A generalized growth model for strategic analysis

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Abstract

This paper presents an adoption model where the rate of adoption is disaggregated into three components, and feedback paths to each component from three stock variables. The strength and sense of the feedback loops are expressed as elements of a 3x3 matrix easily varied. The model is a generalization of an analysis of growth in a local photovoltaic market (Jones, 2009). Informants in that study had a variety of opinions on the net strength and valence of feedback paths incorporating multiple effects. A strategy that depends upon reinforcing feedback (returns to scale, learning curve, get big quick) can be adopted when the mechanism is poorly articulated or poorly understood. This model acts as a framework for analysis of such situations.

Introduction

In a new or changing industry, the relationships that form the feedback structure may be difficult to uncover. Analysis of and strategy within such systems cannot rely on the same quality of data as is available in more developed systems. Neither data for estimating parameters nor well-developed basic insights for specifying structure (Forrester, 2003) are available with which to construct useful models. Indeed, some of the system structure will have yet to arise, and actions by the founding members of an industry will mold the forces that make up the system.

System dynamics should be a useful methodology for developing strategy in systems that have not yet formed. System design is in fact a higher order goal than understanding (Meadows & Robinson, 1985). In addition to modeling projects on new business and new industries, several traditions within system dynamics are applicable to systems before they are well formed. Models as boundary objects and modes as archetypes are both means of communicating more than they are representations of specified systems.

This paper is meant to add to that tradition by presenting a piece of model structure applicable to a wide range of growth phenomena. The model expands on dynamic complexity while abstracting out details. In essence, this model is intended to represent all possible feedback loops forming the causal structure of adoption rate (or equivalently sales rate, installation rate, etc.). It groups all causal factors of the adoption rate into three categories, and all the possible accumulations of adoption rate likewise into three categories. With balancing and reinforcing loops, there are 3x3x2=18 possible feedback loops in this structure. The equations are specified with a common form so that any structure can be built by changing a small number of constants.

The model is intended as a tool for understanding two types of questions. In analysis, it can be used to answer "given the observed behavior, what kind of feedbacks must be working"; in strategy, to answer "what kind of feedbacks do we have to create to get the results desired". In the following sections, I justify the formulation based on organizations and market behavior; describe the equations; and outline the behavior under some simple conditions.

Strategy, feedback, and new markets

New industries and new market growth has long been understood as a product of reinforcing feedback mechanisms (Arthur, 1989; David, 1985; Forrester, 1961; Gort & Wall, 1986; Mansfield, 1961). Business leaders and policy makers often articulate a belief in positive feedback as a justification for strategy (Arthur, 1996; Best, 2001; EOP, 2009) and there is a tradition in system dynamics of uncovering the maladaptive outcomes in such cases (Forrester, 1968; Sterman, Henderson, Beinhocker, & Newman, 1995, 2007). Learning curves (Argote & Epple, 1990) and word-of-mouth (Bass, 1969) effects have become ingrained into policy and strategy discussions. Multiple mechanisms for positive-feedback driven growth are possible (Sterman, 2000 ch10).

Balancing feedback mechanisms are less well articulated, although mechanisms that depend on balancing feedback to operate are no less important to strategy. (Oliva, Sterman, & Giese, 2003). Goal setting is a dominant strategic action, but the role of feedback in the approach to goals is less recognized (Bourgeois, 1984; Greve, 1998; Lant, 1992). Learning is described as ever upward rather than as a process where state of belief approaches an actual state (Levitt & March, 1988; Weick, 1991). When processes are governed by balancing feedback, growth and change are more likely to be seen as the deterministic outcomes of forces or actions, and not as variables embedded in feedback loops (Van de Ven & Poole, 1995).

Whether or not feedback is recognized in the mechanisms underlying change, actors in system often do not recognize their role in the system (Simon, 1991). Actors in the system create the interactions that lead to feedbacks, even if they think of their actions as being constrained by market forces. Learning by doing only occurs if manufacturers find ways to lower production cost over time and then actually lower the prices. The expectations as to how the industry is supposed to work affects how it does work, because unlike in natural sciences, theories in management alter the field being studied through their impact on management practice (Ghoshal, 2005).

Price signals to the supply chain are especially problematic in two cases: new industries (because of poor communication, low volume, and many components being sourced from other industries) and declining-cost industries (because a need for higher capacity is not signaled by rising prices). Growth is deliberate rather than in response to price signals; norms about how much to invest in R&D or capacity or marketing will not have been developed. Whatever choices made early might become institutionalized as the industry develops (Barley & Tolbert, 1997; Zucker, 1987) but early on all the routines that form feedback loops are uncertain.

