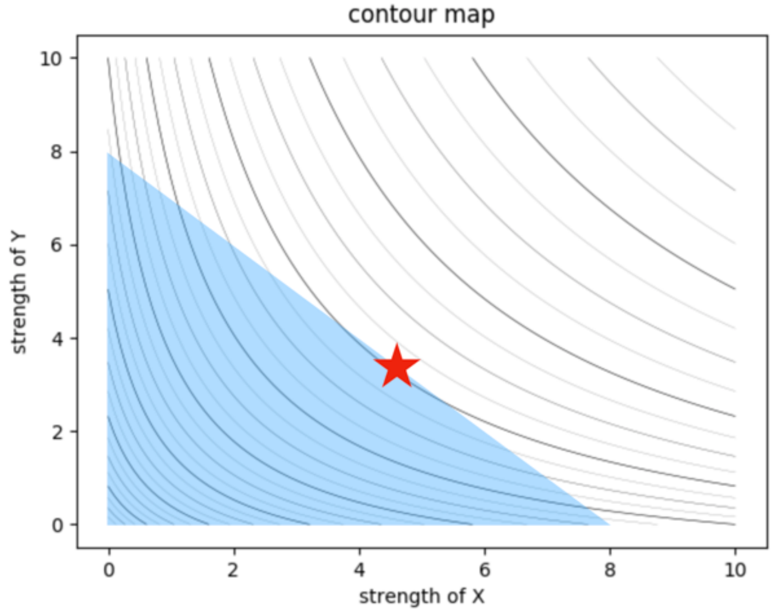

Figure 8 indifference curves, producible products and the highest utility product

Figure 9 shows the utility on the constraint line. The horizontal axis is the ratio of X to maximum X which is technically possible at that time t. Regardless of the value of t, you can see that products with 60% X take maximum utility.

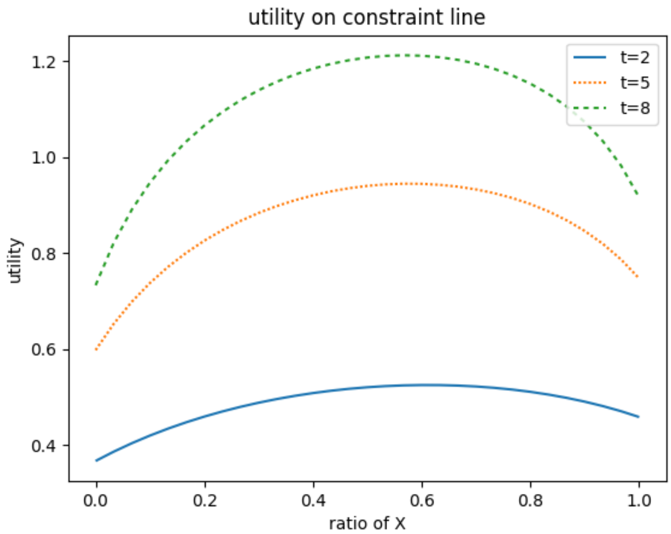

Figure 9 Utility on the technology constraint line

Figure 10 depicts the most preferred products available at each technology level t. Along with the gradual change of technology, we can see that product performance X and Y are both improved gradually.

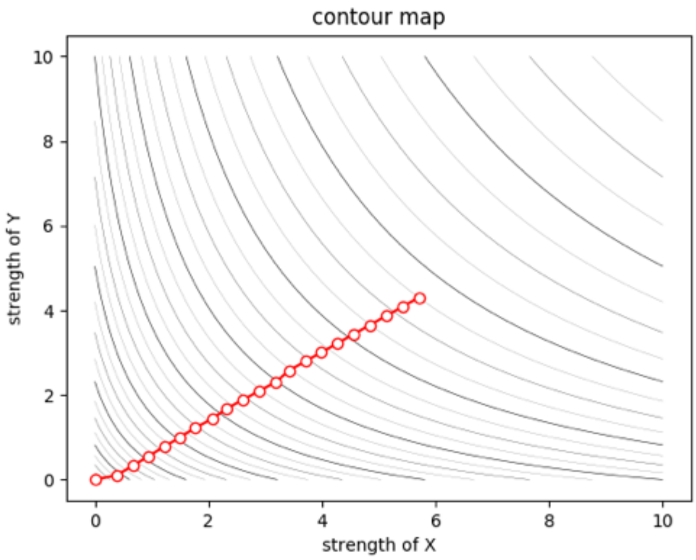

Figure 10 The most preferred products available at each technology level t

Figure 11 depicts these products with the technical level t on the horizontal axis and the strength of each product characteristics on the vertical axis. No remarkable phenomenon occurs in particular.

