

Chapter 2

Escalation of Expectations over Past Performance

Complexity Arises When You Try to Please Customers

The past is never dead; in fact, it's not even past.

William Faulkner¹

The principle of *escalation of expectations* describes the idea that customers value innovation to the extent that it surpasses their performance benchmarks, which were in turn created by the accumulation of past innovations. However, this is not a simple linear relationship in which the outcome is proportionate to the input effort. Instead, the result of innovation firm's efforts is quite nonlinear, often behaving much like the proverbial single straw that breaks the camel's back. The *escalation of expectations* is the mechanism that allows small changes, for instance, a small request made by a random customer demographic, the passage of a new law, or perhaps the wishes of a CEO, to become astronomically amplified in its impact throughout the innovation system. The escalation of expectations sets entire firms along a particular path of innovation, in which targets get set, ideas emerge, alternatives are searched for, and chances are taken. Out of this process, firms build up deeper reserves of know-how, and customer expectations ratchet forever upward (and sometimes, as we will see, even sideways).²

¹Requiem for a Nun, Random House (1951).

²Dorothy Leonard (1995) was among the first scholars to offer arguments for building capability through a self-reinforcing or "virtuous" loop. She has also pointed out that *innovation capabilities* are "deeply rooted in the past," and often grow organically. These arguments have shaped our thinking about the principle of escalation of expectations in the sense that we integrate the issues of evolutionary complexity and selection through market feedback mechanisms into the broader literature on product innovation capability. This literature has evolved considerably over the past 20 years; see, e.g., an edited volume by Garud and Karnoe (2001), and a recent exposition of these ideas at Infosys Technologies by Garud et al. (2006).

In order to explore the nature of escalation of expectations, we consider the development of the automotive industry during the last quarter of the twentieth century. The 1970 U.S. Clean Air Act and its various amendments combined with rising gasoline prices forced automotive engineers to reduce air polluting auto emissions and increase fuel efficiency. Up to that time, automotive engines were controlled primarily by mechanical means such as centrifugal spark advances and carburetors. However, the prevalent mechanical control technologies could not attain the degree of precision necessary to meet the legislative requirements associated with increased fuel efficiency. To solve this problem, the “Big Three” automotive companies in the USA shifted their engine control architecture from mechanical to electronic control. Therefore, these automakers were able to implement sophisticated software algorithms instead of mechanical manipulation to control the flow and combustion of gasoline in the engine. Electrical engineers with an expertise in control systems needed to implement this innovation stream simply did not exist within automotive design teams prior to 1970. To train and develop these engineers in sufficient numbers took automakers more than a decade. However, by the end of the 1980s, legions of them were employed by all the major automotive companies. Nowadays, engines are routinely controlled by electronics within small microprocessor devices, similar to those devices that run the personal computers.

In summary, for automotive manufacturers, a disruption created by Clean Air Act and the rising gasoline prices in the early 1970s led to a need for greater capability in electronic control system design. Firms could only accomplish this by developing sufficient numbers of in-house engineers with the appropriate training in electronics and experience in automobiles over a 10-year period. At first this capability was used simply to meet the requirements of the Clean Air Act. After raising product performance back to acceptable levels by developing a capability in electronic control systems, the automotive industry began to look for other market needs that these capabilities could fulfill. As stated by Jerry Rivard, former vehicle controls guru of Ford Motor Company:

As integrated circuit technology evolved, it became possible to design many functions into integrated circuits, thus eliminating a lot of discrete components ... electronic engine controls were representative of how the [automotive] industry evolved vehicle subsystems.³

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- Leonard-Barton, D.: *Wellsprings of Knowledge: Building and Sustaining the Sources of Innovation*. Harvard Business School Press (1995).
 - Garud, R., Karnoe, P.: *Path Dependence and Creation*. Lawrence Erlbaum (2001).
 - Garud, R., Kumaraswamy, A., Sambamurthy, V.: *Emergent by Design: Performance and Transformation at Infosys Technologies*. *Organ. Sci.* **17**(2), 277–286 (2006).

As pointed out in the body of the chapter, this logic does not apply to competence destroying innovations:

- Henderson, R., Clark, K.: *Architectural Innovation: The reconfiguration of existing product technologies and the failure of established firms*. *Administrative Science Quarterly* (1990).

