Application of the Real-Option Technique to Investments in Learning

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Abstract:

The aim of this paper is to apply the option valuation technique to the problem of firm's investments in learning, defining the structure of its two-staged optimization problem. It is shown further that even in this more complete setting, there still are such factors as inertia and the peculiarities of supply-side uncertainty, that cannot be modeled under the assumptions of optimizing behavior. The analysis points out the linkage between path-dependent behavior, inertia and the phenomenon of hysterisis, as well as the influence those factors have on the decision of the firm to investments in learning. Paper concludes by drawing five results proposing the likely effects on firm's decision making, and the possible changes in the industry structure, that different sets of the analyzed parameters would have.

JEL Classification Numbers: D23, D81, L21, O31, O33

Extended Non-Technical Summary:

What is the way in which firms make their investment decisions? How to they choose whether to invest in project A or project B, to be innovative or follow the leader? How is the set of firm's investment opportunities is created and maintained in the first place? Why and how does the investment policy of a given firm change over time? This is a list, although an incomplete one, of the questions this paper deals with.

The framework is not new, the Option Valuation Approach, a line of research stemming from the works of Fisher Black and Myron Scholes, was applied to real investments by numerous economists. What is novel though, is that while those applications concentrated on the question of what is the optimal way in which the firms can use the options they were endowed with, I consider this only a part of a problem a firm solves.

The real investments of the firms can be thought of as second-order investments, while the firms also have to decide on the investments in learning, or knowledge-accumulation, and these are the latter which are the main topic of the present paper.

Imagine indeed Firm A that is largely involved in specialized learning, building extensively on the previously acquired core competencies. It is innovative in the sense that due to the high specialization of the knowledge already existent within the structure of the firm, the large part of the further knowledge base building process involves internal learning processes. In case when no demand uncertainty is present, this firm is clearly in a good position, due to the acquired ability to create more valuable investment options. When market uncertainty is present, the picture changes. By placing itself within the narrowly defined brackets of highly specialized endogenous learning processes, the firm bears significant risks due to the large sunk costs connected to the investments in highly specialized learning. Also, this firm would have to bear large costs of re-learning, if a rival firm, or even the firm under consideration itself, comes upon a technological breakthrough, which deems the majority of Firm A's previously acquired knowledge unnecessary.

Now imagine Firm B, which is more flexible in the sense that it has broader set of competencies. If the demand is stable, it is clearly worse off: from one side it would have fewer and less profitable investment possibilities than the specialized firm, while from the other, the vast part of its capabilities would stay non-utilized. In the conditions of high demand uncertainty though, the flexibility of holding various capabilities becomes valuable. They give the firm an opportunity to switch from the current set of mostly utilized capabilities to the existent but currently underutilized capabilities, given some recent changes in technology deem that necessary.

Both firms bear dynamic transaction costs, although of a different kind. Firm A bears the costs of not having the necessary complementary capabilities when a drastic change occurs, while Firm B bears from one side the costs of not being able to make optimal investments from within the broad range of its competencies, due to being underspecialized; and from the other, the costs of having excess capacities when the marked demand is relatively stable.

The costs and benefits that enter the option valuation formula of the model thus include the sunk and variable costs ratio, supply-side costs, as well as bureaucracy costs connected both with learning processes and excess capacities.

Two further issues are analyzed: (1) how does exogenous and endogenous inertia influence the choices of the firm, and, (2) how does the supply-side uncertainty determine the size of the firm.

Exogenous inertia is related to the inflexibility of the overall institutional structure of the economy, affecting the activities of all the firms. Endogenous inertia depends on the intra-firm routines, and is applicable only to one exact hierarchy. Inertia is created by the previous learning within the firm, when it acquires high enough level of adaptability, and, although being very flexible within the statically taken state of institutions and the level of technological development, becomes largely inflexible to the drastic changes in either of them. Knowledge bases and the routines constitute an initial and irreversible (for any future time) sunk costs. In this circumstances, a firm, possessing less distinct and structurally rooted competencies may well be more effective in utilizing a new technology.

Thus, the analysis points to an interplay between the desired level of flexibility (both static and dynamic) and uncertainty. When the level of environmental uncertainty in the economy is low, the highly hierarchical and integrated structure of a large and specialized firm provides a more efficient framework for the further learning, due to a higher ability to utilize the positive externalities created in the process (economizing on the static flexibility). When the environment in which the firm operates is uncertain, the bounds of the core capabilities of a single firm will tend to be much narrower, while on the other hand the firm will tend to have a broader range of basic capabilities, market-sourcing will be used extendedly, and the framework of a small, but highly dynamically flexible firm organization will prevail.