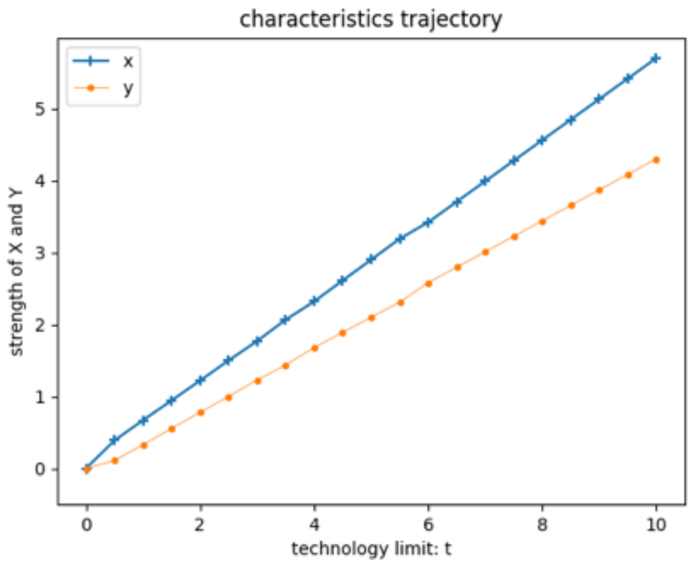

Figure 11 the strength of each characteristic of the most preferred products available at each technology level t

Smooth S-curved utility curves (sigmoid)

Let's see what happens if the utility is S-curve. We use sigmoids as smooth S-curves.

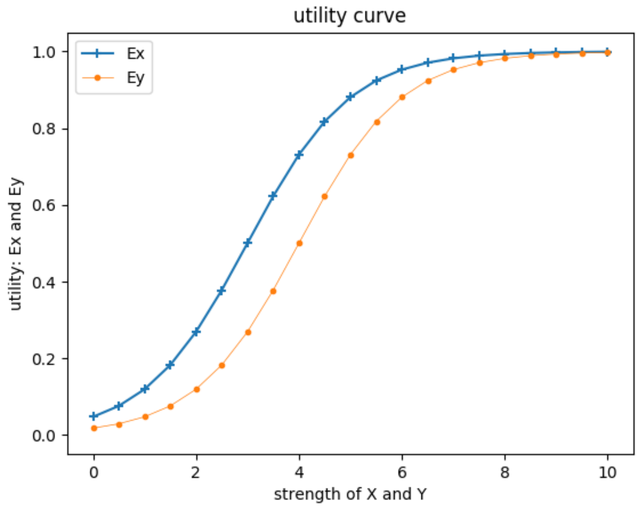

Figure 12 Smooth S-curved utility (sigmoids)

In this case, the indifference curves are as follows (Figure 13). You can see that the convexity changes at a time t = 7. It is concave to the origin at t < 7 and convex to the origin at t > 7.

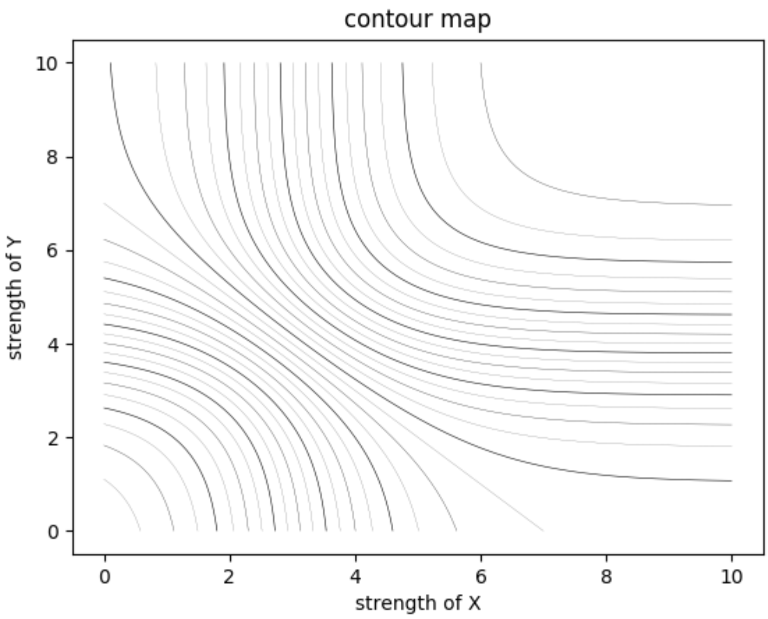

Figure 13 Indifference curves (sigmoids)

The figure of the utility on the constraint line expresses this change clearly (Figure 14). At t < 7, products with 100 % X are most preferred, but at t > 7 products that combine both X and Y are preferred.

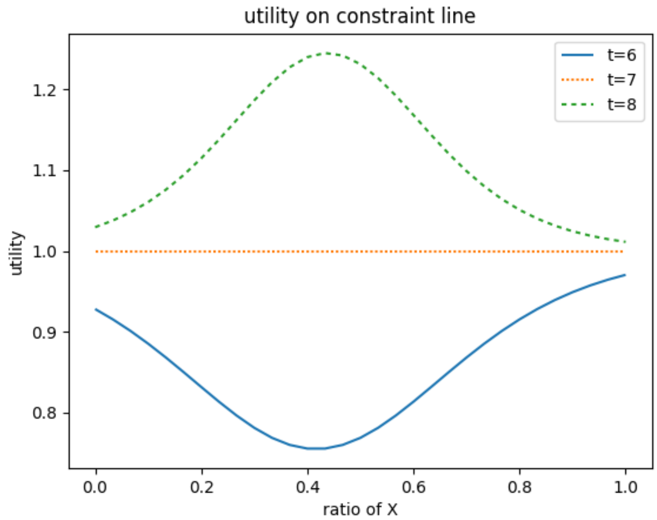

Figure 14 Utility on the technology constraint line

Figure 15 is the plot of the customer's most favorable product at each point. Although technology has changed only gradual, we can see that the products preferred by customers are changing drastically.