Managers are relatively free to make choices in this environment (Bourgeois, 1984), but the market responses to those choices are highly uncertain. Organizations act in settings where approaches to learning may not work, and have to use analogies and imagination to decide how the system behaves (March, Sproull, & Tamuz, 1991) this would be particularly true in new industries, where the forces acting on market decisions have not yet been revealed by experience. Actors are forced to predict what factors might be important and design strategy against those.

For these reasons, it may not be justified to use much detail in representing new and growing markets. The knowledge in a new industry is often biased in favor of technical knowledge over market knowledge (Aldrich & Fiol, 1994; Thornton, 1999). The detailed mental models about technology, cost, and performance managers hold are rendered moot by the lack of knowledge of how those factors affect sales. The people building the industry are acting as institutional entrepreneurs (Garud & Karnøe, 2001; Maguire, Hardy, & Lawrence, 2004) as much as business entrepreneurs—they are working to change the environment in which businesses operate rather than just run a business in a given environment.

Models useful to understand their actions or to develop strategy can therefore abstract away much of the detail complexity. Since no actor in the system knows all of the interactions which create the system structure, and since actors will be founding new interactions as well, it is best to have all possible feedback structure available. The model here is intended to balance those two conflicting requirements: keeping every feedback path but jettisoning the detailed formulations of those paths. To accomplish this, I attempt to group all the factors in product adoption into a small number of variables, and all the information about product adoption into a small number of stocks. I then create a generic structure for each stock to be connected to each factor, with a common functional form. The common form of the equations makes it simple to generate any structure by changing constants. Other models may be more useful for forecasts or problem diagnosis; this is intended more for strategy.

The generic process of new product growth

In this model a number of concepts are grouped to develop the simplest equations with all the feedback structure. The variable names are generally chosen to be one of the concepts subsumed in a group, hopefully the most familiar to managers. A table of abbreviations is shown at the end of the paper. As a model of a growing market, the central variable to develop is Adoption Rate (AR). The model treats adoption as equivalent to sales, installation, shipments &c. Feedbacks on

AR pass through level variables that measure adoption in some manner, and to the proximate determinants of adoption.

Adoption Rate has three inputs, grounded in the process of new product sales but logically encompassing possible factors. The first is Attention (Atn), conceptualized as how many consider the product. Before consumers can make a decision about a product, they have to be aware of its existence. Some level of cognitive effort goes into weighing options, and not everyone will invest that effort in any given time. It is analogous to contact rate in market growth models (Bass, 1969) or contagion models (Rahmandad & Sterman, 2008).

The second factor is Attractiveness (Atr), which determines the fraction of those who consider the product who buy. It is the same concept as infectivity, effectiveness of the sales force (Forrester, 1968). Only once paying attention is it possible to compare costs and benefits, which are determined by factors like price and performance. While it is true that an attractive product attracts attention, the model keeps those variables separate—if they are caused by the same processes that should be found in the feedback structure.

The fundamental difference between Atn and Atr is that the effect of attractiveness on adoption is logically limited to between zero and one: the number who adopt must be less than or equal to the number who consider. Meanwhile attention is only limited by the population or other limiting feedbacks: any number could look, even if only a few of them will buy. Thus the fraction adopting (FA) is a function of Atr strictly bounded by zero and one.

Absent other limits, the Adoption Rate would be the product of Atn and FA (depending on Atr). These variables cannot be made to contain the Capacity (Cap) concept. Capacity limits the adoption rate, but does not draw people in or convince them to buy. Capacity is made up of many components, including manufacturing, distribution, sales force and installation, but the variable Cap is the aggregate of all limits on adoption. Like the other factors, interactions between elements of Capacity and elements of Attention and Attractiveness are decomposed to give each factor a single, unambiguous role in the calculation of Adoption Rate.

With the simplest formulas that meet the requirements for Attention, Attractiveness, Capacity, and Adoption Rate, the model of adoption becomes:

(1) $AR = MIN (Atn * FA , Cap)$

(2) $FA = Atr / (Atr + 1)$

The factors making up adoption rate are affected by feedbacks via information about past adoptions. Whether the information is about physical phenomena (installed base, revenue from past sales, market size) or intangible (knowledge, market power, hype), information is in the form of stocks – accumulations of Adoption Rate. While many stocks with different time characteristics might exist in a particular system, all fall into one of three classes: a smooth or running average, a finite-lived integration, or an estimate of the rate of change.

