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1. Introduction

Diffusion of innovation has traditionally compared one generation of products replacing another; black and white television sets being replaced by color and later high definition sets for example, or bulky cathode ray tubes being replaced by flat panel displays. How might we consider the dynamics of diffusion though if one generation of a product is real and subsequent generations increasingly virtual; compact disc recordings being replaced by MP3 formats and miniature memories holding thousands of songs, with those in turn being supplanted by ubiquitous streaming services?

Our purpose in this paper is to briefly review the evolution research on the emergence and diffusion of innovation, and to provide a new and more nuanced model of diffusion. That model will necessarily address multiple products of both and real and virtual forms competing at the same time and also various modes of competition beyond pure competition or a simple zero-sum game. At least at the beginning of races between new and older products, processes and services, growth of one will often stimulate growth of the others. We will term this *symbiotic* competition. Later the interacting technologies may fall into equilibrium, or a perhaps cyclic state that we will term *predator-prey* competition, and finally a zero-sum game of *pure competition* in economic terms may ensue. This has significant implications with regard to innovation diffusion and strategy.

We do not intend our work to be a forecast of technological trajectories or futures. Rather looking at generations of products, processes and services and how they evolve should help us to think systematically rather than incrementally. Thinking systematically should help us avoid the risk of lengthy and lavish overinvestment in dying businesses, which is often the case observed. Thinking systematically should also help us grasp opportunities that provide premium growth.

We will show how our model of the dynamics of competition and diffusion of innovations can be simply and practically applied and will provide a few examples analyzing the transition from real to virtual products and listening experiences in the music industry.

2. Motivation

Why is diffusion of innovation important? Ideas and inventions are major sources of both economic growth and of the expansion of human possibilities. In order for ideas to matter though, they must not only be reduced to practice, but their application must also spread or diffuse among potential users. Ideas and inventions are sometimes seen as sweeping established practices aside and somewhat hysterically as displacing or disrupting whole swathes of industry. Who though would agree that we should give up electric light and return to gas lighting or that using ice for refrigeration is more natural, convenient and efficient that an electric refrigerator and freezer? Would anyone wish to give up a mobile phone to return to land lines and pay phones?

Transitions do indeed require major structural adjustments and sometimes the development of whole new industrial ecologies, supply chains and business models to advance into practice. But each displacement may lead to broader use and possibilities as happened for illumination, refrigeration and communication, greater efficiencies, increases in quality and much expanded markets. Moreover, the spread of electric generation and distribution networks led to many other industrial applications and household conveniences. The rise of refrigeration led to air conditioning and great expansions of cities and land values in previously oppressive climates. Mobile devices have led to the convergence of cameras, music players, maps and location finding and a myriad of other functions and uses into a single iconic object, instead of just creating a device, which allows us to 'talk anywhere.' We will later illustrate the complexities of this phenomenon as it applies to recorded music and the experience of listening to music.

3 Models of diffusion and steps toward a new model

How does the diffusion of new products, processes and services occur? Everett Rogers (1962) conceived of innovation as something entirely new expanding into an unoccupied market. Rogers famously described different phases in the diffusion process in which customers with different inclinations played distinct roles in sequence with earlier adopters persuading and influencing those more slowly convinced and more reluctant to adopt. Rogers' equations make the growth rate of an innovation in the market proportional to the filled niche compared to the unfilled market niche resulting in a logistic curve. Modeling diffusion thus requires an estimate of potential market size.

John Norton and Frank Bass (1987) were among the first to consider a new product or process generation replacing a prior one. Their model importantly allows for both the growth and later decline in the use of a product and assumes a growing market from generation to generation. The model has been applied simultaneously to multiple generations, such as semiconductor memory chips of increasing capacity. Norton and Bass implicitly assume that different generations of a product or device are in pure competition with one another. Thus, sales of generation one may be declining toward zero while generation two has reached its height and a new generation three is beginning to grow. Norton and Bass' model applies to many products, but as we will show later, clearly not all.