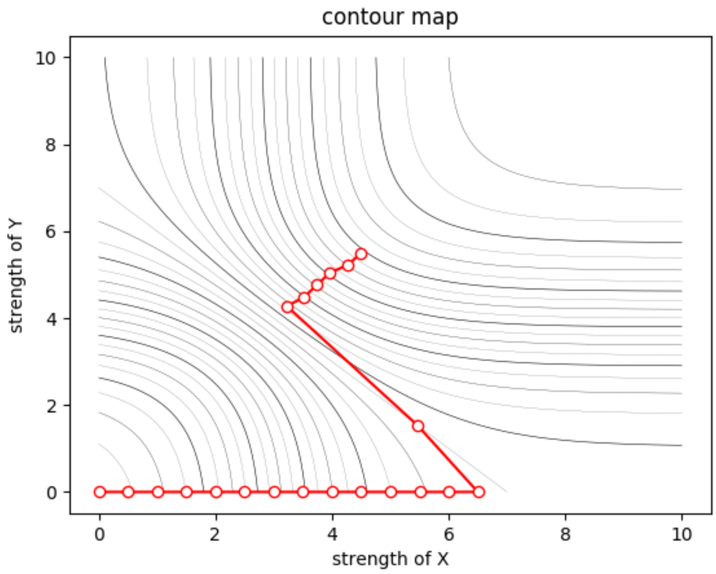

Figure 15 The most preferred products available at each technology level t (sigmoids)

Figure 16 shows the technical level on the horizontal axis and the characteristics of the product on the vertical axis. It turns out that at around t = 7, customers select goods with inferior performance X. The trajectory of the performance X is similar to the trajectory of destructive innovation.

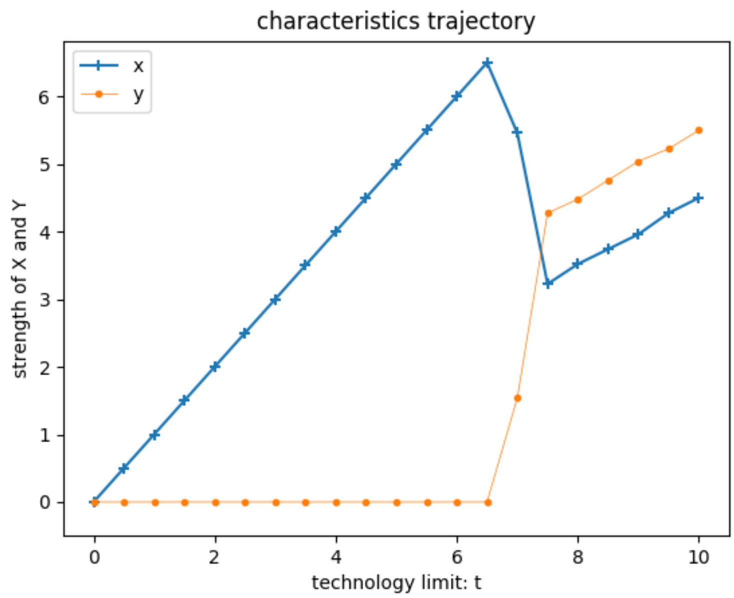

Figure 16 The strength of each characteristic of the most preferred products available at each technology level t (sigmoids)

Utility curve with a threshold

Let's consider the utility function with a threshold. Compared to the sigmoid case, this utility function has a point that is not smooth, so the graph created is a bit more complicated. From a global point of view, the same phenomenon as in the case of sigmoid occurs, so comparing both cases may help to understand.

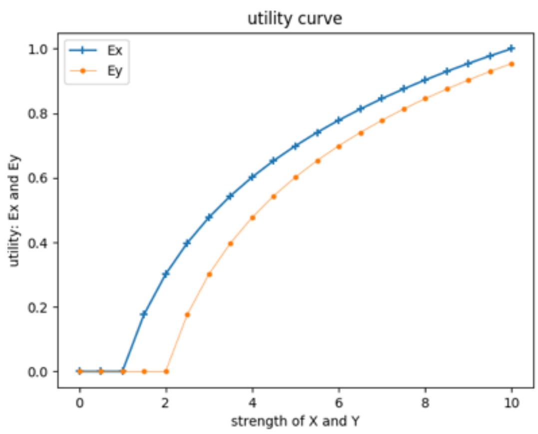

Figure 17 Utility curves with thresholds

The indifference curves are as shown in Figure 18. Because the utility curve is non-differentiable, the indifference curve also becomes a complicated shape which can not be said to be convex to the origin nor concave to the origin.