A simple integration with finite lifetime could represent both physical objects and the effects of cumulative experiences. It is just as common for processes to be dependent on the experience gained from sale, adoption, manufacturing as it is for the existence of the object or the identity of the adopter. In the general case, experience could be longer or shorter lasting than the actual object; in a detailed model potentially several stocks with different lifetimes would represent experience, installed base, resources, the population of users, etc. In this model all those concepts are subsumed into a single stock, called S for "size" (of the installed base) or (number of) "systems" (sold).

Other effects are related to the pace of adoption rather than the cumulative adoption. Adoption Rate, is that pace, but information availability is always delayed. This model uses the first-order smoothing function, which is similar to a running average. This would be actors' impression of the Market Size (MS), which is commonly calculated or estimated in industry reports.

Predictions about the future and impressions of momentum are related to growth rate. Estimates of the rate of change update slowly (Sterman, 2000 ch16) and are subject to delays relating to the time to perceive changes and the time over which growth is considered. The variable here is called Market Trend (MT) and is characterized by the Trend Time (T_{MT}).

So the stocks through which possible feedback loops pass are:

(3) $S = \int (AR - S / T_{Life})\, dt$

(4) $MS = \int ((AR - MS) / T_{MS})\, dt$

(5) $MT = \int (1/T_{MT})\, (\text{slope of } AR)\, dt$

From each stock there is potentially a link to each factor in Adoption Rate: Attention, Attractiveness, or Capacity. Since both positive and negative effects exist, the model includes both for a total of 3x3x2=18 possible feedback loops. The effect of a stock on a factor has to be in relation to some reference point. In balancing loops, the reference in the goal in seeking behavior, in reinforcing loops it is often the basis against which growth is measured. The simplest form that captures an effect of a stock on a factor is the ratio of the stock to its reference raised to some exponent (γ). It can be thought of as the elasticity of the factor with respect to the stock: positive exponents yield a reinforcing loop, negative a balancing loop.

There is a common form of all feedback loop equations; when the effect of each stock on each factor, both reinforcing and balancing, is given by:

(6) $\text{effect}_{[\text{factor, stock, valence}]} = (\text{Stock} / \text{Ref}_{[\text{factor, stock, valence}]}) \wedge \gamma_{[\text{factor, stock, valence}]}$

Where factor → {Atr, Atn, Cap}, stock → {IB, MS, MT} and valence → {reinforcing, balancing}, and the stock is used both as its value and as a subscript for selecting the appropriate reference and exponent. The reference points may vary for the stocks' effect on each factor, and for positive and negative links. In fact, if the positive and balancing feedback loops use the same reference, it is equivalent to a single ratio raised to the sum of the exponents. In general, the goal in a balancing loop is different from the base point of a reinforcing one.

For each factor, the six effects can be multiplied to figure the total effect. The factors are modified by the feedback effects in relation to some base. Each factor has the equation:

(7) $\text{factor} = \text{Base Factor} * \prod_{[\text{stock, valence}]} (\text{effect}_{[\text{factor, stock, valence}]})$

Where the product function is evaluated over each stock and reinforcing and balancing valences.

