ATTACHMENT D:
DIFFUSION OF INNOVATION

A. RECOGNIZING THE ROLE OF SUPPLY AND DEMAND

The innovation diffusion process has typically been represented as a logistic (S) curve that represents the overall flow of product development and adoption actions (see Figure V-1). Figure V-1 shows the supply-side process preceding and overlapping with the demand-side process. It depicts the supply-side of the innovation process as moving through three phases, while the demand side of the process moves through five phases. The phases are created by processes that take place within organizations and markets.

On the supply side, in the first phase, technology incubates and emerges from research and development to be launched. The early supply-side period is very challenging and has been called the "valley of death" that must be traversed if the product is to advance.[1] The product undergoes continuous development as it is commercialized and is successful, a process that has been called the slope of enlightenment.[2] The product stabilizes as it matures and then saturates the market. Saturation may not be at 100 percent, since some parts of the market may never adopt a product for a variety of reasons.

SUPPLY: Incubation > R&D > Launch > Commercialization > Business Success
Research > Concept > Tech. > Prod. > Prod.
Invent Dev. Dev. Mktg.

DEMAND: Takeoff > Growth > Slowdown > Early Maturity
(acceleration) (inflection) (Deceleration)

On the demand side, the process begins with initial adoption by market mavens and innovators, then spreads through early adopters, early and late majorities and finally laggards.. The adoption process accelerates rapidly with takeoff then slows with maturity. The speed and ultimate level of adoption have been primary focal points of analysis on the demand side.

The analysis of the diffusion of products has shifted its focus between the supply-side of the market and the demand side several times over the past century. The pre-World War II focus was on ""invention and innovation," but the three decades after the war focused much more on the demand side, so much so that by the 1990s, the field was criticized for ignoring the importance of the supply-side. The definition of technological diffusion offered in a 1998 review of the field, reflects this central tension.

> Technological diffusion can be defined as a mechanism that spreads successful varieties of products and processes through an economic structure and displaces wholly or partly the existing 'inferior' varieties. While the process of invention and innovation are necessary preconditions for the development of a new technology, it is the process of diffusion that determines the extent to which the new technology is being put to productive use.[3]

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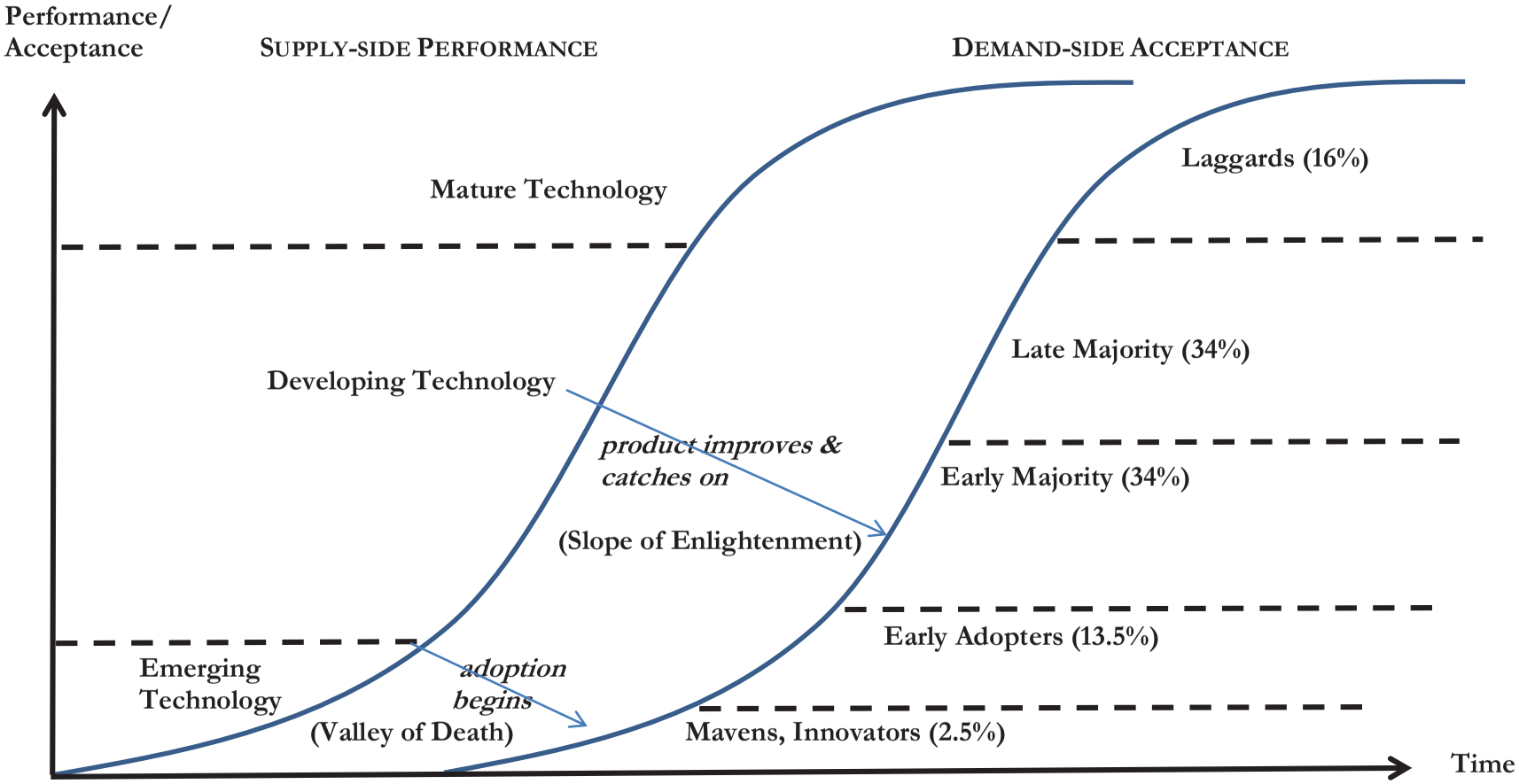
[1] Osawa and Miazaki, 2006.
[2] Gartner, 2013,
[3] Sarkar, 1998:131.

