Advances in Economics, Business and Management Research, volume 47
International Scientific Conference "Far East Con" (ISCFEC 2018)

The Modeling of Market Forces Influence on Innovation Performance

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Abstract— **This article provides a built and analyzed model of incremental technological innovations implementation which is based on the law of supply and demand. It is illustrated that the development of available technologies leads to the reduction of manufacturing costs, what, consequently, results in the increase of the quantity of manufactured goods and price reduction. However, revenue dynamics and profit margins are less clear, and the decrease after reaching the peak replaces the initial growth. It is proved that innovation performance depends on the slopes of supply and demand curves. Generally, innovation performance goes down along with the decrease of price elasticity of demand, and with the limit on the resources used in production. The proportionality ratio K is derived, and its high values lead to reduced efficiency of incremental innovations implementation.**

Keywords— The law of supply and demand, Innovation process, Modeling of innovation performance.

1. Introduction

Nowadays the innovative development is one of the priority areas of economy. In the majority of the Russian sources it is supposed that, above all, the intensity of research and development projects, the state of scientific and technical capacities affect innovative activity(e.g. [1-5]). Research also revolves around the process of market penetration of innovations (e.g. [6]) or interaction between innovations and available technologies, and products on the market. However, in some foreign papers [7,8], in Clayton M. Christensen's work [9] in particular, it is shown that the efficiency of seemingly most profitable innovations depends on the state of the market, producers' orientation of business processes on certain market segments, consumers' demands, etc. As a result, large, multinational corporations with great scientific and technical potential and which aim at market dominance, that are highly effective in most cases [10,11], can lose their market share due to untimely innovation adoption; for instance, when the demand was weak, and did not correspond with the size of the company.

Clayton M. Christensen's works [9,12,13]posed the question to our group about the possibility of mathematical modeling of market indicators influence on the efficiency of innovations implementation. Some of the research results are shown in this paper.

2. Materials and Methods

As a part of the research on the market indicators influence on the efficiency of innovative activity we suggest a model of incremental innovations implementation and assess the economic component of this type of innovative activity. In this study methods of mathematical modeling and mathematical analysis were used. Now we will comment on some notions related to innovative activity which are used in this paper.

Innovation — a newly introduced or substantially improved product (goods, service) or a process, new sales technique or organizational method in business practice, workplace arrangements or external liaison [14] (see also[7,8,15,16]). There are product innovations and technological innovations. The former ones lead to the appearance of new products, and improves the qualities of previous goods or service. The latter, which are modeled in this paper, concern changes in the manufacturing technologies, what results in the reduction of production costs.

In terms of the scope of change there are radical innovations (disruptive) and incremental (improving, evolutionary) [7,17]. Radical innovations are based on absolutely new or significantly changed technologies. Incremental innovations aim at changing technologies and products by making small, incremental improvements1. So, when conducting research on technological innovations it is reasonable to assume that incremental innovations steadily increase production performance, in other words reduce marginal costs of production. Furthermore, innovation process can be considered as a set of interrelated and interchangeable innovations which reduce marginal costs with certain pace (which can change over time, apparently). These days there is such a flow of incremental innovations in some fast growing industries — first and foremost, in computer technology development, telecommunication technologies, automation technologies, etc. — and has been reflected in Metcalfe's and Moore's laws and other (e.g.[18]).

Now we will consider everything mentioned above in terms of the law of supply and demand. Let us describe marginal utility (the utility of Q unit of production for the customer) with the equation $D(Q)=a-b\cdot Q+c(Q)$, where $E\equiv 1/b$ is price

[1] what brings this notion closer to kaizen philosophy, that is improvement by small steps[20].

elasticity of demand (similarly to [7]). According to the law of diminishing marginal utility, $b \geq 0$ (e.g. [19]) and $-b \cdot Q + \varepsilon(Q) < 0$ ($D(Q)$ decreases with the sales growth). In most cases, $0 \leq \varepsilon(Q) \leq b \cdot Q$ (however, in some cases it can be less than zero).

Marginal production costs (cost of producing Q unit of production) are described by the following equation: $Z(Q) = \alpha + \beta \cdot Q + \xi(Q)$. In most cases $\beta \cdot Q + \xi(Q) > 0$ (due to the increased cost for using additional and rare resources), however, the opposite is possible. Rare cases in which $\beta < 0$ are related to the decline of marginal costs alongside output growth. Usually, such rare cases occur due to insufficient use of fixed assets, network effect and similar occurrences of synergy. In such cases market mechanisms can often prove ineffective, and public regulation is necessary through implementation of 'natural monopolies'.