³Rivard’s views are described in www.sae.org/automag/electronics/09-2002. Many of the details in this part are based on the first authors work at Ford. For detailed discussion of the underlying

That is, once the electronic design capability was developed to address legislative requirements, U.S. automotive manufacturers found that they had acquired product architecture, control and software engineering capabilities that allowed them to develop a number of features that were inconceivable prior to the introduction of electronic controls. According to Rivard, this change enabled the development of such customer-pleasing features as antilock brakes, traction control, all-wheel drive, advanced maintenance diagnostics, communication and navigation systems, and thermostat-controlled air-conditioning, which had nothing to do with the 1970 Clean Air Act Requirements that created the auto industry's electronics controls capability in the first place. Interestingly, these new features were initially positioned by automotive marketers as exciting novelties, but, as in the case of antilock brakes, some of them shaped consumer preferences to such an extent that they soon became "standard" options without which a new automotive model could not compete in the marketplace.

Other features such as four-wheel steering did not find any customers and disappeared seemingly without a trace. A similar innovation-change cycle may be underway again with the advent of hybrid and electric vehicles. Some of the underlying technologies that might be ushered in by these changes involve energy storage and charging of batteries. Interestingly, one could argue that this current development, involving hybrid vehicles and perhaps remotely controlled vehicles, would have been impossible without the prior development of electronic control capabilities driven by the Clean Air legislation and allied amendments. If one compares the dimensions on which rating firms, such as J.D. Power Associates, review the performance of automobiles, it is easy to see that electronics and smart/clean technology-based performance measures are increasingly evolving into the key basis of comparison among automotive consumers. Some of the follow-on innovations like GM's OnStar system were embraced; others, such as four-wheel steering were not. In both cases, however, these developments were unanticipated results of the 1970 Clean Air Act that disrupted the industry and led to an unforeseen series of customer-pleasing innovations.

It is difficult, but possible, to study the emergence of software and electronics development capability within the automotive "ecosystem." Such studies may specify individual elements, such as the performance specifications for microprocessors or battery technologies in terms of simple sets of mathematical rules. One can then abstract these individual actions and connect them appropriately through feedback loops to explore the complex interactions that create the patterns of their collective behavior. Next, we describe a graphical methodology that will allow the reader to follow these connections we have identified between market needs and product performance within an innovation system. Later, we show that this system follows the *principle of escalation of expectations*, which reflects the collective evolution of the

case, see Anderson and Joglekar 2005 (Anderson, E.G. Jr, Joglekar, N.R.: A hierarchical product development planning framework. *Prod. Oper. Manage.* (2005)). The integration of mechanical and electronic technologies that is needed to implement offerings such as OnStar is discussed in Joglekar and Rosenthal (2003).

- Joglekar, N., Rosenthal, S.: Coordination of design supply chains for bundling physical and software products. *J. Prod. Innovat. Manage.* (2003).

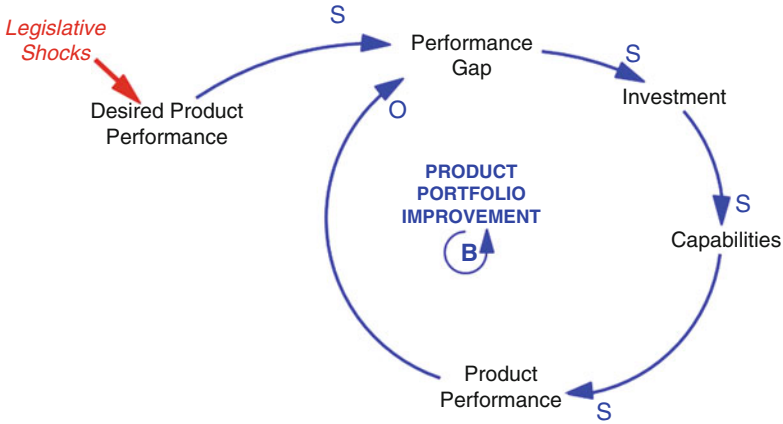


Fig. 2.1 Capability development—a balancing loop

market landscape. These behaviors can be studied more deeply with the aid of a computer simulation, as discussed in the appendix.

Our discussion of *escalation of expectations*, however, cannot complete until we discuss disruptions. From time to time, a novel type of product emerges based on a new architecture that makes the existing stock of painfully accumulated capabilities irrelevant. For instance, Henderson and Clark (1990) offer a discussion of competence destroying innovation sequences from the photo-lithographic industry. Such a disruption did in fact happen to the mechanical control engineers who designed carburetors and spark plug advance mechanisms in the automotive industry, as described earlier. Hence, the escalation of expectations results in the innovation system behaving predictably some of the time and almost randomly at other times. This is why we mentioned in our earlier discussion that market expectations can sometimes move sideways. Moreover, shifts between predictability and unpredictability are often unexpected. Thus, in some sense, the role of time in the *escalation of expectations* must be reset, for example, a firm's capability levels may be reduced or even wiped out and some new types of capabilities may need to take their place. Thus, understanding the impact of the butterfly effect becomes, if anything, more significant in such settings.