EXHIBIT IV-1: THE INTERACTION OF SUPPLY AND DEMAND IN THE CREATION/DIFFUSION OF INNOVATIVE TECHNOLOGIES



Source: See Mark Cooper

The bottom line in a review of the diffusion literature was a call for balance: "What is needs to be achieved in the field of diffusion research now is a *Balance* between the two archetypical modeling mechanisms of diffusion, their underlying assumptions, and the postulated modes of interaction."[4] The definition of technological diffusion offered in this review of the field, reflects this central tension.

Exhibit V-2 shows the factors that have been identified as affecting the diffusion process. The causal factors on the supply-side are shown on the upper part of the figure. The causal factors on the demand-side of the diffusion process are presented in the lower part. The literature identifies four broad categories of factors that affect adoption on the demand side: demographics, social influences, attitudes and the ability to make calculations. Because of its focus on the consumer adoption decision, the diffusion literature was very sensitive to causal factors that drive diffusion, factors that are grounded in behavioral economics including: "Perception: Type of Uncertainty, Uncertainty Model, Preference Structure: Attributes, Risk Attitude, Adoption Decision Rules: Maximize Expected Utility, Learning: Model, Sources of Information [5]

On the demand side, the assumption is that the underlying process "is a social learning process which results in consumers slowly changing their attitudes and values… some individuals change their views quicker than others; it is a "rolling snowball" phenomenon which starts with just a few people and gets bigger as it fathers momentum."[6] The demand side approach looked both at the aggregate level of penetration and the individual adoption decisions.

> [A]ttempts have been made… to develop diffusion models by specifying adoption decisions at the individual level. In these models… a potential adopter's utility for an innovation is based on his uncertain perception of the innovation's performance, value or benefits. The potential adopter's uncertain perception of the innovation, however, changes over time as he learns more about the innovation from external sources (e.g., advertising) or internal sources (e.g., word of mouth). Therefore, because of this learning, whenever his utility for the innovation becomes greater than the status quo, (he is better off with the innovation), he adopts the innovation. [7]

However, the challenge of diffusion is first, and foremost, a matter of supply-side innovation. To put the matter simply, consumers cannot adopt technologies until they are offered to them in the marketplace. Innovation must precede diffusion.

> Marketing literature has traditionally portrayed new product development as essentially a market/consumer-led process, but paradoxically, many, major market innovations appear in practice to be technology driven, to arise from a technology seeking a market application rather than from a market opportunity seeking a technology. This, of course, is the antithesis of the marketing concept, which is to start with the customer, then design something to meet his needs. While this may be intuitively reasonable, and indeed appropriate in a market where changes are slow and can reasonably be anticipated, it may be less appropriate in faster changing markets with higher technology content. However, for successful technology – driven market development, in addition to a technological discovery, there needs to be an element of insight as to how it should be applied… It would seem that innovation is fundamental to the strategic management of businesses,