The initial conditions as of the time when we start to apply the presented method of investment valuation have crucial effects. Depending on the level of specialization, and the level of knowledge accumulation already achieved within the firm, its optimal strategy would differ.

When the firm deems the demand-side uncertainty to be low enough, it gets involved in innovative activities. Given these were successful, it pays to go further and utilize all the investment possibilities that were created in this process. The firm would try to suck off all the juices from the created competencies, and it will be in a better position to do so than the new, less burdened with the relevant knowledge set firms. The followers then would try to get involved into connected, but requiring different set of competencies, learning processes. Eventually, sooner or later, some of the "new" firms would come up with an innovation that would undermine the advantage of the incumbent firm.

Now, would the latter firm shift to the newly designed technology straight off? The answer is – no -- it would by far not always be optimal to do so. Although the newly designed technology might be more beneficial ceteris paribus, given the proficiency and the experience of the incumbent firm in mastering the technological practices it uses, the eventual shift to a new technology would come much later.

This phenomenon is called hysterisis, and means that depending on the initial conditions in which the firm finds itself at the beginning of the period under consideration, its behavior might follow different patterns.

Imagine that the initial conditions can be parameterized as increasing with an increase in the existent relevant knowledge-base. Then, if we start the system at a point where the value of the parameter is small, and start to increase it, the system will stay stable, converging to an equilibrium in which it pays to the firm to be innovative, up to some point, when it will jump to a different temporarily stable equilibrium state, characterized by further utilization of the outdated technology, and accumulation of the knowledge required to master the newly designed technological processes. Increasing its value even further up, we would reach another jump, this time to an optimal policy characterized by further utilization of the outdated technology with the involvement in a separate innovative practices aiming at making the technology that is modern now obsolete with the introduction of even newer and more efficient technology.

Due to the continuous nature of the decision making process in the firm, it cannot adjust to the changing market conditions fully, because while the adjustment takes place, the problem that a firm solves changes just as well. In fact a firm's attempt itself to solve that problem changes the parameters of it, and hence, firm exhibits a "satisficing" rather than "maximizing" behavior.

The other crucial point analyzed further is the treatment of the supply-side uncertainty, and the impact it has on the decision of the firm about its optimal size. If both supply-side and demand-side uncertainty is high, depending on the initial *conditions, firms will stay relatively less specialized. In this case there still is a choice for them of whether to internalize the general knowledge acquisition, or market-source it. The interplay is in the relative significance of the bureaucracy costs related to excess capacity within the hierarchy and the supply-side costs related to the opportunistic behavior of potential knowledge-providers.*

The analysis in the most of the recent applications of the real-option technique to an investment decision theory concentrated on the question of what is the optimal way in which the firms can use the options they were endowed with in the process of choosing between internalizing relatively more specific or relatively more flexible assets in the production process. It was shown that with slight notational changes, the well-known technique of financial options valuation can be applied to any kind of situations that involve a choice between desired flexibility level in the conditions when both demand and supply uncertainty are present.

In my view, this kind of investment decision of the firm constitutes only a part of its overall decision problem. The real investments of the firms can be thought of as the second-order investments, while the firms also have to decide on the investments in learning, or knowledge-accumulation (the first-order investment decisions).

I would also argue that the decision making process that a firm has to undertake involves not only a choice between investing in different kinds of production assets, but also a choice between investing in different types of learning. Apparently, learning, and thus the process of creating the set of options for the real investments in the future, also involves a choice between investments with various sunk to variable cost characteristics, and can as well be modeled using a modified form of Black & Scholes option valuation technique.

Indeed, let us see on a simple example, what kind of choice does a firm have, and what kind of interplay is created when a firm makes a decision regarding the learning process.

Imagine a situation when a person, who already has some specific educational background, contemplates on the decision whether to further go *broader* in her education, acquiring specialties only remotely connected to the present one, and thus, expanding the future possibility of applying her resources on the job market depending on which specialties will be more valuable in the market conditions present at that time, or, otherwise, learn *deeper*, becoming better specialized in the field of previous studies, learning further only within and narrowly around the currently acquired specialty, and thus expecting to be paid a higher salary compared to the previous case. What are the parameters on which the decision is contingent upon?