Each of these foundational models is a highly simplified version of the world. More realistically competition to overturn relatively stable products and markets involves a welter of different alternatives coming from both familiar and unfamiliar sources and origins. Some alternative offerings enjoy increasing investment and commitment, while others drop out of the race or fill a specialized niche. In many cases innovations are put forward by newly formed firms or firms that have newly entered the competition by diversifying from an unexpected direction. An iconic historic example is the race in the computer industry in the 1970s to replace magnetic core memory (Utterback and Brown, 1972). The winner was famously semiconductor memory-chips manufactured by Intel, other newly formed firms and by several large incumbents. What is often forgotten is that this race also included a number of plausible alternatives including thin magnetic films and plated wire memories, shown in Table 1. (IBM was advancing both core memory and all three new alternatives; thus there are more entries than firms in column one).

Table 1: Computer Memory Manufacturers in 1970[1]

	Established firms	New Firms
Core Memory	26	O
Plated Wire	8	O
Thin Film	5	1
Semiconductor	6*	7**
Totals	31	8

* Includes IBM and AT&T **Includes Intel

Today we can see a similar phenomenon in the race between the long established recording media and modes of providing music to listeners. Published sheet music used with a piano or other instruments in one's home was the first contender in this race. Edison's cylinder recording system, first intended for business use famously followed and was quickly reduced in size and cost and made easier to use. Moving from a cylinder to a Bakelite disc increased recording time from four to eight minutes. Thus began a progression of recording discs of better and lighter materials and recording speeds aimed at increasing the amount of music recorded, lowering costs and culminating in producing stereophonic sound. The progression of physical media continued through magnetic tape and compact discs in both analog and later digital formats until today's popular MP3 format of compressed data. Data compression has enabled listeners to own vast amounts of music in miniature form and to listen to a wide range of music on demand and in streaming form almost anywhere (Yilmaz, 2017).

Another assumption we must remove in order to devise a better model of diffusion is the idea that innovations are independent of each other and always in *pure competition*. Rather, we will argue that modes of interaction among technologies are varied, and that new and older products, at least at the beginning of the diffusion process may experience the expansion of markets for both. If a new competitor causes the market for an established product to grow, sometimes even accelerating its growth, we will, borrowing a term from ecology, call that mode of competition *symbiosis*. A popular example appears in *Mastering the Dynamics of Innovation* (James Utterback, 1994). The first large scale and practical use of refrigeration began in the early 19th century with tools used to cut blocks of ice from ponds during the winter and store them in large insulated buildings for use over the summer months. With the development of steam-powered machines for freezing blocks of ice, year-round ice became a commodity available everywhere on demand. Far from reducing the demand for conveniently harvested ice, mechanical freezing tripled its demand while vastly expanding the use of refrigeration (Utterback, 1994, Chapter 7)!

New and established products in reality almost always influence one another in both positive and negative ways. To borrow another term from ecology, competitors often co-exist as *predators*

[1] The table is constructed using data from James M. Utterback and James W. Brown, "Monitoring for Technological Opportunities," Business Horizons, October 1972, Vol. 15, 5–15.

and prey, the new products seen as predator and current product as prey. Wolves tend to prey on slower or less able deer and other herbivores, keeping their population in check. Too small a population of wolves results in overpopulation of herbivores, which then starve for lack of food before the end of winter. Too many wolves may lead to small populations of herbivores and the starvation of wolves. Thus, wolves and herbivores coexist in an oscillating equilibrium with healthy populations of both. Predator-prey competitive modes were extensively examined and modeled (by A. J. Lotka, 1920 and by V. Volterra, 1926). We will build on their work to generalize their idea to the world of technologies, economics and markets.[2] To continue our example, harvested ice and machine-made ice both served ample segments of the market for refrigeration well into the 20th century and well after the appearance of electric refrigeration. Ultimately delivered ice entered pure competition with electric refrigeration and retreated to small and specialized niches in the market.

In sum, modes of competition need not be unitary, but one mode may evolve into another over time. In general, it is a dynamic process. In the examples we have studied in some detail it is tempting to speculate that we may see symbiosis first; later evolving to a form of predator prey interaction (with either the old or new product dominant for a period of time); followed by the emergence of pure competition with the extinction of one or the other.

The main contributions of this work are the following:

1) We have developed a model for the diffusion of technology not just for head to head competition but also for alternative competitive modes such as predators (N) and prey (M) in equilibrium and in symbiosis.
2) The model provides for analysis of diffusion not simply of one new product (N) contending with one established product (M), but rather for multiple M_i and N_j.
3) Earlier models such as those presented by Rogers and by Norton and Bass can be readily shown to be special cases of our more general equations.
4) By relaxing the necessity of assuming pure competition, changing modes of competition can be calculated year by year as they evolve.
5) Similarly, by relaxing the need to estimate a total market or niche size in advance, market penetration can be calculated year by year as it evolves.
6) The model is realistically path dependent providing varying results depending on the starting point of each competition.
7) By using our software and model and analyzing 40 years of data from the music industry, we will provide an illustration and application.