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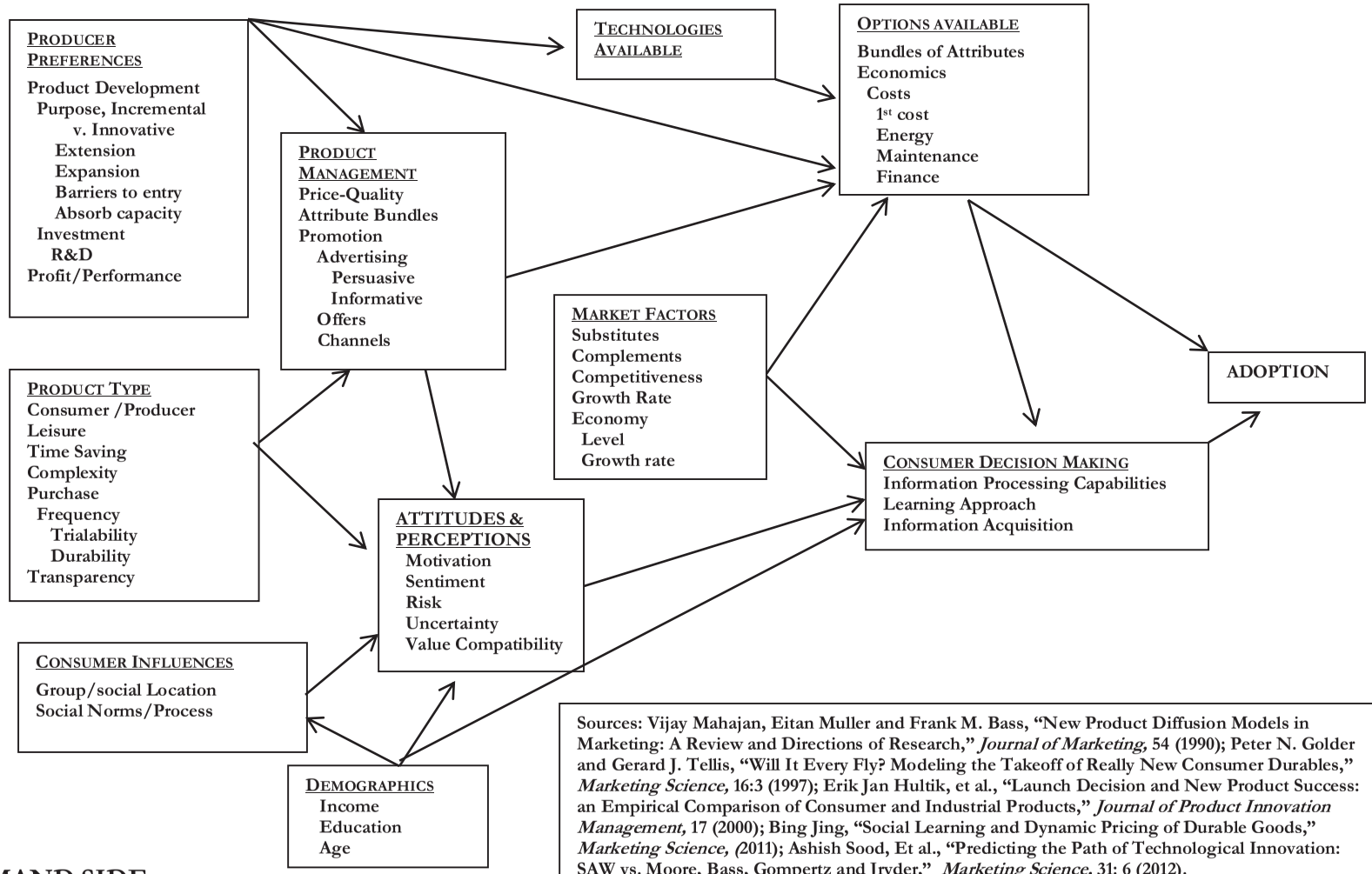
[4] Sarkar, 1998:167.
[5] Mahajan, Muller and Bass, 1990: 6-7.
[6] Brown, 1992: 62.
[7] Mahajan, Muller and Bass, 1990, pp. 6-7.

EXHIBIT V-2: CAUSAL FACTORS THAT DRIVE THE SUPPLY AND DIFFUSION OF INNOVATIVE PRODUCTS

SUPPLY-SIDE



Sources: Vijay Mahajan, Eitan Muller and Frank M. Bass, "New Product Diffusion Models in Marketing: A Review and Directions of Research," *Journal of Marketing,* 54 (1990); Peter N. Golder and Gerard J. Tellis, "Will It Every Fly? Modeling the Takeoff of Really New Consumer Durables," *Marketing Science,* 16:3 (1997); Erik Jan Hultik, et al., "Launch Decision and New Product Success: an Empirical Comparison of Consumer and Industrial Products," *Journal of Product Innovation Management,* 17 (2000); Bing Jing, "Social Learning and Dynamic Pricing of Durable Goods," *Marketing Science, (*2011); Ashish Sood, Et al., "Predicting the Path of Technological Innovation: SAW vs. Moore, Bass, Gompertz and Jryder," *Marketing Science,* 31: 6 (2012).

DEMAND SIDE

> but that it is a complex and potentially risk-laden activity… No doubt the debate over the extent to which radical innovation is caused by "technology push or by "market pull" will continue [8]

Recognition of the important of the supply-side also reflects a greater emphasis on the role of entrepreneurship and management in the innovation process because "takeoff is not instantaneous and requires patience and careful planning on the part of managers."[9] Management faces a variety of challenges in shepherding innovative technologies to business success.[10] Exhibit IV-2 emphasizes the factors that affect the supply side, by placing them at the tope of the process.

Management can have different motives for technology innovation and use different tools to increase the likelihood that the technology will achieve a large enough market to be profitable.[11] Entrepreneurs make the decisions about what technologies to develop and products to market, as well as how those products are priced, brought to market and promoted. They do so in response to their perception of the market they are located in and their understanding of consumers, as well as their own preferences. Their ability to perform these activities is neither perfect nor uniform.[12]

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[8] Brown, 1992, p. 65.

[9] Golder and Tellis, 1997, p. 267.

[10] Golder and Tellis, 1997, p. 267. [S]ome other variable may also help explain the takeoff of new durables. Such variables include technological change, product quality, relative advantage of the new product over substitute products, availability of complementary products that increase the utility of the new product, and the number of competitors.

[11] Golder and Tellis, 1997p. 267 Increasing the rate of price reduction *increases the peak probability* of takeoff in each curve, as well as *advances the time* at which the peak occurs. Ironically, as Hultik, et al., 2000, p. 5, point out, the advice given to management in the standard texts does not reflect the findings of the analysis of innovation diffusion, "The relationship found in these data between success and launch decisions differ quite markedly from the standard normative prescriptions… None of the extensive advice provided in the normative literature on competitive or innovation strategy decisions, as found, in this research, to be associated with success. Additionally, a number of strategic objectives related to success for consumer goods were identified in this study, none of which are mentioned in the normative literature."