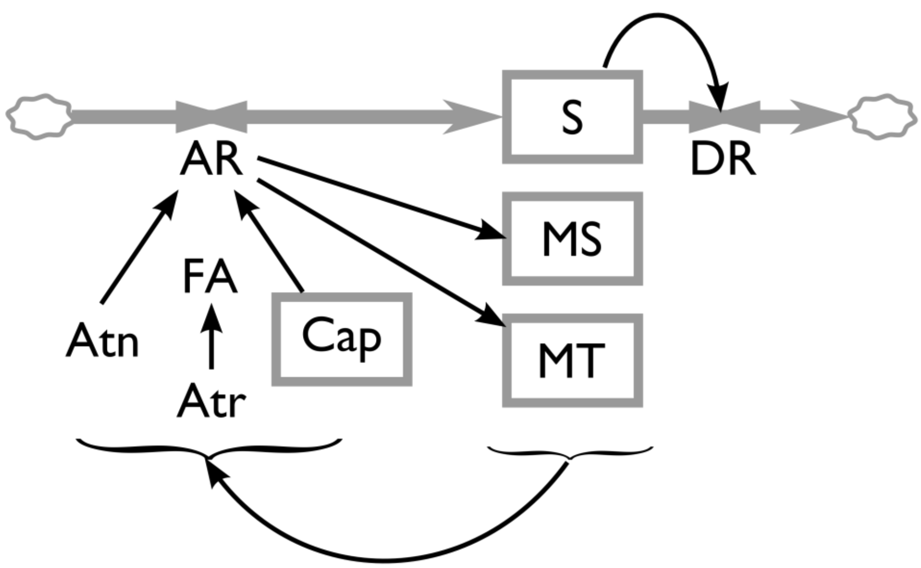

Figure 1: Feedback structure of general growth model

Figure 1 shows the feedback structure created by equations (1-7). The 18 potential feedback loops represented by the single arrow are defined by two three-dimensional matrices of order 3x3x2: a strength matrix with elements $\gamma_{[\text{factor, stock, valence}]}$, and a reference matrix with elements $\text{Ref}_{[\text{factor, stock, valence}]}$. By altering these matrices, the feedback structure of the model can be adjusted to any form. The model is simple enough to program without specialized system dynamics software; for accessibility, it is implemented as a spreadsheet in Microsoft Excel and included with the supplementary materials or available from the author.

The mathematical structure of the model is designed for ease of exploring behavior. As a boundary object for strategic thinking, it serves to provide a concrete relationship between structure and behavior. A goal for industry behavior can be translated into the possible structures that yield it, or a proposed structure can be tested for the resulting behavior. The real-world connections that create the desired structure must be formed by entrepreneurs and policy-makers.

In short, this is an organizing principle for thinking about feedback in a new market rather than a representation of a particular market.

Model behavior

Despite the simplified structure, the model behavior provides several important lessons. By tuning the feedback structure, the model can reproduce the classic behavior modes found in prior research: sustained growth, slow growth, failure to grow, boom-and-bust, and oscillation. A few examples below illustrate the kinds of strategic insight that can be found by interpreting a simple model with complex behavior.

It is clear from equation (1) that Adoption Rate cannot exceed Capacity, but what that means is not always clear. Capacity can limit Adoption to a level below demand, but can also constrain demand. Figure 2 shows a simulation where the reinforcing feedback to Capacity follows the heuristic "grow capacity at the same rate as the market"; "demand" is counted as Atr*Atn. Since initial Cap is only slightly above AR, delays in perceiving Market Size and accumulating Cap cause AR to catch up to – and become constrained by – Capacity. If sales are used as a proxy for demand, as is common, businesses will not know about the lost opportunity. Further, if Attention and Attractiveness depend on feedback from AR, the demand will be lower than it would be if adoption were not so constrained.

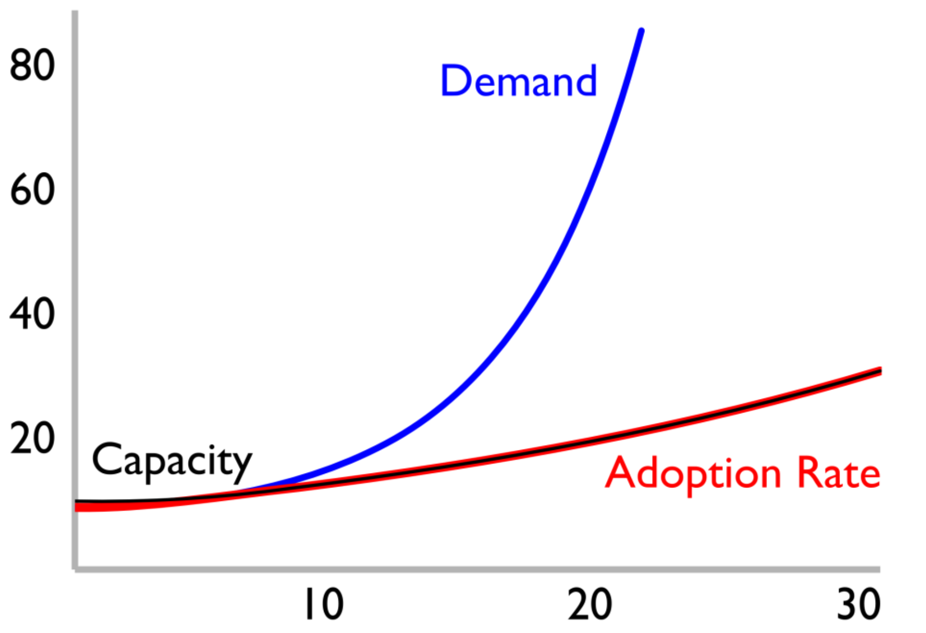

Figure 2: Response to slow Capacity growth

Any market size can be the result of different combinations of Attention and Attractiveness, but they have different implications. A lot of people looking but few buying is a more expensive (for the sales force) option compared to fewer looking but all of them buying. In contrast, getting more people to look is more effective at causing growth. Figure 3 shows the Adoption Rate for simulations with reinforcing feedbacks only on Attention versus only on Attractiveness. The Atn curve grows faster, but represents great wasted effort, while the Atr curve has a slow and finite growth. Balancing Attention and Atractiveness is an important strategic concern.