If the job market (at least in the field of prior educational background of the person) is rather stable, and the demand on that specialty does not show a tendency to change in the future, then having several specialties, while using in result only the first acquired does not pay. It can be said that the costs (the sunk costs) incurred by the person to acquire a second specialty are never recovered in the future, in the sense that they do not increase either the possibility to find a job, or the expected salary. Thus, in the conditions of a stable and static job market, a person should clearly choose to go *deeper* rather than *broader*.

From other side, though, when the job market is volatile, the flexibility created when the person goes *broader* and thus acquires two or more specialties becomes valuable. In this case, even if the first specialty that a person did acquire is not valued on the market anymore (or is valued less), she has a choice to shift to a job where she can use her second specialty with smaller switching costs. Indeed, it sure is possible that even a person who went *deeper*, in the conditions when the demand on the specialty she acquired prior to that falls, can learn something else and apply these, new skills thereafter. It is just that in this case both the switching costs are higher, due to the absence of previous background in that new field, and the timing costs are higher, due to the fact that more time would be required to start from nil than to build upon the already existing capabilities.

It should become quite clear from the example that the structure of the decision-making problem in the example above is quite similar to the structure of the firm's investment decision problem that is usually analyzed in the recent stream of the literature on the topic[1]. What a person chooses is whether to acquire more specific skills, or be more flexible in the face of job market demand changes.

Clearly also, it is not only the individuals who are involved in the learning process, but also the firms. The example above can be easily retranslated to the question of a firm's learning process.

Imagine two firms in the economy with the following characteristics:

Firm A is largely involved in specialized learning, building extensively on the previously acquired core competencies. It is innovative in the sense that due to the

[1] See for example, Sanchez (1995), Sanchez (1998), Dixit (1992), Dixit and Pindyke (1994), Kreps (1984), Bowman and Hurry (1993), Riordan and Williamson (1985)

high specialization of the knowledge already existent within the structure of the firm, the large part of the further knowledge base building process involves internal or endogenous learning processes -- the firm has to learn by doing. In case when no demand uncertainty is present, this firm is clearly in a good position, due to the acquired ability to create more valuable investment options, based on the highly specialized and tacit internal knowledge.

When market uncertainty is present in the economy (or the industry in which the firm operates) to a large extent, the picture becomes less bright and optimistic. By placing itself within the narrowly defined brackets of highly specialized endogenous learning processes, the firm bears significant risks. Investments in highly specialized learning are characterized by large sunk costs. If the firms will take every opportunity to be innovative, they would have to incur these sunk costs every time, and in the conditions of a highly uncertain demand on the new products, produced with the help of acquired specialized core competencies, these sunk costs would become very risky. Apart from that threat, the highly specialized innovative firm would have to bear large costs of re-learning, in case when a rival firm, or even the firm under consideration itself, comes upon a technological breakthrough, which deems the majority of the previously acquired knowledge and skills of the specialized firm unnecessary.

It is quite clearly so in the case when the breakthrough comes from the rival's actions. Let us say that a *Firm A* was highly specialized and was very efficient in providing telephone cable connection. Then, with the invention of mobile phones, large part of its competencies becomes obsolete, because while the outcome of the possible investment projects still remains the same -- to provide telephone connection – the methods to be used in this process are different.

It still remains true even in the case when its the *Firm A* itself that makes the invention. Teece [1986] brings a perfect example of this possibility: the EMI's experience with CT scanner. The firm was highly sophisticated in electronics which let it develop the scanner, for which Godfrey Houndsfielf of EMI got the Nobel prize in 1979. It was not though sophisticated enough in the provision of medical supplies that the invention deemed necessary.

> GE subsequently acquired what was EMI's scanner business […] for what amounted to pittance. […] Though royalties continued to flow to EMI, the company had failed to capture the lion's share of

> the profits generated by the innovation it had pioneered and successfully commercialized.[2]

Thus, the innovative firm can actually harm itself with the innovations it makes, if it does not have the complementary capabilities. In this case, more flexible firms, although not being pioneers in any of the competencies they have, might be much better off than the innovative, but only narrowly specialized firms.