Evolution of Complexity

Describing the dynamic complexity of the innovation butterfly and its implications for the innovation systems with mere words is difficult. System dynamics is a social science methodology that explores dynamic complexity in industrial landscapes and offers a visual language for helping us understand them called causal-loop

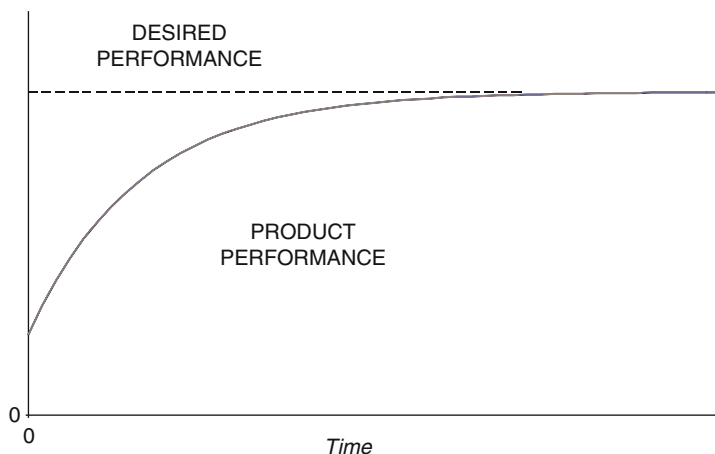


Fig. 2.2 Balancing loop behavior of product performance

diagrams.⁴ A causal-loop diagram of electronics capability development in the automotive industry is shown in Fig. 2.1.

Causal-Loop Notation: S stands for support (or positive correlation), e.g., increase in desired performance increases the performance gap. O stands for oppose (or negative correlation), e.g., increasing product performance reduces the performance gap. If there is no symbol shown for ease of exposition, the link would implicitly indicate “S” relation in reading the diagram.

In Fig. 2.1, start with *Legislative Shocks*; in the language of causal-loop diagrams, this is a variable, meaning that it has a value that can increase or decrease. Because the number of legislative shocks affects *desired product performance* in terms of acceleration and other measures of engine quality, an arrow shows the causal relationship between the two variables. All other things being equal, increasing requirements, e.g., legislated standards for fuel efficiency, increases desired product performance; likewise decreasing legislative requirements decreases the desired product performance.

Following the chain of variables around the loop in Fig. 2.1, as auto engine performance improves, the gap between desired performance and actual performance decreases. An “O” at the head of the arrow links these two variables to show this opposite relationship. This in turn will reduce the need for further *investment* in that particular capability. Because *investment* moves in the same direction as the performance gap, this link is left unmarked. If the performance improves and the performance gap reduces over time, it will reduce the need for future investment in that capability. When this cycle repeats over multiple generations of product introduction, any change in capability—or any other variable in the loop—will eventually feedback on itself. When this occurs, the circular chain of linked variables is termed a “causal loop,” or more simply, just a “loop.” Interestingly, increasing any

⁴Sterman, J.D.: *Business dynamics: systems thinking and modeling for a complex world*. Irwin/McGraw-Hill, Boston (2000).

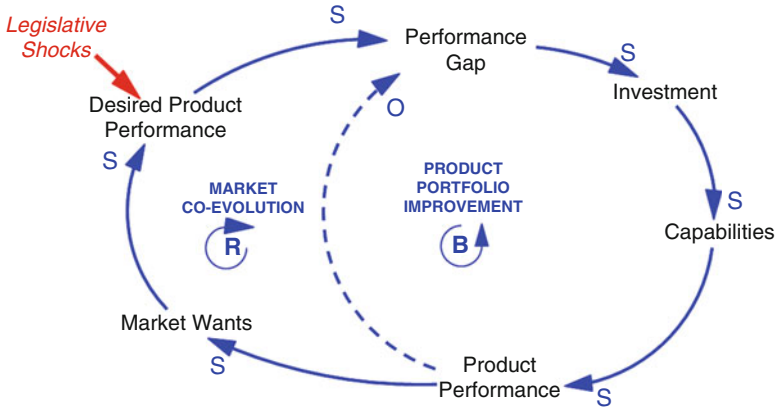


Fig. 2.3 Twin loops in an innovation system (A version of these loops was initially suggested by Professor Jay Forrester. For a formal analysis of these loops, involving investment in R&D and production capabilities, using a data set on several generations of Intel’s microprocessor products, and allied market demand, see Joglekar (1997)⁵)

variable in this capability loop will eventually result in a countervailing pressure to reduce further changes in that variable. These are called “balancing” loops and are denoted with a “B” within a circular arrow at the center of Fig. 2.1. The resultant evolution of product performance is shown in Fig. 2.2 in which a balancing loop creates a drive in the system toward a desired performance goal.