Now we will look at the simplest option, when $\varepsilon(Q) = 0$ и $\xi(Q) = 0$.

In the long run, prices and sales are determined by equilibrium price and sales (P^*; Q^*), when producer's costs for manufacturing extra production unit $Z(Q^*)$ are equal to customer utility, who is ready to buy that extra production unit $D(Q^*)$.

Thus,

$$a - b \cdot Q^* = \alpha + \beta \cdot Q^* \quad (1)$$

$$Q^* = (a - \alpha) / (b + \beta) \quad (2)$$

$$P^* = \alpha + \beta \cdot (a - \alpha)/(b + \beta) = a + b \cdot (a - \alpha)/(b + \beta) \quad (3)$$

According to the arguments presented above, we can assume that during incremental technological innovations either α or β decreases. The former corresponds with the increase of the production technologies efficiency of any production unit; the latter corresponds with the change of scarcity of resources as a result of incremental innovations implementation to their production, as well as due to improved use of substitute resources (e.g. the increase of use of fixed assets to substitute manual labour).

Now we will consider the influence of incremental innovations implementation. Let the constant component of marginal cost of production decrease as a result of incremental innovations implementation with the rate of $d\alpha/dt$.

For simplicity let us take $d\alpha/dt = \text{const} = \zeta < 0$. Thus, $\alpha(t) = \alpha_0 + \zeta \cdot t$. Let us consider the equilibrium amount of production when incremental innovations are implemented:

$$Q^*(t) = (a - \alpha_0 - \zeta \cdot t) / (b + \beta) = (a - \alpha_0) / (b + \beta) + \zeta \cdot t / (b + \beta)$$

$$Q^*(t) = Q^*_0 - \zeta \cdot t / (b + \beta) \quad (4)$$

In a more general case, when $d\alpha/dt \neq \text{const}$, the equilibrium amount of production is $Q^*(t) = Q^*_0 + (\alpha_0 - \alpha(t)) / (b + \beta)$.

Thus, equilibrium issuance, which occurs due to incremental implementations, is increasing in proportion to the reduction of production costs. In case with linear drop in marginal costs the increase of equilibrium issuance is also linear (see (4)).

Now we will place emphasis on an indicator which influences significantly the effect of innovations:

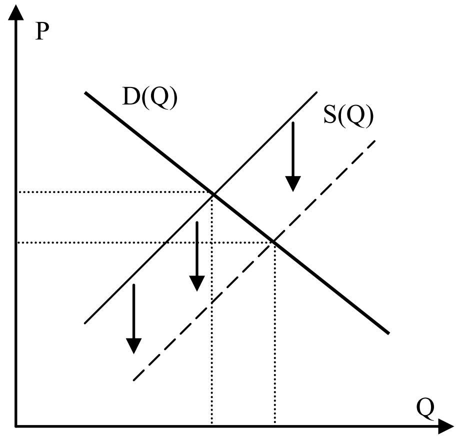

Fig. 1. The change in the supply curve due to incremental innovations implementation

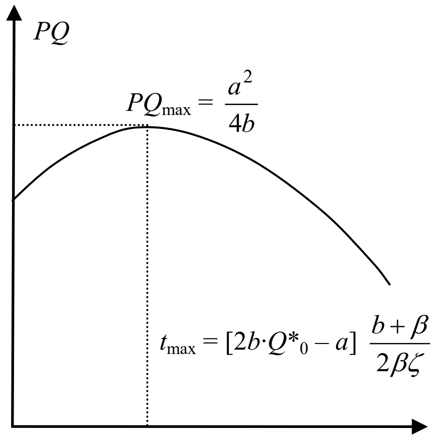

Fig. 2. The change in turnover under incremental innovations implementation

$$K = b + \beta \quad (5)$$

High values of K decrease the rate of production increase in terms of innovations implementation. Note that $K > 0$ for all economically relevant values of b and β since $b > 0$ from the law of diminishing marginal utility, and β is more than zero in the majority of cases. If $\beta < 0$ under heavy synergistic effects of goods production, the value of K is still more than zero since otherwise $b > -\beta$, which means that unit cost of any produced goods is higher than their expected maximum utility, and that makes such production unreasonable.