Now let us see the other possible extreme. Imagine *Firm B*, which, unlike the *Firm A*, is much more of a follower than an innovator. It is flexible in the sense that it has much broader set of competencies than the first firm. If the demand on the products in the industry where *Firm B* is operating is stable, then it is clearly worse off. From one side it would have much less investment possibilities than the specialized firm, and the investment opportunities it would have would be much less profitable, due to a lesser degree of knowledge accumulation in the particular field, and thus lesser probability of making a breakthrough. From the other side, it would be worse off because the vast part of its capabilities will stay non-utilized (at least if we do not consider possible for the firm to be large enough to utilize all the relevant and existing capabilities).

In the conditions of high demand uncertainty though, the flexibility of holding various currently non-utilized or underutilized capabilities becomes valuable. In the same line of reasoning as in the case of theorizing about the value of asset flexibility, the flexible set of capabilities gives the firm an opportunity to switch from the current set of mostly utilized capabilities (or the current set of investments) to utilization of already existent but currently underutilized capabilities, deemed to lead to more profitable investments given some recent changes in technology, or, in other words, given the change structure of the market demand. A firm then can be said to be holding a broader set of options.

These benefits arising from the flexibility considerations, should then be weighted against the costs of underutilizing the existent knowledge bases of the given firm.

Both firms bear dynamic transaction costs, although of a different kind. *Firm A* bears the costs of not having the necessary complementary capabilities when a

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[2] Teece, David J. [1986], *Profiting from Technological Innovation*, Research Policy, 15:6 , pages 298-

drastic change occurs, while *Firm B* bears from one side the costs of not being able to make optimal investments in the field which is the most profitable at the moment, and which is within the broad range of its competencies, due to being underspecialized; and from the other, the costs of having excess capacities when the marked demand is relatively stable.

Thus we can say that no single optimal policy for organizing the activities of the firms actually exist, the market structure is characterized by the existence of multiple equilibria.

It is possible to restate the option valuation technique to evaluate the investments in knowledge-bases, and this will be done further in this paper, but prior to doing that I would have to note that the problem here becomes much more complicated, due to the even bigger difficulties in treating the uncertainty and the problems that inertia brings about.

For now though let us recall the basic option valuation formula:

$$C = R_0\, N(h) - Ve^{-rt}\, N(h - \sigma \sqrt{t}) \qquad (1)$$

It is possible to reinterpret it in the following manner: C is the value of flexibility to be able to invest in a broader range of knowledge-bases, avoiding to specialize straight off, and thus holding an option to further specialize in one of the previously acquired competencies; R_0 is the current value of revenue stream from the learning process; $N(.)$ is the normal distribution function; h stands for a combination of the formula's other variables relating the movements in R_0 to movements in C; V is the expected variable costs of further learning contingent upon the movements in market demand; r is the risk free rate or return; t represents the time period when the acquired knowledge can be utilized; and σ is the standard deviation of R_0.

So, here the firms invest in learning to create an option to invest in particular kind of production technology later, upon the arrival of the information about the profitability of this further investment. And again, as in the case of investing in the production technology, both the firms that have previously chosen to invest into highly specialized learning and the ones that have chosen to invest into more flexible, general knowledge have the option to invest in the related technology or refrain from investing in it, contingent upon the state of the market demand.

Not surprisingly, the notion of *erosion* (see Sanchez [1998]), although in a bit different interpretation, is valid here as well. As it was mentioned already, one of the risks that the firm bears is connected with the fact that it might not have the necessary knowledge bases in order to recognize and use the options to invest in the relevant technology at the right time. If the market is competitive enough, this option will not stay there forever, and will be overtaken by a rival firm at some time. Thus the more time it takes for a firm to utilize its knowledge-bases in order to be able to further utilize the option to invest in the relevant technology, the less would be the value of the option created through acquiring the relevant knowledge-base.

Thus, the basic formula should be reformulated in the following way[3]:

$$C(\alpha) = R_0 e^{-\alpha t} N(h) - Ve^{-rt} N(h - \sigma \sqrt{t}) \qquad (2)$$

where α is the erosion rate.

In this representation, $R_0 e^{-\alpha t} N(h)$ stands for the present value of the revenue stream from the learning process, while $Ve^{-rt} N(h - \sigma \sqrt{t})$ is the present value of the expected variable costs of further learning contingent upon the movements in market demand.

Clearly, in the case when no uncertainty is present, the present value of the revenue stream from investing in specialized learning would be higher than in the case of more general learning, due to the fact that former creates much more, and much more profitable investment opportunities for the future. At the same time, the variable costs of future learning in case of a firm that have chosen to go *deeper* will be lower compared to the cost of the firm that have chosen to go *broader*, simply due to the fact that the latter firm would still have to learn more than the former in order to be able to realize and use the created investment possibilities.