Although the term *competition* is frequently used in the context of innovation and industrial economics an exact description of the term is not usually explicitly given. The interaction between technologies is often not one of competition in the strict sense of the word, as there are many cases where technologies interact in a relationship, which is not necessarily confrontational. The multi-mode approach for interaction among technologies provides a useful framework within which to understand and apply this richer landscape of interaction. Not only do the multiple modes provide the flexibility to examine interaction in the various circumstances

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[2] The analogy is not perfect of course, as deer do not eat wolves.

where the different technologies inhibit and enhance one another's growth, i.e. in the three distinct modes described below, but it also allows one to account for the transitional effects as the interaction between the technologies transgresses from one mode to another with time. The notion that the modes of interaction between two technologies can change with time is one of the main points that differentiate the technological framework proposed here from similar natural ecological frameworks.

By considering the possibility that one technology may either enhance or inhibit another technology's growth, one finds that three possible modes of interaction can exist, viz. *pure competition* where both technologies *inhibit* the other's growth rate, *symbiosis* where both technologies *enhance* the other's growth rate and *predator-prey interactio*n where one technology *enhances* the other's growth rate but the second *inhibits* the growth rate of the first. Although such frameworks had, of course, been successfully applied in the fields of biological ecology (Pianka, 1983) and organizational ecology (Brittain and Wholey, 1988) a survey of the literature circa early 1994 showed then that with regard to *technologies*, pure competition was often discussed, symbiosis sometimes referred to but that predator-prey interaction between technologies was very rarely mentioned (Pianka, 1983 in Carroll (Ed.), 1988).

The multi-mode framework is illustrated in Figure 1 for the case of two technologies. In principle, the framework can be extended to any finite number of technologies. Note that although there are three modes, two possible predator-prey interactions are indicated (depending on which technology is the predator and which the prey), and hence four possible types of interaction. In developing our model in the following section, however, we shall refer to three distinct modes.

Figure 1: Multi-mode framework for the interaction among two technologies

		Effect of A on B's growth rate	
		Positive	Negative
Effect of B on A's growth rate	Positive	Symbiosis	Predator (A) – Prey (B)
	Negative	Predator (B) – Prey (A)	Pure competition

Once the multi-mode framework has been formulated, the next step is to develop a mathematical model. One of the first challenges is to find a metric which defines the concepts of 'competition', and 'good for one another or not', with mathematical rigor rather than just as qualitative concepts. The concept of *growth rate* offers itself as a suitable and appropriate way of classifying the process of interaction among technologies, so that in general, *interaction* can be manifested in the concept of the reciprocal effect that one technology has on another's growth rate.

The following section discusses a mathematical model, which can be used to describe and simulate a framework for multi-mode interaction among technologies described in the previous section (Utterback, Pistorius and Yilmaz, 2019). Then we will use the simulation to present an extended example simulating the diffusion and interaction of multiple music formats over the four successive phases of the industry.

Our original contribution here is to present and illustrate the use of a Matlab[3] program based on our model developed by Yilmaz, specifically for modeling the multi-mode framework for interaction among technologies. This program has been successfully applied to model the dynamics, and also has the ability to estimate parameters of the LV equations over 40 years by also finding the mode of interactions for the first time.

In the final section we will consider strategic and tactical applications of our model and suggest directions for future research.

4 A modified LV system for multi-mode interaction among technologies

In order to mathematically model the multi-mode framework for interaction among technologies, the traditional and classic substitution models, which are based on single equation formulas, are hence not fit for purpose. It is necessary to model all the technologies, each with its own equation, although they must be coupled with coupling coefficients to account for the interaction between them. A *system of coupled differential equations* is therefore required, with each technology represented by its own equation and coupling between them. A system that is applicable to this problem (albeit in modified form) was formulated some time ago by the ecologists Lotka and Volterra, known as the *Lotka-Volterra (LV) equations*.

4.1 Lotka-Volterra equations for ecological systems

The premise of the Lotka-Volterra system is that each population ('species') is represented by its own equation similar to (1a) in the absence of its interaction with another population. When two or more populations start interacting, a term representing this interaction is then added to each equation.