We should note that the rate of change of issuance depends not on the certain values of marginal cost and marginal utility, but on the rate of their change. The higher the elasticity of demand and the lesser the cost of producing extra goods (the lesser the rarity of used resources), the higher is the speed of production increase.

Let us examine the change of equilibrium prices under incremental innovations:

$$P^*(t) = \alpha(t) + \beta \cdot (a - \alpha(t)) / (b + \beta) \quad P^*(t) = \alpha_0 + \zeta \cdot t + \beta \cdot (a - \alpha_0 - \zeta \cdot t) / (b + \beta) = P^*_0 + \zeta \cdot t\,(1 - \beta / (b + \beta))$$

$$P^*(t) = P^*_0 + \zeta \cdot t\,(b / (b + \beta)) \quad (6)$$

Thus, along with the linear decrease in expenditure costs go down linearly with the coefficient as well $\frac{b}{b+\beta}=\frac{b}{K}$. As in the case with the change of production volume, high values of K decrease the effect of innovations implementation, but, on the one hand, low elasticity of demand increases the value of K, and on the other, compensates for its influence on the drop of the rate of price fall.

In a more general case when $d\alpha/dt \neq$ const, $P^*(t)=P^*_0 + (\alpha_0 - \alpha(t)) \cdot b/K$, which means that prices on the market drop in proportion to the decrease in production.

We should note that when $b \geq 0$ and $\beta \geq 0$ prices always change slower than expenditure declines, since $b/(b+\beta)<1$.

Let us consider the change in turnover under incremental innovations implementation:

$P^*(t)^* \cdot Q^*(t) = [Q^*_0 - \zeta \cdot t / (b+\beta)] \cdot [a - b \cdot Q^*_0 + \zeta \cdot t \cdot b/(b+\beta)]$ $P^*(t)^* \cdot Q^*(t) = Q^*_0 \cdot P^*_0 + t \cdot (\zeta/K) \cdot [2b \cdot Q^*_0 - a] - b \cdot (\zeta/K)^2 t^2$ (7)

We can see that the quadratic function describes the change in turnover under incremental innovations implementation. The maximum point is where

$(\zeta/K) \cdot [2b \cdot Q^*_0 - a] - 2b \cdot (\zeta/K)^2 \cdot t = 0$, in other words, when

$t_{max} = [2b \cdot Q^*_0 - a] \cdot K/(2b\zeta)$ (8)

According to (7), initially the turnover grows, but after t_{max} time starts to fall. If $Q^*_0 \geq a/2b$, the turnover starts to fall right after incremental innovations implementation. Let us define the highest value of turnover, PQ_{max}:

$PQ_{max} = Q^*_0 P^*_0 + [2b \cdot Q^*_0 - a] \cdot K/(2b\zeta) \cdot (\zeta/K) \cdot [2bQ^*_0 - a] - b \cdot (\zeta/K)^2 \cdot ([2b \cdot Q^*_0 - - a]$

$K/(2b\zeta))^2 = Q^*_0 P^*_0 + \frac{[2b \cdot Q_0^* - a]^2}{4b} = Q^*_0 \cdot (a - bQ^*_0) + \frac{[2b \cdot Q_0^* - a]^2}{4b} = \frac{a^2}{4b}$ (9)

The maximum of reached turnover depends only on the characteristics of the demand curve (a and b values). Nevertheless, turnover volume increases with lower $\frac{a^2}{4b}$ production volume, and decreases further (see Fig. 2).

Let is examine the change in customer's profit under incremental innovations implementation. Profit can be defined as revenue that is earned after paying the costs of producing under established sales volume (in equilibrium point), or:

$$P(t) = P^*(t) \cdot Q^*(t) - \int_0^{Q^*} Z \cdot Q \; dQ$$

For a simplified version with the linear functions Z and D with a rational limit $\alpha > 0$[2] it is obvious that $\Pi(t) = (P^*(t) - \alpha_0 - \zeta \cdot t) \cdot Q^*(t) / 2$.