However, Fig. 2.2 does not fully capture what happened as the consumers came to embrace various manifestations of the electronic controls revolution in the automobile industry. The desire for product performance is never likely to remain static—it evolves over time. For instance, product features such as antilock brakes became standard equipment because of shifts in consumer expectations and desires. This second dimension to the growth of electronic control system capabilities is shown in Fig. 2.3 in the “market co-evolution loop.”

The “desired product performance,” term captures the formulation and escalation of the consumers’ expectations for the product. As the available product performance increases, the consumer want even a better product and raise their expectations, i.e., raise the desired product performance level.

If one tracks the outer loop in Fig. 2.3, it is evident that as *product performance* improves, it prompts *market wants*, i.e., consumers’ desire enhanced product performance, to also increase.

This phenomenon drove U.S. auto manufacturers to raise their *desired product performance* in order to remain competitive, thereby increasing the *gap* between desired and actual performance. This gap caused firms to increase *investment* in the capability to further develop this aspect of product performance. Over time, the

⁵ Joglekar, N.: *The Technology Treadmill: Managing Product Performance and Production Ramp Up in Fast-Paced Industries*. MIT Sloan School of Management, Thesis (1997).

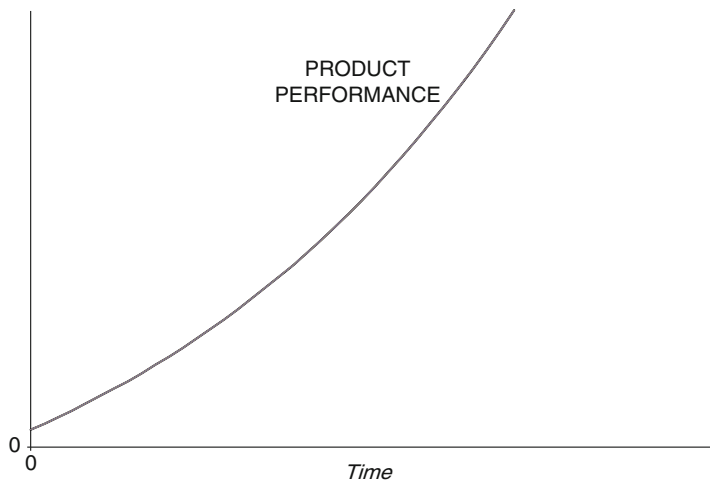


Fig. 2.4 The reinforcing effect of the market co-evolution loop

capability itself improved, resulting in improved product performance. These sorts of loop dependencies drive performance escalation as shown in Fig. 2.4. The fact that any increase in product performance (or any other variable in the loop) will result in further increases in that same variable lead labeling the loop a “reinforcing loop” and is noted in the left-hand side of Fig. 2.3 by an “R.”

For convenience, this loop is identified in Fig. 2.3 as the “market co-evolution loop,” because product performance, firm capabilities, and market desires co-evolve and lead to a reinforcing effect between the variables involved in this loop. However, such a reinforcing behavior may operate both ways. If a product’s performance declines, eventually consumers will adjust their behavior and demand for this product will decline—although this may take a long time—changing what had been a “virtuous” cycle of growth into a “vicious” cycle of declining demand. For instance, with the advent of sensor technologies in videogaming, the competitive focus and market demand have moved away from improving the graphics and rendering quality, as discussed for the Wii case in the previous section.

Embedded Complexity⁶

“Their work was, as it were, a wheel within a wheel...” Ezekiel 1:16

This is far from the end of the loops within loops that complicate the management of innovation systems. Typically, another reinforcing loop is also at play. The practice of any given capability will ultimately result in individual and organizational

⁶Complex physical systems are endowed with nested or replicated patterns connections (see for instance, http://en.wikipedia.org/wiki/Mandelbrot_set) for a discussion of Mandelbrot Set.