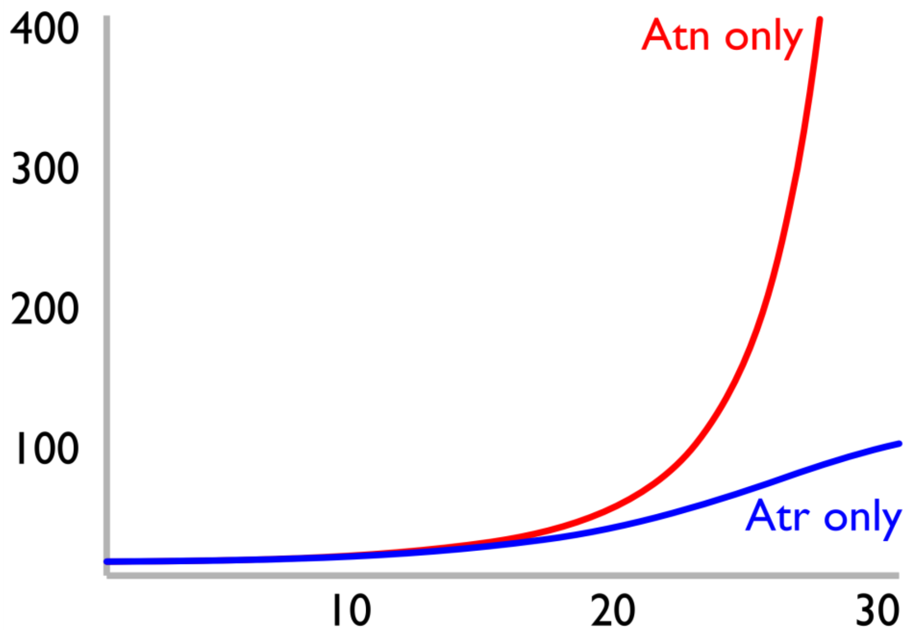

Figure 3: Difference between Attention and Attractiveness growth

There are two basic modes of growth which are mixed in real systems: reinforcing feedback building on any starting growth, and balancing feedback seeking a goal higher than current conditions. In a new industry, the goals are vague and abstract and set in large part through institutional entrepreneurship; changing the implicit goals that industry acts on is a major type of intervention. Figure 4 shows the effect of selecting different forms of goals – single balancing loops from the installed base, market size, or trend estimates.

Finally, an important factor in system growth is coordinated action. Actions taken together can be qualitatively different from the sum of actions taken separately, and feedback loops can interact in surprising ways. Figure 5 shows the effect of two loops separately and together. A reinforcing loop can maintain a system in an (unstable) equilibrium, and a goal-seeking loop will only drive a system to its goal. But in combination, the balancing loop gets the growth started, and the reinforcing loop will cause it to continue until stopped by the negative feedback loop, well above the goal.