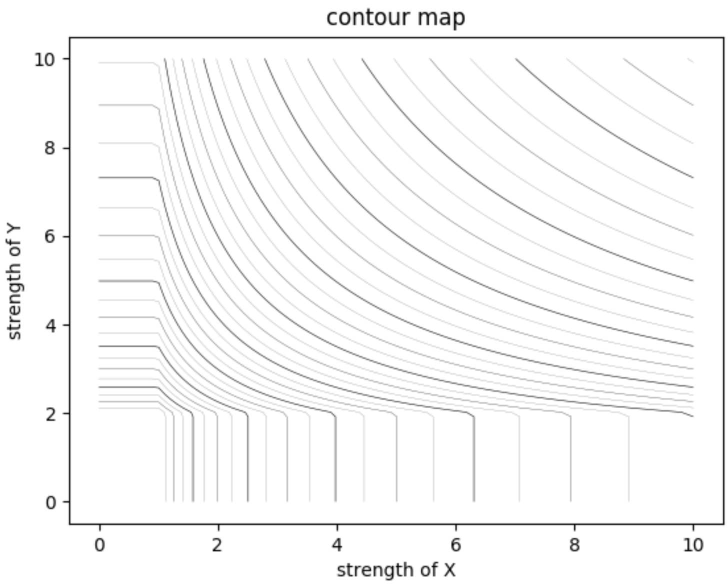

Figure 18 Indifference curves (utility with thresholds)

Surprisingly, the products that customers most prefer at each point of time change in a similar way as for sigmoid.

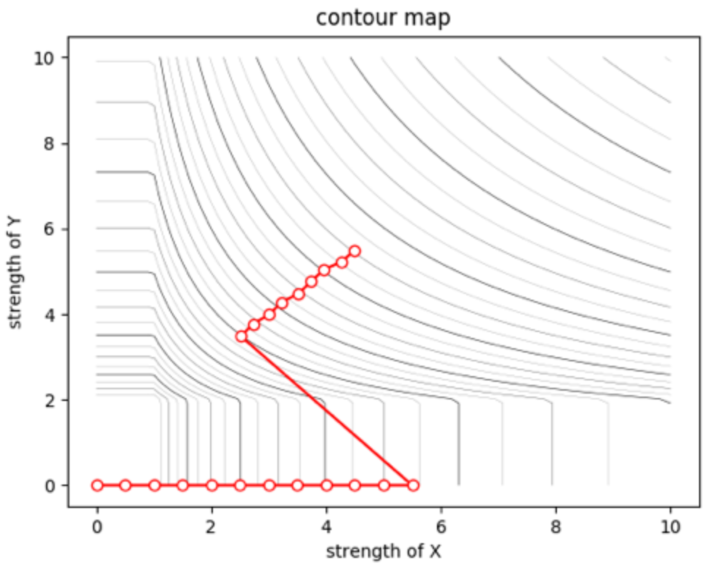

Figure 19 The most preferred products available at each technology level t (utility with thresholds)

To understand what is going on it is useful to observe the utility on the constraint line. Initially, due to not reaching the threshold, a mixture of X and Y has no utility (t = 2.5). As technology advances, the mixture gets utility (t = 5). By the law of diminishing marginal utility, the utility growth of X specialized type and Y specialized type products slows down. On the other hand, the utility of mixed-type products grows faster than them and overtakes them (t = 8).

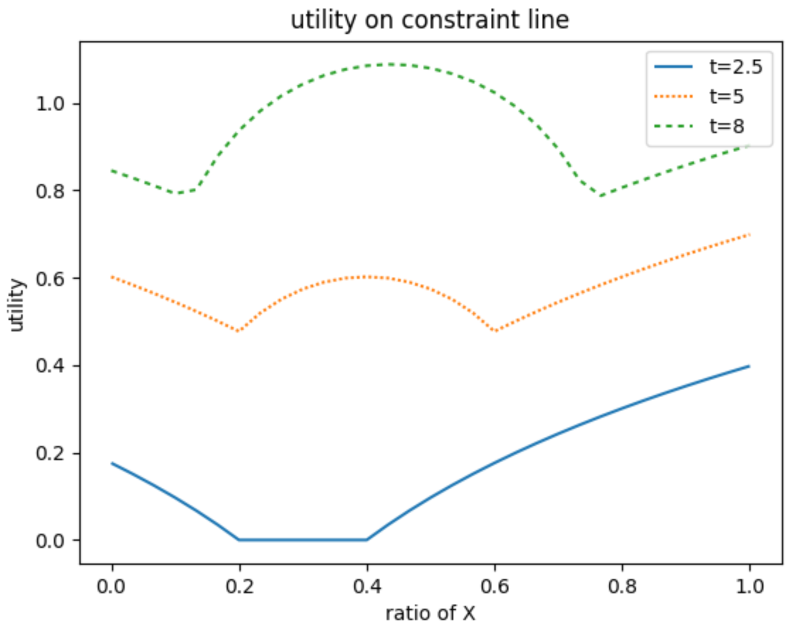

Figure 20 Utility on the technology constraint line (utility with thresholds)

Quadratic function approximation of utility

In the discussion so far, we showed that it is essential that the utility function does not satisfy the law of diminishing marginal utility. Marginal utility is the increment of utility when the customer gets one more unit of X. This is the first derivative of utility. This law of diminishing marginal utility is that the marginal utility decreases as X increases. It means the second derivative of utility is negative.