[12] Golder and Tellis, 1998: 263-264. "No matter how inexpensive the product is, or how high consumers' incomes are or how strong consumer sentiment is, the likelihood of purchase still increases as products become more visible and available to consumers. Widespread distribution will lead to higher market presence and will tend to increase the likelihood of new product success. Market presence reflects the opportunities that potential consumers have to observe a product. These opportunities occur in several ways. First, as sales increase, interest and excitement among consumers about a product increases… Second, as sales of a product increase, retail promotions will increase leading to enhanced visibility. Since store displays are designed to attract consumers' attention and led to sales, retailers promote products they know consumers have some interest in buying. Therefore, products capable of accomplishing this objective are those that already have a demonstrated sales record. Third, as sales increase, the number of stores carrying a product will increase leading to enhanced visibility. Once consumers begin to buy a new product, additional stores carry that product." These authors conclude that "Individual level diffusion models or models that combine economic and communications elements seem especially promising," pointing to a number of studies including Chatterjee and Eliashberg, 1990; Horky, 1990' Kalish, 1985; Lattin and Roberts, 1989. Brown, 1992: 73, "Consider, for example, the development of the market for pocket calculators… The first purchasers were engineers and scientists because they had extensive can complex calculations to perform and existing technology (the slide rule and the log table)… As the early manufacturers of calculators began to benefit from technological advances and from economies of experience and scale prices began to fall. Calculators then began to become attractive to accountants and other commercial users… Compared to engineers and scientists, accountants and commercial users have a lower utility value and could only justify purchase when the price came down… As calculator prices fell still further, so they began to become attractive to the general public. Of course, the utility value to these users was lower than to commercial users, but again the potential larger."

B. THE IMPORTANCE OF TRANSACTION COSTS AND BEHAVIORAL FACTORS

A major source of tension in the innovation diffusion field flows from the approach to modeling behavior and process: the efficient market hypothesis underlying neoclassical economics v. institutional, transaction and behavioral economics views of imperfect markets.

> The issue relates to whether the diffusion process should be formalized as [*neoclassical equilibrium*]… with diffusion patterns reflecting a sequence of shifting equilibria over time in which agents are fully adjusted…modeled as being infinitely rational and fully informed… or as a disequilibrium process… modeled as being constrained by lack of information or understanding on the part of adopters about the worth of an innovation.[13]

The dramatic difference between the approaches to the analysis of innovation diffusion are evident in the side-by-side comparison of the two dominant approaches summarized in Exhibit V-3 shows. The broad critique of the neoclassical economic model rested primarily on the fact that the underlying assumptions of infinitely rational/fully informed actors in the neoclassical model does not fit real world behaviors at all.

> As Simon stressed in his Nobel Memorial Lecture, the classical model of rationality requires knowledge of all the relevant alternatives, their consequences and the probabilities, and a predictable world without surprises. These conditions, however, are rarely met for problems that individuals and organizations face. Savage, known as the founder of modern Bayesian decision theory, called such perfect knowledge small worlds… In large worlds, part of the relevant information is unknown or has to be estimated from small samples, so that the conditions for rational decision theory are not met, making it an inappropriate norm for optimal reasoning. In a large world…one can no longer assume that "rational" models automatically provide the correct answer.[14]

EXHIBIT V-3: DECISION THEORETIC APPROACHES TO MODELING DIFFUSION

	Neoclassical Equilibrium	Evolutionary Disequilibrium
Scientific Analogy	**Newtonian mechanics**	**Evolutionary Biology**
Assumptions:	**Full/limited information**	**Necessarily limited-information**
	Infinite rationality	**Bounded rationality**
	Equilibrium mechanism	**Disequilibrium mechanism**
	Exogenous/endogenous	**Necessarily endogenous**
	Continuous & quantitative	**Continuous & Quantitative (Darwinian)**
		Discontinuous & qualitative (non-Darwinian)
Characteristics of the Diffusion Process	**Predictable**	**Unpredictable**
	Ahistorical	**Path-dependent (historicity)**
	Efficient	**Efficient (Darwinian)**
		Possible inefficiency (non-Darwinian)

Source: Jayati Sarkar, "Technological Diffusion: Alternative Theories and Historical Evidence, *Journal of Economic Surveys,* 2: 1998, p. 149.

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[13] Sarkar, 1998:132.

[14] Gigerenzer and Gaissmaier, 2011, p. 453.

The effort to understand the complex influences on human behavior has moved well beyond the simple "rational v. irrational" dichotomy.[15] The middle ground recognizes that "intelligent choice," "useful inferences" and "smart" decisions are possible without reference to "the classic model of rationality."[16] "Ecological rationality" is a term applied to this middle ground that recognizes the limitations imposed on choice by the environment and the capacity of individuals to make decisions.