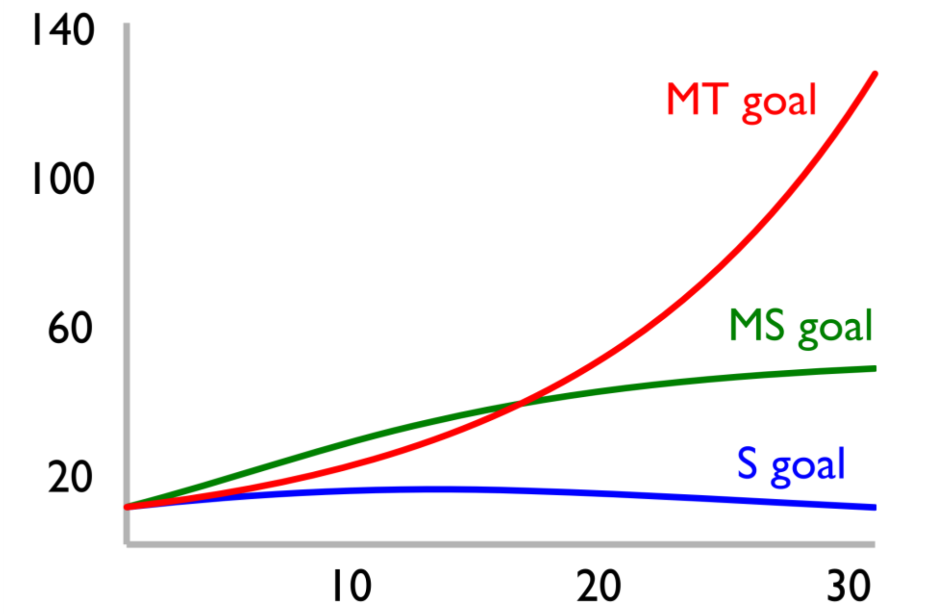

Figure 4: Goal-seeking feedback from different stocks

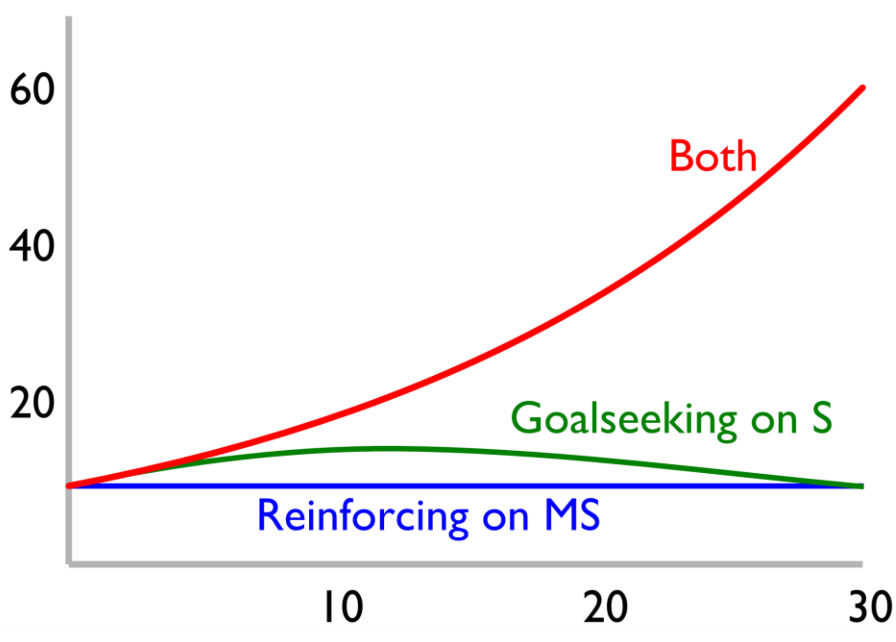

Figure 5: Combining feedback loops

Conclusion

The founders of new industries create the interactions that cause feedbacks, which in turn cause the growth of the market. They do so using their own business decisions and by mobilizing others through networks, media reports and personal connections. An understanding of how these connections create industries that sustain themselves until normal market forces become strong enough is of interest to entrepreneurship scholars and business strategists. A set of common concepts would help to ease communication about these topics. The model presented here is intended to be one such common understanding.

Decisions about new products can be separated into a set of concepts: attention, attractiveness, and capacity. These three factors each have particular impacts on growth—attractiveness can only help if people are considering adopting, while attention gets them to consider. Each of these factors is subject to balancing and reinforcing feedbacks from information about the market, with different time behaviors, standards and comparisons. The important decisions in new industry strategy are about how the real available interventions map onto these concepts, and what effects on structure can be had. Common understanding and dynamic tools could be invaluable for understanding growth.

Variables and Abbreviations

AR	Adoption Rate (unit/month)	
Atn	Attention (unit/month)	rate of considering adoption
Atr	Attractiveness (dmnl)	measure determining FA
FA	Fraction Adopting	fraction of those consider that adopt
Cap	Capacity (unit/month)	ability to deliver to adopters
S	Size (unit)	accumulation of AR
T_{life}	Lifetime (month)	residence time in S
MS	Market Size (unit/month)	smoothed value of AR
T_{MS}	Market Size Time (month)	averaging time for MS
MT	Market Trend (1/month)	perceived growth rate of AR
T_{MT}	Trend Time (month)	perception time for MT

Stock the placeholder or subscript for {S, MS, MT}

Factor the placeholder or subscript for {Atn, Atr, Cap}

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