Thus, I would argue that in a market conditions of no demand uncertainty, the firms would tend to be highly specialized and highly innovative, the optimization condition would require internalization of specific learning, and thus preference would be given to tacit endogenous learning-by-doing practices.

Uncertainty though is present in the real markets and this in my view is the major reason why many firms prefer to be followers rather than the pioneering innovators, and why even the ones that innovate do so only irregularly.

The costs and benefits that enter the option valuation formula above do not constitute a complete listing of all the costs and benefits of specific versus general knowledge acquisition. As in the case of real investments, here again, the formula should be amended with some other parameters. Let us now see what are these other variables that should enter the analysis.

First of all, investing in knowledge acquisition, firms obviously need to incur some sunk costs, apart from the variable costs. If variable costs here are the costs related to the investments in learning upon receiving the information about availability of the option to invest in the related technology, the sunk costs are the initial costs attributable to creating the related knowledge bases in the first place.

Supply-side costs are present here as well. By giving preference to internalized, endogenous learning processes, a firm bears less supply-side risks than in the case of a firm that does not innovate itself, using rather the external sources of knowledge acquisition, and tries to replicate the activities of the pioneering firms. The costs here are connected to the fact that much of the knowledge created internally in *Firm A* will be of a tacit kind, and might as well be protected by patents. It usually is much easier to get the access to relatively more general than relatively more specific knowledge through the market-sourcing procedures.

Apparently, costs of bureaucracy exist here as well. In this setting it is actually quite difficult to state whether more specialized knowledge acquisition involves larger or lesser bureaucracy costs. From one side, *Firm A* will bear substantial costs of organizing the internal learning processes, while *Firm B's* learning is relatively cheap. From the other side though, *Firm A* does not have to spend additional resources on the excess capacities, while *Firm B* will be largely affected by these costs. Therefore, it is better in this case to divide the bureaucracy costs into two separate categories: 1) bureaucracy costs connected to the learning process 2) bureaucracy costs connected to excess capacity.

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[3] just in the same way it was done by Sanchez [1998]for the case of real investments

Hence, in order to correspond to and reflect all the parameters discussed above, the firm's maximization problem can be restated now to the case of optimization of a firm's investments in learning process in the following way:

$$Max\ E[C(\alpha)_{1\ldots n} - (S + B_{lrn} + B_{ex.cp} + K_{ext})]_{1\ldots n} \qquad (3)$$

subject to:

$$l(s,v,f) \in L \qquad (4)$$

where S are the sunk costs of learning, B_{lrn} are the endogenous learning related bureaucracy costs, $B_{ex.cp}$ are the excess capacity related bureaucracy costs, K_{ext} are the supply-side costs related to exogenous learning, *L* is the set of available knowledge-base creation techniques, with its representative element *l*, which depends on the sunk/variable cost structure and the flexibility of being able to utilize the knowledge-base for several related technological processes, and *n* is the set of available technology designs.

This represents the first stage of the decision making process a firm is involved it. Obviously, creating options makes sense only under the condition that they will be used as the basis for the real investments. These are the *second-order*, real, investments, or in other words, the usage of the options created through solving the first stage maximization problem (and not just the options a firm was assumed to be endowed with in the earlier formulations of the problem) that lead a firm to getting profits, something that it in fact originated for[4].

And still, even in this two-stage setting, this is not yet a complete statement of the problem. Two additional points have to be incorporated into the analysis and namely: (1) how does endogenous inertia influence the choices of the firm, and, (2) how does the supply-side uncertainty determine the size of the firm. Those two issues cannot directly enter the maximization problem of the firm, because this is exactly

[4] Hence, although the discussion further in this paper concentrates on the complications with the formulation of the first stage problem a firm faces, it is necessary to keep in mind that in order to get a complete setting of the optimization problem, we need also to state the second stage of it. For, in my view, the most complete representation of this problem, and the one the analysis in the current paper is based upon, see Sanchez [1995] and Sanchez [1998]. I do not though consider it necessary to go in depth of formulation of the relatively more researched second stage investments optimization problem in this paper, due to my belief that the problems connected to it are of the same nature, but of a lesser degree as those we face with the formulation of the first stage problem

due to their existence that the validity of a mere usage of any kind of maximization based model of a firm's behavior becomes quite questionable.