> The study of ecological rationality is related to the view that human cognition is adapted to its past environment. [17]
>
> In a complex and uncertain world, humans draw inferences and make decisions under the constraints of limited knowledge, resources, and time…. These heuristics perform well because they are ecologically rational: they explore the structure of environmental information and are adapted to this structure.
>
> Models of ecological rationality describe the structure and representation of information in actual environments and their match with mental strategies, such as bounded rational heuristics. (8) The simultaneous focus on the mind and its environment, past and present, put research on decision making under uncertainty into an evolutionary and ecological framework, a framework that is missing in most theories of reasoning, both descriptive and normative.[18]

If the baseline assumption of infinite rationality and full information is as far from reality as this discussion suggests, it is reasonable to argue that the baseline should shift to a set of assumptions that are closer to reality. This would make it more likely that the model will avoid the error of assuming that a little more information fed into a context where the underlying forces are almost right will solve the problem. It will avoid the Mercatus Center mistake.[19]

Recognizing the environmental and cognitive constraints on decision making shifts the focal point of the analysis to internal criteria of performance. The focus of study shifts to the origin and impact of constraints on decision making and the tools humans use to make decisions under those constraints.

Within ecological rationality it is of utmost importance to look at how the environment influences

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[15] However, stepping back from the assumption of perfect rationality can lead to an overemphasis on the irrational, or error in decision making. Hoffrage and Reimer, 2004, p. 456 "[H]euristics were invoked as explanation for systemic errors found in human reasoning – mainly deviation from the laws of probability. Although Tversky and Kahneman repeatedly asserted that heuristics sometimes succeed and sometimes fail, they and many of their colleagues focused on the latter category and interpreted their experimental findings as indicating some kind of fallacy…."

[16] Hoffrage and Reimer, 2004, p. 456, "Fast and frugal heuristics, in contrast, are not associated with the value laden term bias. On the contrary, by taking advantage of the structure of information in the environment, these heuristics can lead to accurate and useful inferences; hence they do not necessarily lead to biases but they can "make us smart." Gigerenzer and Gaissmaier, 2011, p. 473 quoting James March [I]f behavior that apparently deviates from standard procedures of calculated rationality can be shown to be intelligent, then it can plausibly be argued that models of calculated rationality are deficient not only as descriptors of human behavior but also as guides to intelligent choice.

[17] Gigerenzer and Gaissmaier, 2011, 2011, pp. 457-458.

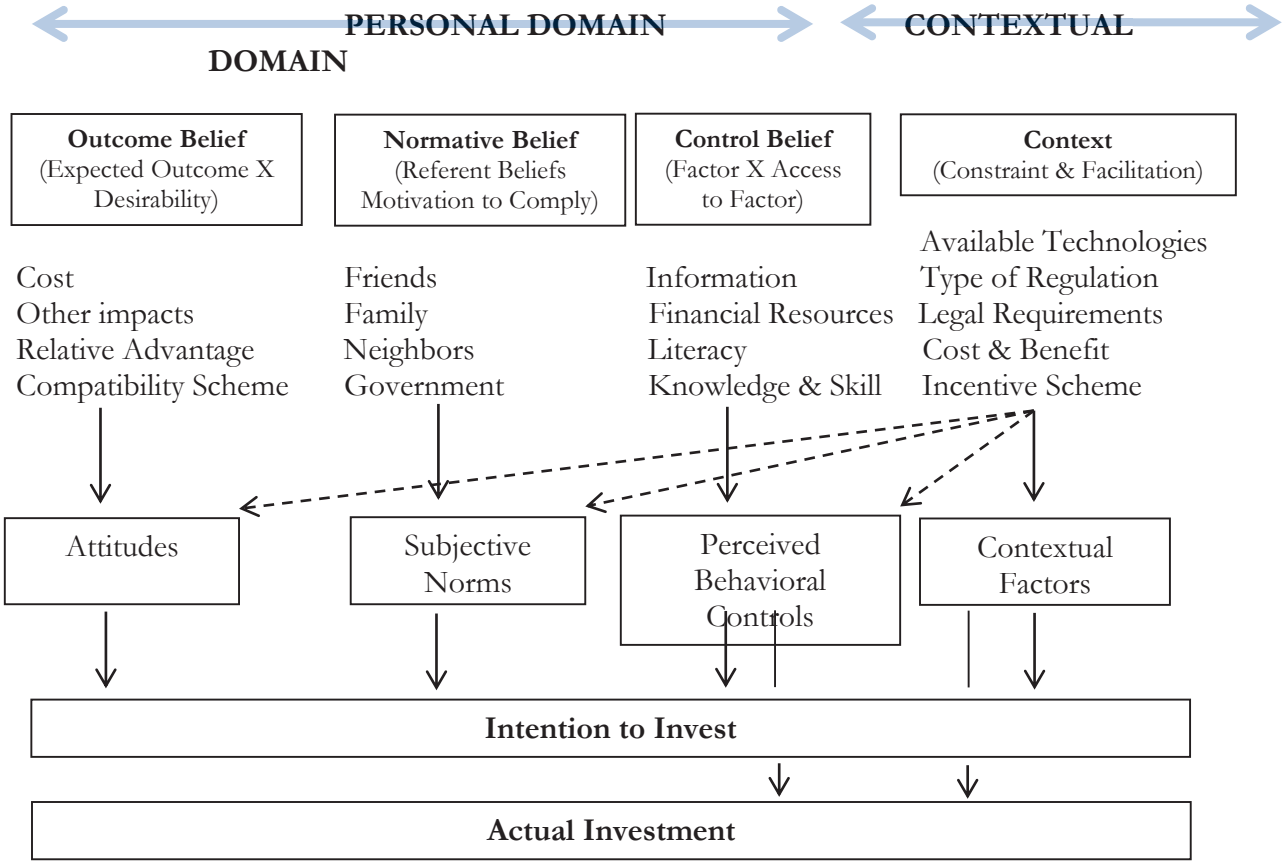
[18] Hoffrage and Reimer, 2004, p. 442 cited in Basel and Bruhl, 17-1; Hoffrage and Reimer, 2004, p. 443.