Consider an ecological system where *N* represents the predator population and *M* represents the prey population. In this case, the system of equations representing the dynamics of the total population (*N+M*) will be (Carroll, 1981):

$$\frac{dN}{dt} = a_n N - b_n N^2 + c_{nm} NM \tag{1a}$$

and

$$\frac{dM}{dt} = a_m M - b_m M^2 + c_{mn} MN \tag{1b}$$

where in this case $c_{nm} > 0$ and $c_{mn} < 0$.

The terms *NM* and *MN* indicate elements of the two different species interacting with one another. In these equations, the terms *NM* and *MN* have similar forms and functions as N^2 and M^2, except that they represent elements of the two different populations interacting with one another rather than elements of the same interacting with itself.

[3] MatLab is a registered trade name.

Equation (1) clearly indicates a predator-prey relationship. Since $c_{nm} > 0$, interaction between elements of *N* (predator) and *M* (prey) will enhance the growth rate of the predator (*N*). Similarly, since $c_{mn} < 0$, interaction between *N* and *M* will have a negative effect on the growth rate of the prey (*M*).

The nature of ecological populations is such that the c_{nm} *and* c_{mn} coefficients will always retain their sign. Mother Nature has mandated that the wolf will always hunt the deer and never the other way around. Hence the relationship between wolf and deer will always be predator-prey, with wolf the predator and deer the prey. As we will show, this is not necessarily the case with technologies, where the mode of interaction can change with time, as can the roles of predator and the prey.

For the moment we are also assuming that the coefficients (*a,b,c*) are constants. However, that does not necessarily have to be so. In the case of technological interaction, it is conceivable that the coefficients may indeed change with time. We return to this issue again later.

4.2 Lotka-Volterra equations for multi-mode technology interaction

The ecological predator-prey equations in Equation (1) can now be modified so they can be used to represent pure competition, symbiosis and predator-prey relationships in a formulation to model the multi-mode framework for the interaction among technologies. The modification is vested in allowing the signs of the c-coefficients to be able to change, and is shown later, for the coefficients to be time dependent rather than constants.

For two technologies, the modified formulation will thus be

$$\frac{dN}{dt} = a_n N - b_n N^2 + c_{nm} NM \qquad \text{(2a)}$$

and

$$\frac{dM}{dt} = a_m M - b_m M^2 + c_{mn} MN \qquad \text{(2b)}$$

where the distinction between the different modes is indicated by whether the *c*-coefficients are positive or negative, as indicated in Table 2. As noted before, *c=0* cases can be considered as distinct modes in their own right.

Table 2: Signs of c-coefficients in modified LV equations, designating interaction modes

<table>
<tr><td></td><td></td><td colspan="2">Effect of N on M's growth rate</td></tr>
<tr><td></td><td></td><td>Positive</td><td>Negative</td></tr>
<tr><td rowspan="2">Effect of M on N's growth rate</td><td>Positive</td><td>Symbiosis
$C_{nm} > 0$ and $c_{mn} > 0$</td><td>Predator (N) – Prey (M)
$C_{nm} > 0$ and $c_{mn} < 0$</td></tr>
<tr><td>Negative</td><td>Predator (M) – Prey (N)
$C_{nm} > 0$ and $c_{mn} < 0$</td><td>Pure competition
$C_{nm} < 0$ and $c_{mn} < 0$</td></tr>
</table>

Marchetti (1987), Hannan and Freeman (1989) and Modis (1993) among others, have suggested similar sets of equations. They to refer only to the case of pure competition (and not for the multiple modes nor for the multi-technology case presented here). Belief then was that the Lotka-Volterra equations and particularly the pure competition formulation cannot be solved explicitly. However, today they can be solved numerically. A Matlab model has since been developed which can determine the values and signs of the coefficients, hence also identifying the particular modes. This approach does not require traditional simplifying assumptions and subsume earlier iterative formulations and models (Yilmaz, 2017; Utterback, Pistorius and Yilmaz, 2019).

4.3 A general solution for multi-mode interaction among technologies

Consider now *J* technologies interacting in the same market niche, and let $T_i(t)$ represent technology *i* with ($1 \leq i \leq J$).