Firm, as a hierarchical structure, allows for better organization of the learning process, but instead, it bears costs connected to a possible increase in the supply-side uncertainty above the limit when it is being offset by the value of the positive externalities created within the firm. And not only this. There exist an antipode to the learning process, *inertia*, that arises within the structure of the firm, and does not let it foster a further optimization of its strategic behavior (or even the tendency towards making it better). Inertia in organization is largely related to the notions of *path-dependency* and *path-creation*, and might take different forms, depending on the internal structure of the firm, the corporate culture within the firm, as well as such exogenous for the firm variables as the state of the institutional development of the environment in which the firm operates.

In this line of reasoning we can define thus two types of organizational inertia: *endogenous* and *exogenous*.

Exogenous inertia is related to the inflexibility of the overall institutional structure of the economy in which the firm operates, and therefore, affects the activities of all the firms. It might not affect all the firms equally, depending on the industry the firm operates in, and some intra-industry particularities. What is important though, and in what the distinction from the endogenous inertia is viewed, is that it stems from the common institutional constraints, and does not depend on the intra-firm behavior and *routines*.

These are exactly the routines of the firm that define the second, endogenous type of inertia. Routines of the firm organization can be considered as an institutional constraint as well, but would differ from the exogenous institutions due to applicability only to one exact hierarchy, or a firm.

Being an antipode to the learning process, endogenous inertia is also a consequence of it. Inertia is created by the previous learning within the firm, when the organization established is considered to feature a high enough level of adaptability. When this stage is achieved, the firm, although being very flexible within the statically taken state of institutions and the level of technological development, becomes largely inflexible to the drastic changes in either of them. It is as if the previously acquired knowledge base within the firm handicaps the ability of being objective enough to face a change. In more economic terminology, it is hard to change drastically the knowledge base and the routines, because they can be said to constitute an initial and irreversible (for any future time) sunk costs. In this circumstances, a new firm, or more generally, a firm, possessing less distinct and structurally rooted competencies may well be more effective in utilizing a new technology, and a 'change in industrial leadership' [Robertson & Langlois 1994] might occur. Thus, "while inertia is a profoundly functional organizational characteristic in stable/predictable environments, it is ultimately destructive when it impedes learning at times of significant change"[5].

Hence, the analysis points out to an interplay between the desired level of flexibility (both static and dynamic) and uncertainty. When the level of environmental uncertainty in the economy is low, the highly hierarchical and integrated structure of a large and specialized firm provides a more efficient framework for the further learning within and around the bounds of the core capabilities acquired and maintained, due to a higher level of ability to utilize the positive externalities created in the process (economizing on the static flexibility). When the environment in which the firm operates is highly uncertain and unpredictable, the bounds of the core capabilities of a single firm will tend to be much narrower, while on the other hand the firm will tend to have a broader range of basic capabilities, market-sourcing will be used extendedly, and the framework of a small, but highly dynamically flexible firm organization will tend to prevail.

Clearly, markets and firms, as alternative structures of organization both provide opportunities to learn, and both suffer from inertia. Learning itself can be both endogenous and exogenous.

Endogenous learning, or learning-by-doing, usually becomes more important when the endogenous institutions of the environment in which firms operate, are underdeveloped. In the face of a major change, like the one we experienced in the near past after the collapse of the Soviet bloc, the market, being itself a rather loose, but complicated mechanism, proved to be very inert. Large, established communist-era enterprises in most of the cases also proved unable to adapt to a change with a

[5] **Robertson, Paul L & Richard N. Langlois** [1994], *Institutions, Inertia, and Changing Industrial Leadership*, Industrial and Corporate Change 3(2), page 366

high speed, and started to lose the advantage in the knowledge-base endowments that they previously had. Newly created, small and dynamic firms, on the other hand, without having in the background the *negative* experience of working in a more stable and static environment, and thus, having less inertia in the structure, were more efficient in building new competencies, necessary to cope with a change. It can be said, that the structure of the markets and the large state-owned firms made it virtually impossible for endogenous learning to take place. Small firms on the other hand, proved to be able to efficiently enough coordinate the individual competencies of the employees and the dynamic flexibility they were endowed with, to fill in the niches created after the change took place, building new competencies.

Another example of the validity of the outlined ideas might be the large presence of jointly-owned enterprises created these years in the post-communist countries. Amalgamating the knowledge of operating in the developed market economies, the *western* part had, and the knowledge of the local market needs and the nuances of the local institutional structure that the *eastern* entrepreneurs had, it became possible for these joint-ventures to create an internal coordination and learning structure best able to adapt to the present dynamic environment.