[19] From such a perspective it is straightforward to study the adaptation of mental and social strategies to real-world environments rather than compare strategies to the norms of probability theory (e.g., *Bayes's rule*, which can be used to update prior beliefs in the light of new data) and logic (e.g., the *conjunction rule*, according to which the probability that an object belongs both to the classes A and B cannot exceed the probability that it belongs to class A). Rather, the performance of a heuristic is evaluated against a criterion that exists in the environment – the distinction between internal consistency versus external correspondence Hoffrage, and Reimer, 2004, p. 437

the tasks and how the environment shapes and has shaped the cognitive capacity of social actors. Humans have an evolutionary past in which they constantly learned and adapted to biological and social environment and this shaped their cognitive capacities… In addition, humans are not error free and, even more importantly; they face a wide range of tasks in a modern technological environment.[20]

Exhibit V-4 presents a common framing of the behavioral considerations. In our earlier analysis, we have identified three broad categories of concepts from the behavioral economics literature that are roughly equivalent to those in Exhibit V-4:

EXHIBIT V-4: INTEGRATED MODEL TO EVALUATE DETERMINANTS OF TECHNOLOGY UPTAKE



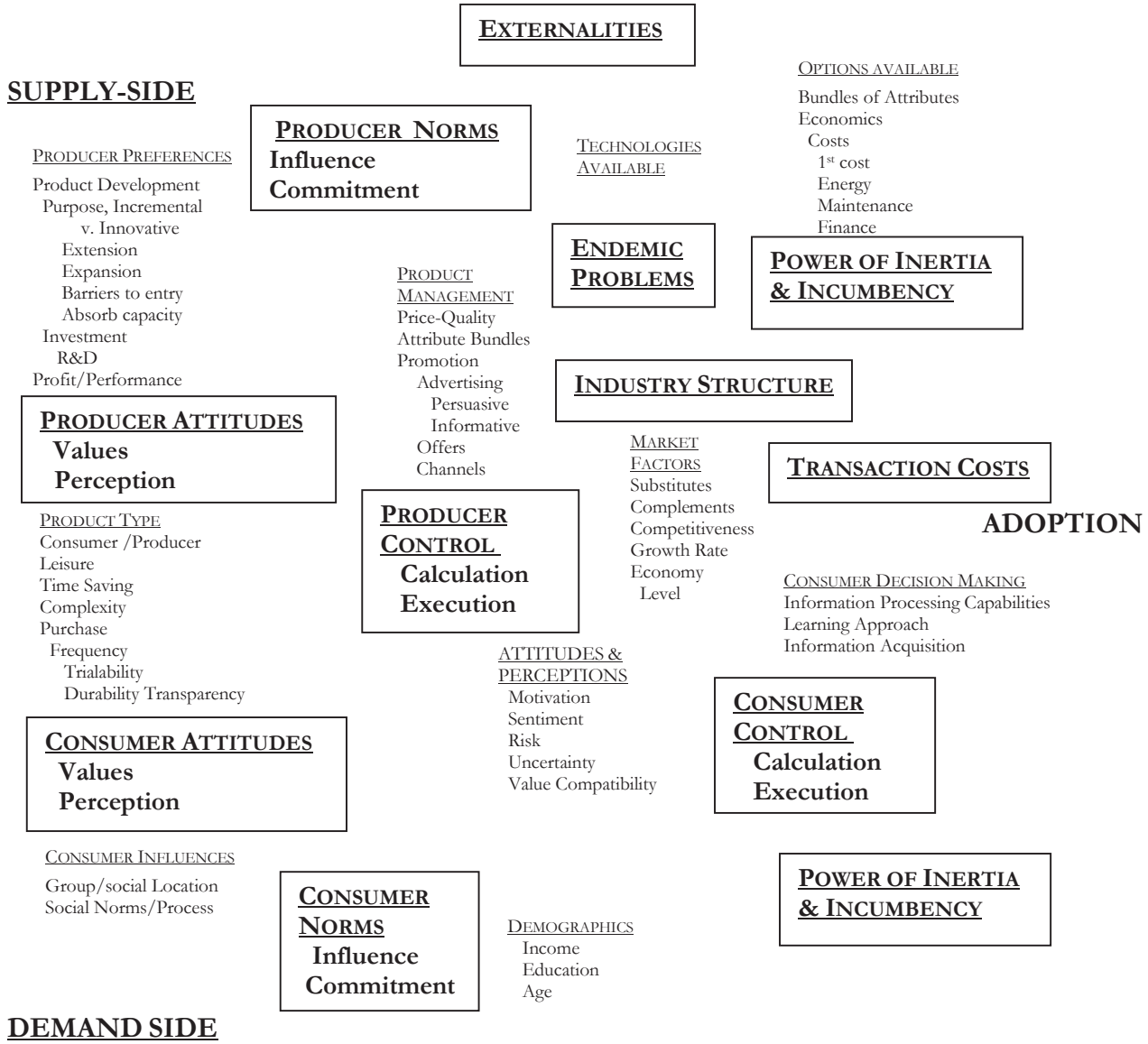
Source: Marius Claudy and Aidan O'Driscoll, "Beyond Economics: A Behavioral Approach to Energy Efficiency in Domestic Buildings," *Dublin Institute of Technology*, 2008; based on Stern, Paul C., "Towards a Coherent Theory of Environmentally Significant Behavior, *Journal of Social Issues,* 56: 2000; see also, Charlie Wilson and Hadi, Dowlatabadi, "Models of Decision Making and Residential Energy Use, *Annual Review of Environmental Resources,* 32:2007, p. 183.