Now we will transform the equation for profit using (4) and (6) for $Q^*(t)$ and $P^*(t)$:

$P(t) = [a - b \cdot Q^*_0 - \zeta \cdot t \cdot (\beta/K) - \alpha_0] \cdot [Q^*_0 - \zeta \cdot t/K]/2=$

$= 0.5\,[P^*_0 \cdot Q^*_0 - \alpha_0 \cdot Q^*_0 + (\zeta \cdot t/K) \cdot (\alpha_0 + \beta\, Q^*_0 - (\alpha - b\, Q^*_0) - 2\,\beta\, Q^*_0) + (\zeta \cdot t/K)^2]$

Since values of $(a - b\, Q^*_0)$ and $(\alpha_0 - \beta\, Q^*_0)$ are P^*_0, according to (1), then

$P(t) = 1/2\,[P^*_0\, Q^*_0 - \alpha_0\, Q^*_0 - 2\beta\, Q^*_0\, \zeta \cdot t / K + (\zeta \cdot t / K)^2\, \beta]$ (10)

The change of profit over time is obtained according to the formula:

$d\Pi / dt = 0,5(2 \cdot \zeta^2 \cdot t \cdot (1/K)^2 \cdot \beta - 2\beta \cdot Q_0^* \cdot \zeta / K) = \zeta \cdot \beta \cdot (t \cdot \zeta / K - Q_0^*)/K$ According to (4), $d\Pi / dt = -\zeta \cdot \beta \cdot Q^*(t)/K$

Since $Q(t) \geq 0$, $b>0$, $\beta \geq 0$[3], and $\zeta<0$, then the deprived value (see (11)) under those limits (particularly, assumption that $\alpha<0$) is always positive. Thus, profit from innovations implementation grows over time, at least while there is spending on the production of any quantity of goods.

3. Results

The modeling of incremental innovations implementation to the market was undertaken in the research. The results correspond with common perspectives: incremental innovations implementation causes a steady growth of production and cost reduction (see (4), (6)), and the rate of growth is inversely

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[2] goods production per se demands input. Reciprocal cases occur under synergistic effects when production of even not sold goods has commercial benefit which surpasses product cost. For example, it can be applied to goods which greatly affect the image of the company, or which provide opportunity to test new technologies, as with the case of IBM's production of not always profitable supercomputers. $\alpha<0$ can also occur if company has to maintain production at the minimal level in order not to suffer losses connected with conservation of equipment, for instance. However, the latter example can refer to the falling market, not innovation market.

[3] for $\beta<0$, which is marginal cost reduction under the production growth, that generally occurs due to strong synergistic effects, market mechanism is hardly efficient. When companies set prices at break-even point they suffer loss which should be offset by the government or, less often, by foundations. It can be seen from formula (10) that incremental innovations implementation leads to the increase of that loss what decreases the efficiency of innovative activity on such markets. However, it is known from the industrial organization that in such conditions natural monopolies are established, where pricing is slightly different and should be modeled independently.

proportional to $K=b+\beta$, the rate coefficient of convergence of supply and demand curves. Thus, the effect of increased production under incremental innovations implementation is lower for markets with low elasticity of demand and scarce resources (particularly, in terms of lack of access to foreign technologies and resources).

Initially, the turnover under incremental innovations implementation rises to the level $a^2/(4b)$, and then decreases. This knowledge is crucial when planning government revenue, which largely depends on indirect taxes that are proportional to the turnover. Company's profit (9), (10) is also growing under innovations implementation, and the rate of profit increase is inversely proportional to formerly introduced coefficient K, but the scarcity of resources raises the profit increase.

A particular result of the study is the highlighted coefficient $K = b+\beta$ in all formulae. When its values are high the efficiency of incremental innovations implementation decreases. Thus, the results of innovative activity depend not only on the characteristics of the innovative process, but also on the characteristics of the market to which those results are implemented. For markets with low elasticity of demand (high b) and scarce resources (high β) the positive impact of incremental innovations is significantly weaker than for markets with elastic demand and abundant resources.

4. Discussion

Built models and applied mathematical methods have shown the efficiency in the chosen subject area. The calculated results make it possible to draw conclusions about several aspects of the influence of market condition on the innovative process (first and foremost, about the influence of the elasticity of demand and marginal cost of resources on the efficiency of the commercialization of innovations). Results can be used in practical macroeconomic and microeconomic policy. Apart from that, even more peculiar results can be obtained when modeling fundamental innovations implementation, and studying the possibility of changing the production technology which is the aim of future research.

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