On the other extreme, endogenous learning is a very important factor, when although the markets are well-established, and the institutional environment provides incentives to innovate, the extremely dynamic development of the industry the firm operates in, strong competition, and the high level of very tacit production knowledge makes it very difficult for the firms to replicate the technology or technological processes, even when the change is not revolutionary, but evolutionary.

Exogenous learning, or learning-by-learning, though, can also be a very important factor, with the conditions of highly developed and comparatively static environment, and when it is possible to learn the value of an investment in the conditions of uncertainty from sources external to the structure of the firm that can take advantage of this information.

The initial conditions as of the time when we start to apply the presented method of investment valuation have crucial effects. Depending on the level of specialization, and the level of knowledge accumulation already achieved within the firm, the optimal strategy of this particular firm would change drastically. The whole process of learning can be said to be highly path-dependent.

As Robertson and Langlois write:

> Inertia results from, and in a sense embodies, the best features of the stable phase of the cycle because it is based on the learning process in which producers determine which procedures are most efficient and effective. Once people are satisfied that they know how to do things well, they have very little incentive to look for or adopt new methods[6].

Stable phase here is the period of time when the firm deems the demand-side uncertainty to be low enough to get involved in an innovative activities, and thus in endogenous learning. Subsequently, given that a firm is already involved in specialized learning, it pays to go further and utilize all the investment possibilities that were created in this process. The firm would try to *suck off all the juices* from the created competencies, and it will be in a better position to do so than the new, less burdened with the relevant knowledge set firms.

But what would the other firms try to do then? Clearly, they would try to answer to this actions by the incumbent firms with involvement into connected learning process, which would though require different set of competencies, a set in which the incumbent firm does not have a comparative, or a head-start advantage. Eventually, sooner or later, some of the “new” firms would find this answer and will come up with an innovation that would undermine the advantage of the incumbent firm.

Now, would the latter firm shift to the newly designed technology straight off? The answer is – no -- it would by far not always be optimal to do so. Although the newly designed technology might be more beneficial *ceteris paribus*, given the proficiency and the experience of the incumbent firm in mastering the technological practices it uses, the eventual shift to a new technology would come much later.

> Inertia is often a product of successful adaptation to earlier innovations, as a firm develops ways of operating that appear to be so well suited to its internal and external environment that it sees

[6] **Robertson, Paul L & Richard N. Langlois** [1994], *Institutions, Inertia, and Changing Industrial Leadership*, Industrial and Corporate Change 3(2), page 361

> no reason to change. In many instances, this adaptation may prove so effective that the firm can retain a total cost advantage for a prolonged period despite using an outdated technology because it can still capitalize on its mastery of compatible support and ancillary operations, while firms adopting a new, and technically more efficient technology, are still wrestling with the expensive process of acquiring the endogenous and exogenous institutional backup necessary to gain full value from the innovation.[7]

This phenomenon is called hysterisis, and means that depending on the initial conditions in which the firm finds itself at the beginning of the period under consideration, its behavior might follow different patterns. Imagine that the initial conditions can be parameterized as increasing with an increase in the existent relevant knowledge-base, and denote this parameter χ. Then, if we start the system at a point where the value of χ is very small, and start to increase it, the system will stay stable and will converge to an equilibrium in which it pays to the firm to be innovative, up to some point (which is called in mathematics a *bifurcation value*), when it will *jump* to a different temporarily stable equilibrium state, characterized with more inert behavior, by which I mean, further utilization of the outdated technology, while at the same time accumulation of the knowledge required to master the newly designed technological processes. Actually, it might be that the system would have two bifurcation values in this case. Indeed, increasing the value of χ even further up, we would eventually reach a point, where the system would make another jump, this time to an optimal policy characterized by further utilization of the outdated technology with the involvement in a separate innovative practices that would aim at making the technology that is modern now become obsolete with the introduction of even newer and more efficient technology.