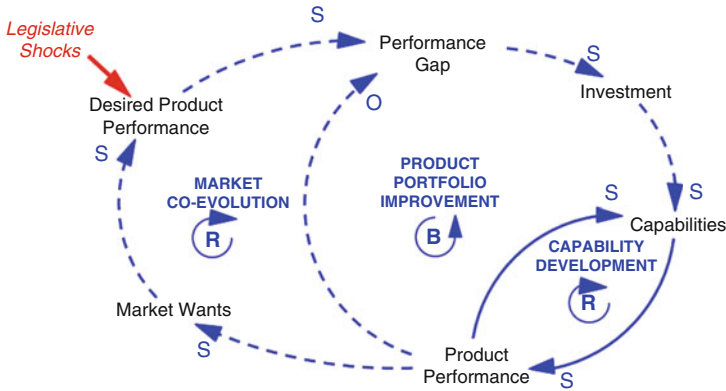


Fig. 2.5 The innovation system with learning effects

learning, leading to an improved capability. This is the classic “learning curve” as it exists in the product development world. It is represented by the “Capability Development” loop shown in Fig. 2.5.⁷

However, we have not yet fully examined how the escalation of expectations (i.e., how the effect of time impacts the outcome) plays out in the product innovation system. In particular, we have not yet considered the fact that variables such as desired product performance, investment and the realized product performance have delays between their cause and effect. For instance, the investment decisions may be a part of an annual planning cycle, while the product performance will only be visible to the consumers after each new generation is launched, which might in some industries occur only every few years. In Fig. 2.6, the most significant delays are marked.⁸

In most industries, the delay in forming market wants is relatively long compared with those of the other two delays, which are associated with product portfolio improvements. However, these long delays are crucial to understanding the system because even managing a very simple feedback loop with a long delay can

Such nested patterns also occur within an innovation system at lower levels of abstraction: a project, a task or subtask, and so on (see Sosa et al. 2007). For ease of discussion, we exclude nested loops that occur in lower levels of abstraction.

- Sosa, M., Eppinger, S., Rowles, C. A Network approach to define modularity of components in complex products. *J. Mech. Des.* (2007).

For discussion of tipping points and disruptive innovations, see:

- Gladwell, M.: *The Tipping Point: How Little Things Can Make a Big Difference*. Little Brown, Boston (2000).
- Christensen, C.: *The Innovator’s Dilemma: When New Technologies Cause Great Firms to Fail*. Harvard Business School Press (1997).

⁷This graphic is a simplification of the reality. For the learning to accrue, teams must be incented, coached, enabled and their success be celebrated, such that such effort becomes a part of the organizational culture. Some of these issues are addressed in Parts II and III.

⁸The effects of delays can be particularly insidious in managing the innovation systems. David Ford and John Sterman have modeled many aspects of their effects in the presence of rework.

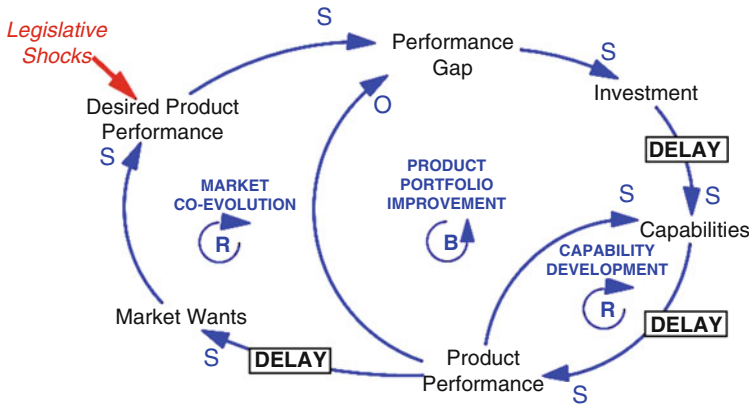


Fig. 2.6 The innovation system including delays

be difficult. As a very simple example, consider your morning shower. When you step into a shower and it is too cold, the natural reaction is to crank up the hot water. Usually, however, the water does not heat up for at least 30 seconds. Because we are often impatient, we crank up the hot water handle further. Then, finally the hot water begins to flow through the pipes to the faucet, at which time we generally discover that we have made the water far too hot and we jump away from the scalding shower. Oftentimes, this is immediately followed by turning the hot water handle down too much, followed by the inevitable cold shower.

This shower example contains only a single loop in terms of the action and reaction between the person controlling the shower temperature and the desired temperature. It also features a delay between the person raising temperature and hot water flowing through the faucet. Similarly, in the innovation system's diagram shown in Fig. 2.6, we have three separate delays, each of which is of a different scale that ranges from weeks to months or even years. One can imagine that managing this system of delays is an inherently challenging task. And, in fact, this is true. Numerous studies have shown that our trouble in adjusting the shower temperature also appears when controlling management systems, only worse (for a survey of the literature on managing feedback and delays, see Sterman 2000). The inherent difficulty in managing the underlying complexity within these three loops is somewhat akin to the act of an elephant balancing a beach ball on top of a long pole, which is in turn balanced on tip of its trunk, as shown in Fig. 2.7.