We approximate the utility function with a quadratic function and examine the effect of the value of the second derivative of utility function on customer behavior. In the quadratic function, the second derivative is a constant value. Approximation by a linear function whose first derivative is a constant value is widely spread. It is called linear regression. However, the graph of the linear function is a straight line, and the slope does not change. Therefore, the approximation by the linear function has an implicit assumption that the slope does not change. When assuming a change in slope, the quadratic function is the simplest. The slope mathematically corresponds to the first derivative, and the change of slope corresponds to the second derivative.

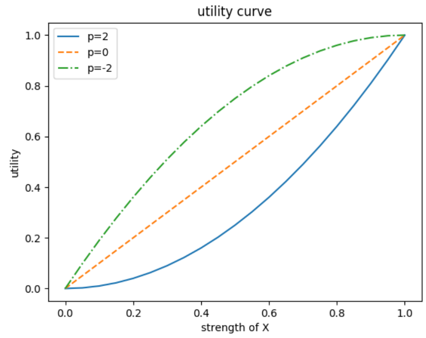

Figure 21 quadratic functions and their second derivatives

There is no reason to think that the entire utility function is a quadratic function. The quadratic function has a peak and is symmetrical. It is not suitable as a utility function. However, we can approximate a part of the utility function by a quadratic function.

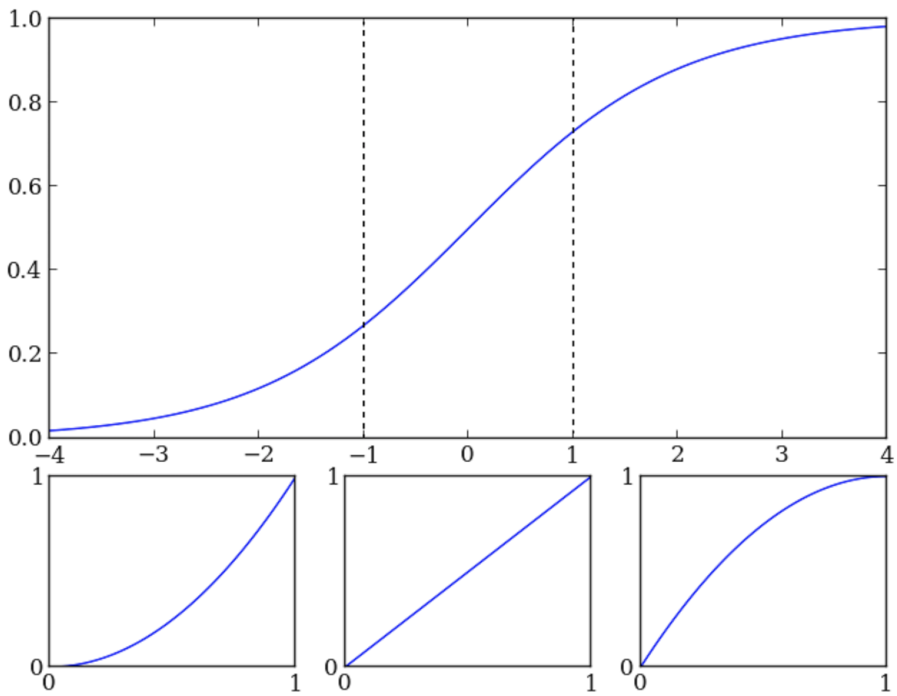

Figure 22 Approximation of sigmoid by quadratic functions

The sign of the second derivative

In the next experiment, we observe how the sign of the second differentiation affects the behavior of the customer. We fix the second derivative of one utility function with a negative value. It means that it obeys the law of diminishing marginal utility.

The figures show how the value of the second derivative of the other utility function affects customer behavior. In any case, customers prefer X 100% type product until some point. There is a difference in behaviors after the change point.

1. In the case of negative, the performance X and Y increase together.
2. In the case of zero, the performance X stops growing, and only the performance Y increases after that.
3. In the case of positive, the performance X gently decreases and the performance Y increases.

We can see the phenomena (1) and (2) in many products. In phenomenon (3) customers select products with inferior performance, in which we are interested.