Interestingly enough, if we start the same process with large values of χ, the bifurcation value will not stay the same as before. As Hale and Koçak note:

> The important observation about this experiment is that a system experiences a jump at two different values of the parameter; moreover, the parameter value at which the jump takes place is

[7] **ibid**., page 368

> determined by the direction in which the physical parameter is varied![8]

Non less interesting is an observation that due to the continuous nature of the decision making process in the firm, it does not really have much chances to adjust its problem to the changing market conditions, because while the adjustment will be taking place, the static optimization problem that a firm solves will change just as well. This statement actually can be expressed even in more radical terms, saying that a firm's attempt itself to solve that problem changes the parameters of it, and hence, firm exhibits a "satisficing" rather than "maximizing" behavior.

The other crucial point that need to be analyzed further is the treatment of the supply-side uncertainty, and the impact it has on the decision of the firm about its optimal size. The previously held analysis showed that under the conditions of high supply-side uncertainty, the specific knowledge accumulation will be internalized within the hierarchy of the firm, given that the demand-side uncertainty is relatively low. But if it is also high, depending on the initial conditions, some firms might decide to be less specialized.

In this case there still is a choice for them of whether to internalize the general knowledge acquisition, or market-source it. The interplay is in the relative significance of the bureaucracy costs related to excess capacity within the hierarchy and the supply-side costs related to the opportunistic behavior of potential knowledge-providers, e.g. in the sense of high level of coverage of this knowledge by patents. Depending on the relative costs, firm would then either stay small, and not pay for the excess capacities, or be larger and not pay the costs of external knowledge acquisition.

Now, I have all the necessary variables defined, and can finally state the results.

<u>Result I:</u>

If there is no major demand-side uncertainty present in the economy, and the market is rather stable, the firms that have previously internalized specific capabilities would be likely to retain the dominance on the given market and be better off, going *deeper* in the knowledge-base creation process, acquiring closely related competencies only.

[8] **Hale Jack K. & Hüseyin Koçak** [1991], *Dynamics and Bifurcations*, Springer-Verlag. New York, page 32

The economy would be characterized by relatively high level of comparatively regular innovations, that would follow a step-by-step evolutionary pattern rather than be revolutionary. In other words, firms would be better-off making *competence-enhancing* innovations, rather than *competence-destroying* revolutionary ones, trying to use the cost-advantages that the mastering of the previously made innovation brought about, while at the same time getting involved in building closely-related competencies that would give them a possibility to introduce an innovation when the costs/benefits analysis tells the firm to do so.

Result II:

In the face of a drastic change that makes the existing capabilities of the incumbent firms obsolete, the specialized firms would be likely to loose the comparative advantage after some time, when the comparative benefits in experience would be overweighed by the comparative benefits of the new firms using newer, lower variable-cost technology. In this case the firms that went broader will be better-off, and if the bureaucracy costs related to excess capacities are not high enough, compared to the costs of external knowledge acquisition, the firms that internalized general knowledge loosely related to their narrowly defined core competencies would overtake the market. At the same time completely new firms can also win, if the relative costs of external knowledge acquisition are low enough, or if the change is so drastic that even the broad base competencies of the flexible firms do not help them to be comparatively faster and more successful in utilizing the new investment opportunities.

Result III:

The stronger is the competition, and subsequently the larger is the rate of erosion, the more is the value of flexibility created within the hierarchy of the firm. Firms that are flexible enough to recognize the investment opportunities quickly will be able to stay in a good position on the market, while the inflexible and inert firms, the knowledge-bases of which handicap the incentives to actively look for new developments and new necessary learning, will probably be able to hold their market share only in the case when the previously acquired learning proves to be very long-living and no major innovations making this knowledge base obsolete are being introduced.

Result IV:

Although already partly mentioned in the previous results, it is very important also to note that the firms that are highly specialized in their capabilities, and build upon them, slowly shifting the exact range of the capabilities, depending on the prevailing market conditions, by both getting involved in learning new similar capabilities, and “forgetting” the obsolete part of the previously acquired ones, will still be less able to adapt new technology which is unrelated to their capabilities, than the firms that do not have the inertia, resulting from the previous experience. This is due to the hysterisis phenomenon, when the same conditions present on the market affect different firms with different starting levels of the acquired knowledge-bases in a different way.

Result V:

If the bureaucracy costs related to excess capacities in the economy are relatively higher than the costs connected to the external acquisition of general knowledge, the firms would tend to stay small and very flexible, although the time for recognition of the options to invest in new technology would come later. If on the other side, even the relatively general knowledge in market is mostly covered by costly to acquire patents, or if the industry in which the firm operates involves a high level of tacitness of technological and production information, firms would tend to be larger, and it will be easier for them to catch up with the emerging new options.

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