The elephant has to manage a dynamic system similar to the shower example, but this elephant has to worry about multiple points of balance rather than one. It also has to account for something mathematicians call nonlinearity, a mathematical term

If one considers the work flowing in their system as a proxy for innovation that is subject to hidden rework that surfaces (e.g., unseen customer needs), when the project progresses then their model examines issues such as how concurrence and delays will affect overall progress.

- Ford, D.N., Sterman, J.D.: Overcoming the 90% syndrome: iteration management in concurrent development projects. *Concurr. Eng. Res. Appl.* **11**(3):177–186 (2003).

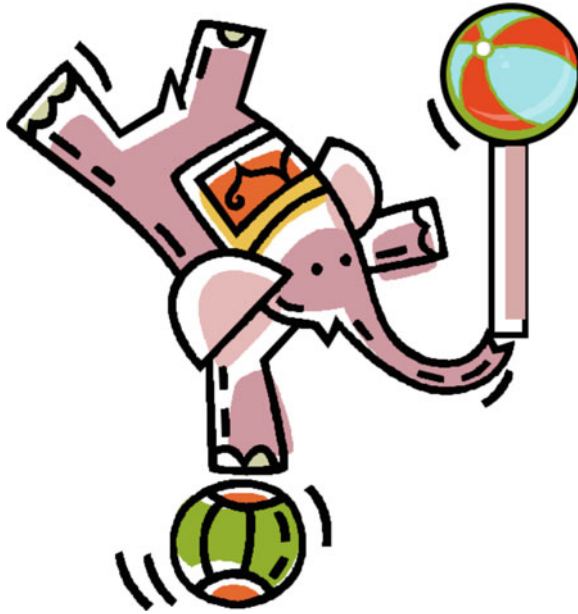


Fig. 2.7 Managing a nonlinear dynamic system⁹

for the uneven relationship between cause and effect. In other words, unlike the shower example, where how much you turn the hot and cold handles roughly corresponds to a proportionate—and hence linear—change in temperature, the elephant would face a tricky situation, even if the stick moved an inch or two. It needs to exert much more than double the effort to adjust a ball that is only two inches off its balance point rather than one that is only an inch off because this elephant has to handle a number of different nexuses of balance that influence the other. In other words, the force between the ball and the stick has a nonlinear connection. The nonlinearity between cause and effect will increase to the point that the elephant will have to go through some wild, if humorous, gyrations to recover. (Any readers who have been to the circus can appreciate this.) Similarly, anyone who has learned to ride a unicycle while juggling simultaneously will have experienced similar nonlinear effects. It can be done, but it requires practice, and most first timers fall many times and need many do-overs before they get the hang of it.

Getting back to the innovation system loops—they too are nonlinear and similarly difficult to control. To make things worse, because each innovation is somewhat unique, managers rarely are permitted the luxury of do-overs. These sorts of systems, which are characterized by multiple feedback loops with embedded delays and nonlinear relationships between cause and effect, are referred to in physics as “dynamically complex” systems. This is the source of the nonintuitive and difficult-to-manage behaviors in the innovation system. As we mentioned earlier, these

⁹This drawing was made with Microsoft PowerPoint and is used with the permission of Microsoft, Inc.

nonlinear feedbacks may even drive the behavior of the innovation system to appear random in some situations, which is what a mathematician would term “chaotic.” Strictly speaking, chaotic behavior is not truly random, it only appears so an observer. However, chaotic processes imitate random behavior closely enough to often frustrate innovation planners.

The good news is that the planning, development, and ultimate acceptance of innovations like antilock brakes are *not* chaotic processes. Ultimately, they will eventually reach some sort of equilibrium level of acceptance. However, the bad news is that managing innovations is still far from simple, being much like the elephant’s balancing trick. Worse, they are extremely sensitive to initial conditions. For instance, if the original 1970 Clean Air Act had been just a bit less stringent or microprocessor technology had not been available in the late 1970s, it is quite possible that automotive companies may have gone to variable-venturi carburetors (an alternative mechanical technology that could improve emissions), which would have delayed or perhaps blocked the development of electronic capabilities that resulted in outcomes such as antilock brakes and the evolution of OnStar.