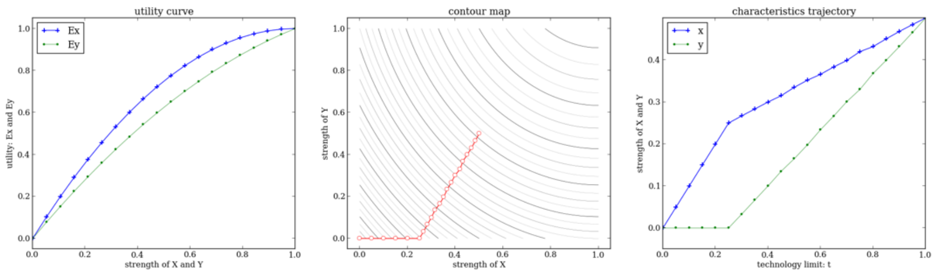

Figure 23 Case 1: negative(-1) second derivative

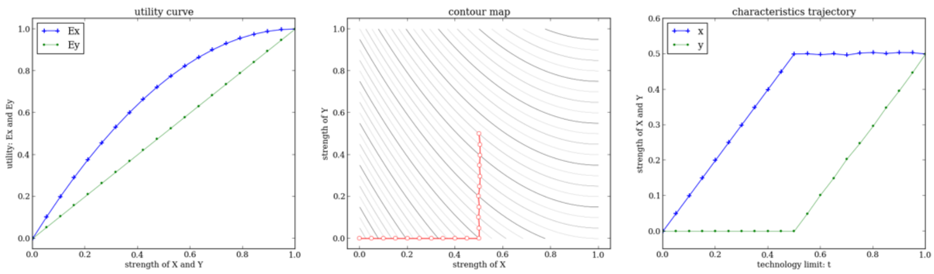

Figure 24 Case 2: zero second derivative(linear)

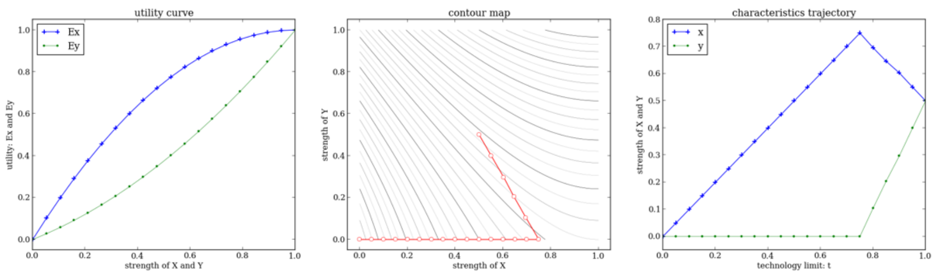

Figure 25 Case 3: positive(+1) second derivative

Speed of disruption

A slight change in the value of the second derivative indicates a significant influence on the speed of disruption. In previous experiments, we show that if the second derivative of the utility curve is positive, customers choice inferior products.

The figures show the results when the second derivative of the utility of Y is 1.0, 1.5, and 1.8, respectively. It is difficult to distinguish the difference in the utility curves between 1.5 and 1.8. However, this slight difference brings about a big difference in the speed of change in the products preferred by customers.

When the products preferred by customers changes rapidly, it is recognized as a disruptive innovation. This rapid change and the phenomena (1) and (2) come from the same model. The only difference is the value of one continuous parameter. There is no boundary line between these phenomena.

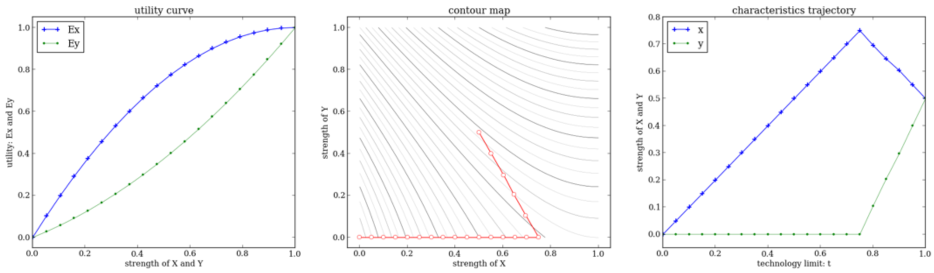

Figure 26 Case 3: positive (+1.0) second derivative (again)

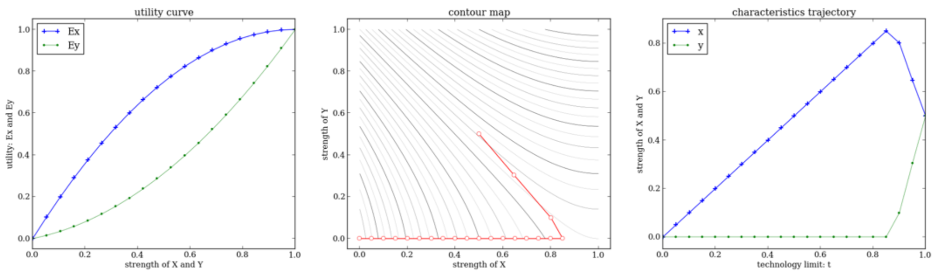

Figure 27 Case 4: positive (+1.5) second derivative

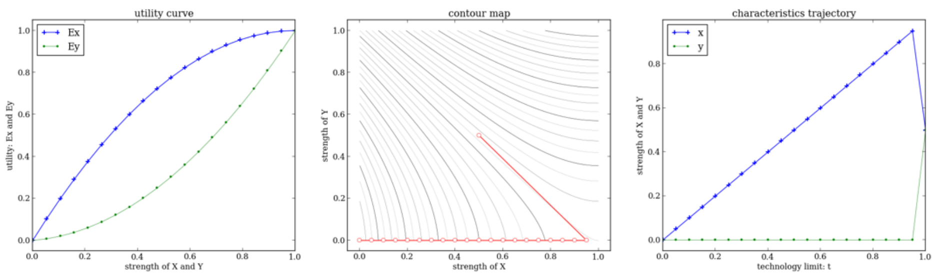

Figure 28 Case 5: positive (+1.8) second derivative

Conclusion and discussion

Three conditions which are not necessary

We showed three conditions which tend to be considered necessary is not necessary. The phenomena that customers choose products with inferior performance can happen without (1) competition between multiple firms, (2) rapid change of technology or (3) changes in customer preferences.