[20] Basel and Bruhl, 2011, p. 19.

C. The Intersection Market Barriers and the Innovation Diffusion Process

Exhibit IV-5 locates impediments to diffusion in the broad categories of market failure identified in in the "efficiency gap" analysis of Section II. We locate the barriers and imperfections at different points in the flow of innovation/diffusion. We include the three major types of behavioral factors on both the supply-side and the demand side. Arguably, the supply-side is less affected by these factors, since the assumption of profit (welfare) maximizing economic enterprises fits the supply-side better. However, the fit is certainly not perfect and several of the barriers that we observe on the supply-side, like status quo bias and internal structural constraints fit in the behavioral arena. We also include the power of inertia and incumbents on both the supply and demand sides of the market.

Exhibit IV-5: Market Barriers and Imperfections and the Causal Factors that Drive the Supply and Diffusion of Innovation



The central questions in the efficiency gap analysis involve the process of the adoption of new technologies. Treating the efficiency gap as a special case of the diffusion of innovations allows us to draw on the much broader study of the factors that affect the speed with which technologies are developed and sold to the public. By examining some of the key themes and developments in innovation diffusion literature, we deepen the understanding of the efficiency gap.

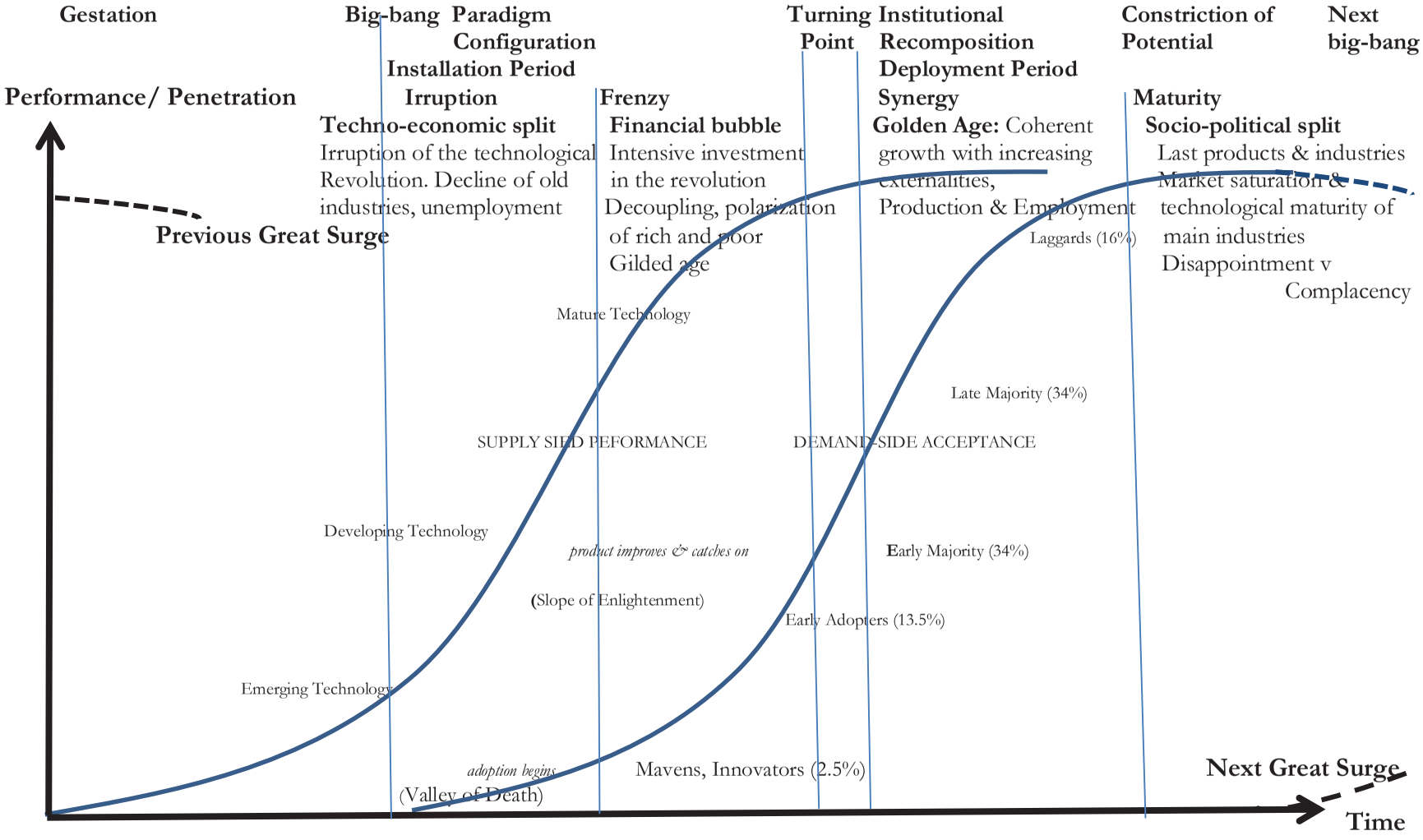
- The literature emphasizes the importance of the supply-side, which does not receive sufficient attention in the efficiency gap literature because of the focus on consumer behavior.
- The literature identifies the factors that account for slow innovation and diffusion on both the supply and demand sides of the market.