Thus, only a slight difference in initial conditions can evolve into at least two, and more likely several, radically different ultimate results. As evidenced by this case, emergence resulting from the competition among multiple alternatives is the most common behaviors of complex systems seen in the management arena. Malcolm Gladwell describes emergence in this context using the language of “tipping points,” the point beyond which a potential emergent path metamorphoses from a possibility into inevitability. For example, the fact that drivers drive on the right-hand side of the road in the USA rather than the left side (as in Great Britain) is an emergent phenomenon that results from a tipping point being reached. Another term used by business *scholars* to describe such nonintuitive emergent phenomena is “disruptions” because they cause one apparently stable business system to rapidly evolve into something completely different. Because these disruptions in business systems, often caused by innovations, typically result in the wholesale failure of many leading firms and sometimes even industries, the great economist Joseph Schumpeter referred to the process of emergence as “creative destruction.”¹⁰

However, the difficulties described so far in managing the escalation of expectations in product innovation are far from complete. To begin to fully comprehend the nature of those portions of the system that can lead to tipping points and business disruptions, we need to consider the effects of random shocks and other uncertainties in the system as well: in particular, what is the source of innovation butterflies?

Randomness and variability impact the system as shown in Fig. 2.8 at a number of points in the innovation system (so much so, in fact, that some experts have

¹⁰Schumpeter, J.A.: The Process of Creative Destruction. *Capitalism, Socialism and Democracy*, pp. 82–85 (1942).

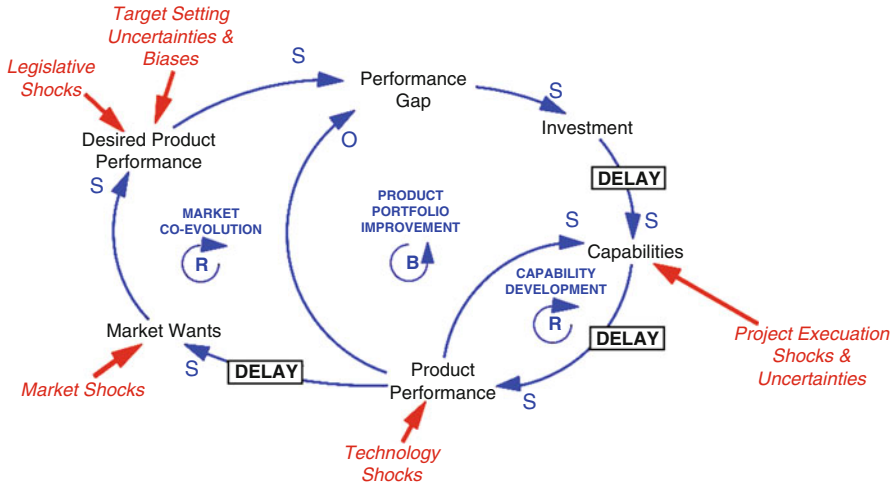


Fig. 2.8 The innovation system with multiple uncertainties

argued that elemental (or component) uncertainty is the central driver of complexity in an innovation system¹¹). The effect of *legislative shocks* has been described. Unexpected advances in or negative effects of technology can also impact product performance. This effect may have either a positive or a negative direction, however, because it is unclear in which direction it will drive product performance. The direction depends on the context. For example, improved technology generally results in improved product performance, *if the technology works as expected*. If for some reason a new technology has some unforeseen drawback(s) or negative outcomes, it could actually drive product performance down. An excellent example of this phenomenon is the tendency of plasma screen television displays pixel clarity to deteriorate within 3–4 years, which was not the case with traditional televisions. This opened the door to competing technologies such as the DLP screens.¹² Similarly, market shocks may drive market desires in sudden unforeseen directions, particularly if an unexpected esthetic or fad arises. For example, the recent preference for predistressed blue jeans clearly reduces the longevity of those jeans over those made for an older generation.

Target-setting uncertainties are related but subtly different because they result from random shocks stemming from the difficulty in accurately determining market desires. Translating them into useful design specifications that are

¹¹ Suh, N.P.: Complexity: Theory and Application. Oxford University Press (2005).

¹² Digital Light Processing (DLP) is a trademark owned by Texas Instruments, representing a technology used in projectors and video projectors. The image is created by microscopically small mirrors laid out in a matrix on a semiconductor chips. www.cnet.com/1990-7874_2-5108443-3.html.

meaningful to engineers introduces yet more uncertainty into the process.¹³ For instance, customer focus groups described one pickup truck produced by a U.S. firm as having “less acceleration” than its foreign competitor. The engineers assigned to develop this pickup truck could not understand this complaint at first. In the U.S. automotive industry, the standard measure to assess the acceleration has been based on the time takes to go from standing position, i.e., how many seconds it takes to go from 0 to 60 miles/hour. The designed vehicle was superior in all the standard tests of acceleration. However, deeper probing of the focus groups revealed that customers were more interested in accelerating quickly, while already in motion, in order to pass other vehicles than in reaching 60 miles/hours quickly from a standing start. This would require designing and testing the vehicle for different standards than 0–60. Additionally, it turned out that the same exact acceleration pushed people more deeply into the seats of the foreign designed pickup than into those of the U.S. vehicle. Hence, customers perceived—incorrectly—that they were accelerating more quickly in the foreign pickup.