First, multiple firms and competition between them are not necessary. In our model, there are no multiple firms and no differences in knowledge, capability nor inertia. Even if the same company sells X 100% type products and X-Y mixed type products, the share of X 100% type product is robbed by X-Y mixed type product, which is inferior in performance X.

This phenomenon is often observed in the form of inter-company competition because it is rare that the same company continues to sell both X 100% type products and X-Y mixed type products. Many companies make decisions to concentrate resources on a well-selling X 100% type product.

Second, no rapid change in technology is necessary. Disruptive innovation is often thought of as a phenomenon in which a rapid change in technology occurs, and a new entrant who can follow the change beats an incumbent who can not follow the change. However, that is not necessary. We showed even if the technology is gradually changing, the phenomenon of rapidly losing the market occurs. Even in the process of disruptive innovation in the HDD pointed out by Christensen, there was no significant technical change in the hard disk.

Third, no changes in customer preferences are necessary. Many people think that customer preferences made unpredictable changes. Focusing on the goods purchased by the customer, what the customer likes seems to have changed from X 100% type products to X-Y mixed type products. However, the customer's utility function for characteristics has not changed. It is a distortion of cognition that the supply-side firms identify different X 100% type products as one product series. The demand-side customers do not select a product series, but select individual products based on their characteristics.

Two necessary conditions

We showed that if the two conditions are satisfied, the phenomenon that the customers choose a product with inferior performance occurs.

1. There are tradeoffs of multiple characteristics due to the technical constraint.
2. The utility function of at least one of the characteristics does not obey the law of diminishing marginal utility.

Regarding (1), We use a linear constraint in the analogy of the budget constraint line. Many other shapes can result in arguments in the form of utility functions by transformation of axes.

Concerning (2), depending on the shape of the utility function, the customer moves slowly to the product with inferior performance. Disruptive innovation is a phenomenon in which this movement is fast. Since the speed of this movement varies continuously according to the continuous change of the shape of the utility function, there is no boundary line between disruptive innovation and the rest.

Disruptive innovation under the gradual situation

The possibility of the phenomenon under the gradual situation tends to be ignored. To predict the rapid replacement of existing products with inferior performance products, we need to collect information on the utility of customers.

You may think it is already standard practice in marketing. However, we point out that there are common pitfalls. Do not investigate which product customers prefer, by showing customers the improvement from the best-selling products at the moment (Figure 29).

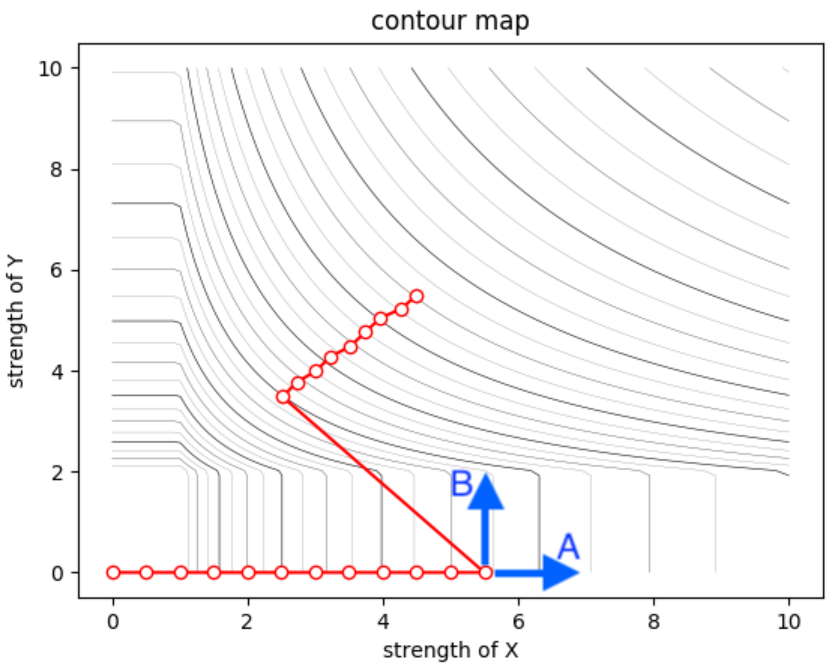

Figure 29 Asking customers which product do they prefer

If you ask your customer to compare A and B, they answer that A is better than B. Consumers always preferred the X 100% type products over the X 99% Y 1% type products due to the performance threshold. If the search scope of the survey is narrow, it strengthens the wrong belief. In figure30, A is always better than B, but the best product is C3. (If the utility function is sigmoid, this slope reverses at the moment of destructive innovation.)