The innovation diffusion literature exhibits concerns about factors that affect adoption that are similar to the market imperfections and barriers identified in the efficiency gap literature.

D. Technology Revolution as Diffusion

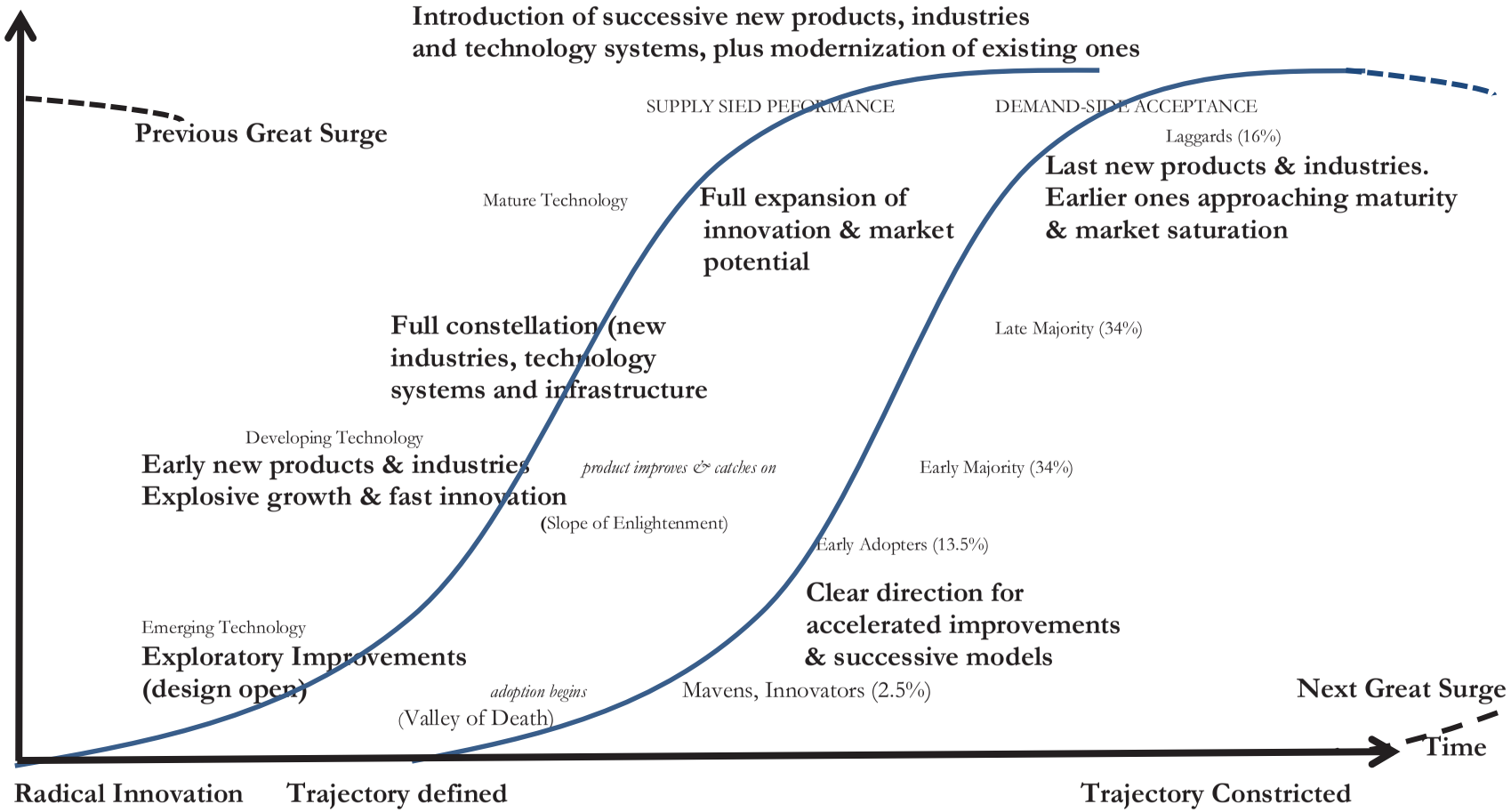
Exhibits IV-6 and IV-7 overlay the diffusion curves from Perez's technology stage analysis on the innovation diffusion curves discussed in this section. Although the diffusion curves deal with products, rather than the entire economy there is a strong similarity.

FIGURE III-1: STAGES IN THE LIFE CYCLE OF TECHNOLOGICAL REVOLUTIONS



Source: Carlota Perez, *Technological Revolutions and Finance Capital* (Edward Edgar, 2002), Figures 3.1, 4.1, 14.1.

FIGURE III-1: PROCESSES IN THE LIFE CYCLE OF TECHNOLOGICAL REVOLUTIONS



Source: Carlota Perez, *Technological Revolutions and Finance Capital* (Edward Edgar, 2002), Figures 3.1, 4.1, 14.1; *Financial bubbles, crises and the role of government in unleashing golden ages*, FINNOV, January 2012, Figure 1.