Finally, execution shocks can also affect individual projects in a complex manner. For example, many of the worries surrounding the late delivery of the Boeing 787 Dreamliner, revolve around the impact that delay will have upon Boeing’s other projects. In particular, the diversion of engineering resources to cope with the 787’s delays is blamed for allowing “more engineering errors [to escape] than what would be considered normal” during the development of the new 747-8 (a modernization of the venerable Jumbo Jet),¹⁴ thus creating a domino effect of delays in one project begetting delays in subsequent projects.¹⁵ Moreover, as we see in the next chapter, execution shocks can result in even more complex chains of consequences.

We have described a multiple set of shocks that feature legislative, target setting, market, technology, and execution uncertainties. In the end, the net effect of these multiple sets of uncertainties is to render the management of a complex dynamic system underlying product development extremely difficult *because any one of them is a potential innovation butterfly*. Behavioral studies on people managing dynamically complex innovation systems uncertain input are scarce, but the

¹³For a treatment of the translation process see Griffin and Hauser (1993) and von Hippel (1988). For a discussion of the randomness associated with such processes, see Khoo and Ho (1996).

- Von Hippel, E.: The Sources of Innovation. Oxford University Press, New York (1988).
- Griffin, A., Hauser, J.R.: The Voice of the Customer. Market. Sci. (1993).
- Khoo, L., Ho, N.: Framework of a fuzzy quality function deployment system. Int. J. Prod. Res. (1996).

¹⁴Cohen, A.: “Boeing 747-8 Delay to Death by a 1000 Cuts,” Seattle.pi Blogs, posted on 8 October 2009. <http://blog.seattlepi.com/aerospace/archives/181424.asp> (2009). Accessed 27 May 2010.

¹⁵Gates, D.: “747-8 Delay Causes Doubts at Boeing.” The Seattle Times, 7 October 2009. http://seattletimes.nwsource.com/html/boeingaerospace/2010013013_boeing07.html (2009). Accessed 27 May 2010.

few studies on this indicate that random events diminish what little managerial capability exists to manage them.¹⁶

As the examples in this chapter show, it is difficult to capture the scope of the time dependence and interconnectedness of any system. Unsurprisingly, managing risk in even a simplified product development system characterized by dynamic complexity and randomness in an optimal manner surpasses the cognitive capabilities of managers, even when they are given high levels of computer support.¹⁷ This should not be surprising. Borrowing from our balancing elephant metaphor, the elephant has trouble enough balancing just one ball on a flat surface at a circus arena. Staging this balancing act on a bumpy lawn outdoors on a windy day with gusts striking the ball from all directions is unlikely to improve the elephant's ability to keep the ball on its trunk and off the ground. Innovation leaders face exactly the same problem, which is precisely why managing the innovation butterfly is so difficult.

While the principle of the escalation of expectations has broad implications for planning and managing innovation, the examples in this chapter actually understate some of the other issues associated with managing complexity in the innovation system as we see in the next two chapters. So what is an innovation leader to do? A number of potential solutions exist for managing the escalation of expectations that can keep an innovation butterfly from turning into a destructive tsunami. We describe these in Chaps. 5–7. But, each solution may create another set of problems. We discuss this problem, and its resulting tradeoffs, as we turn our attention to the *principle of exchange* in the next chapter.

¹⁶We offer a detailed discussion of such biases in Chap. 4.

¹⁷This problem is what scientists refer to as NP-Hard, meaning that the time to solve the problem increases more rapidly than the number of different states taken to any arbitrary power (Anderson and Joglekar 2005). Practically speaking, solving any managerial problems of such difficulty in an optimal manner is essentially impossible. Some compromises must be made, such as ignoring certain feedbacks in Fig. 2.8, such that the problem can be decomposed into easy to understand pieces.

- Anderson, E.G. Jr, Joglekar, N.R.: A hierarchical product development planning framework. *Prod. Oper. Manage.* (2005).

The Innovation Butterfly
Managing Emergent Opportunities and Risks During
Distributed Innovation

Anderson Jr., E.G.; Joglekar, N.R.

2012, XII, 176 p., Hardcover

ISBN: 978-1-4614-3130-5