The differential equation for $T_i(t)$ can be expressed as (3)

$$\frac{dT_i}{dt} = a_i T_i + \sum_{j=1}^{J} c_{ij} T_i T_j$$

where all coefficients are positive and $s_{ii}c_{ii}$=-b_i. Furthermore, s_{ij} = +1 if technology *j* has a positive influence on technology *i*'s growth, whereas s_{ij} = -1 if technology j has a negative influence on technology *i*'s growth. Marchetti (1987), Hannan and Freeman (1989) and Modis (1993) among others, have suggested similar sets of equations. However, at the time, they seemed to refer only to the case of pure competition (and not the multiple modes presented here). They did not offer solutions for the equations and specifically not for the multi-technology case.

One of the key insights from this model was recognizing that the computer simulation could not only estimate the absolute value of the coefficients, but also their sign. This is the key, which indicates the nature of the relationship and the mode of interaction. The amplitude of the coefficient indicates the ‘strength’ of the interaction relationship and the sign the nature of the relationship (pure competition, symbiosis or predator-prey) at a given point in time.

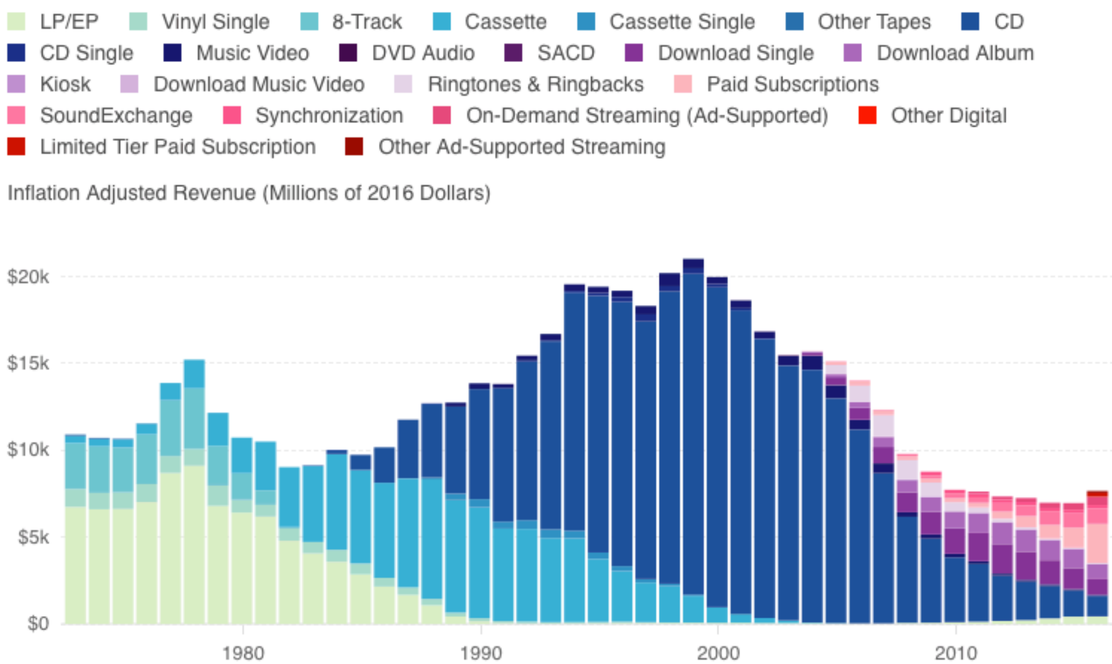
The authors believe that these findings open a very rich field of inquiry to explain why the modes and how the modes appear, and also the sequence in which the modes follow one another – first symbiotic, then predator-prey, and eventually competition.

5 The Transition from Products to Services in the Music Industry

A logical step is to examine a case for which a real product evolves into a virtual service. A case we have analyzed is the transition from real to virtual in recorded music, and that involves serious issues of metrics and units. Music has evolved from single songs recorded on a cylinder or both sides of a disc in Edison’s day, to different record formats (72, 45 and then 33 1/3 rpm), to compact discs, and finally to subscriptions to music streaming services. What is the meaning of units when one can consume all the music possible in a month for a low monthly fee, and how can that be compared to an hour or two of music recorded on a record or compact disc (Yilmaz, 2017)?

The music industry has a dynamic and global market with strong competition in every segment. As shown in the figure below, the major source of revenue has transitioned between physical products and then from physical products to virtual products, and lately from virtual products to services in the recorded music business. With the service approach, the consumption of music has become easier than it has ever been before. It is safe to assume that technological developments will continue to make it even easier to consume music for wider audiences.