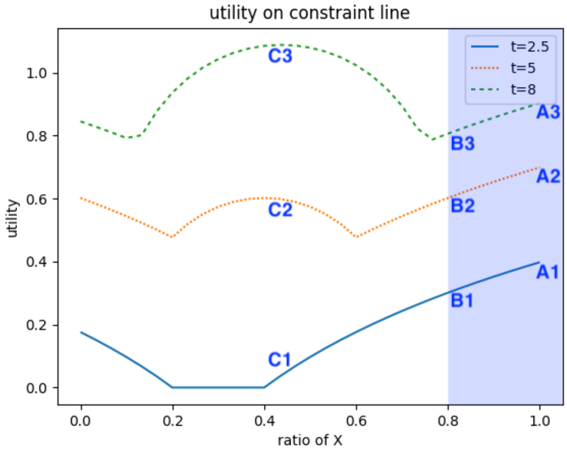

Figure 30 Focusing on improvement from current best-selling product

Strategies of new entrants

Many think that disruptive innovation is brought about by new entrants. Entrants often have disadvantages on production possibilities and production costs compared with existing companies. Therefore, they search customers avoiding the market of existing products (A1).

At t = 2.5, there are no customers (C1). They may find a small mountain (C2) at t = 5. This mountain is still low at this moment. So even if incumbent knows the mountain, they do not think it attractive (A2 > C2). However, this mountain grows faster than existing products (A3 < C3). If new entrant builds entry barriers, it leads to rapid growth of the entrant.

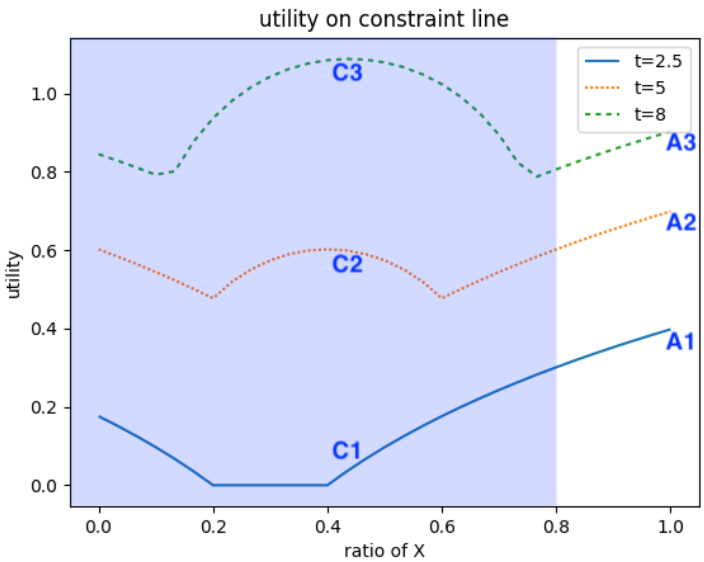

Figure 31 Focus of new entrants

Strategy of incumbents

Problems of existing companies tend to be narrowing their perspectives centering on products that are currently profitable.

If we consider the existence of customers as resources, incumbents concentrate too much on the use of resources they have already discovered, and there are few efforts to search for new resources. It is in contrast to new entrants taking much effort to search for new customers.

In the context of reinforcement learning, we call this an exploitation-exploration trade-off (Macready and Wolpert, 1998), and March (1991) discussed similar concepts in the context of organizational learning. A strategy that keeps the most profitable option based on past knowledge is called 'greedy policy.' It is known to be inefficient in the long run as it can not find better options. It is known that the strategy 'ε-greedy policy' which acts randomly with probability ε has greater profit in the long term (Sutton and Barto, 1998).

It is equivalent to assigning a certain percentage of resources to random actions, so in the context of management, it would be equivalent to, for example, allowing employees to use 20% of their working hours for free research.

Several algorithms based on the principle of "optimism in the face of uncertainty" are proposed. One of them, called the UCB algorithm (Jouini et al., 2010), compares choices using the upper bound of the confidence range from past experiences, not the expected value. The more uncertain an option is, the broader the confidence range, the more optimistically judged. In the context of management, it is a strategy when judging whether to invest in uncertain return assume high return optimistic. This strategy allocates resources to search for uncertainties.

Exercises for those involved in new product development in incumbents

Also, we propose a method to counter against bias that emphasizes the main characteristics of existing products. In the development of a new product, identify the cost to be used for the most important characteristics of the currently selling product, then halve the cost for the characteristic.

It is not just a cost reduction. By allocating the reduced cost to other characteristics, search products that increase customer's utility as a whole. Challenging this difficult task avoids excessive concentration in improving existing products.

In "Blue Ocean Strategy," the value innovation is a process to achieve both product differentiation and low costs (Kim and Mauborgne, 2004). If key performance falls due to cost reduction, this is strongly related to disruptive innovation.

Our future works

We found a pattern that customer shifts from X 100% to Y 100% and then shifts to X-Y mixed type. We also developed a method to observe changes in customer selection as a distribution by creating a model with limited customer cognitive ability.

We observed that the products preferred by customers first dispersed, then they converged to mixed type. This phenomenon may be related to the concept of the dominant design (Utterback and Abernathy, 1975).

In this paper, we assume that the shape of the technology constraint line is linear. As future research, we investigate the influence of the shape on customer behavior. The structure of technology may affect the shape of the technology constraint line, which may affect customer behavior.

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