Figure 2. Inflation Adjusted US Recorded Music Revenues by Format (Source: RIAA1 https//www.riaa.com/u-s-sales-database/ Accessed in December 2016)

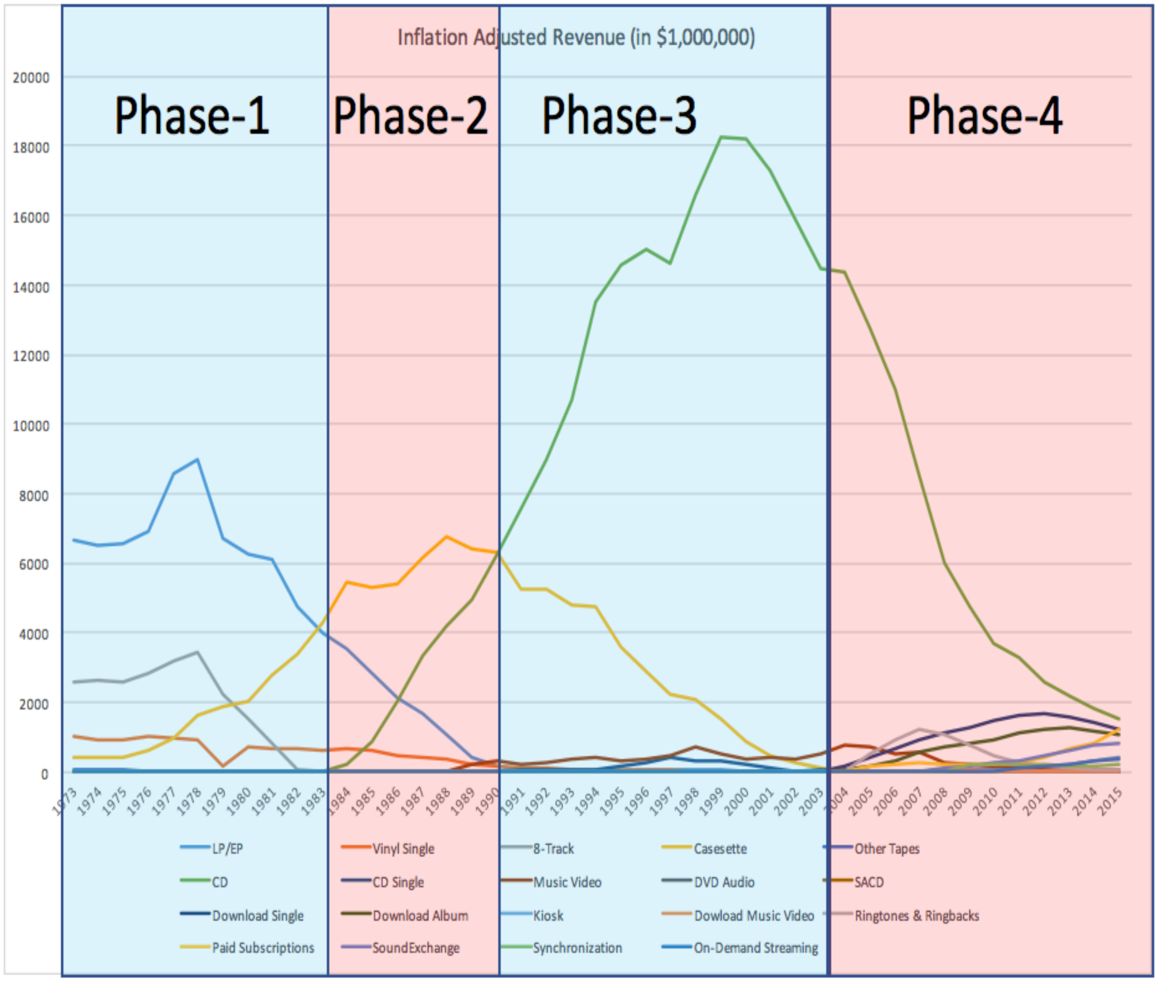


5.2 Capturing Value from Recorded Music

Unless it is captured in a physical medium, a song is an abstraction. The transformation of music from fleeting to physical has been studied extensively by Gillett (2011) – examining how it has changed from a piece of paper, to a rotating cylinder that can be played on a phonograph, to a vinyl record that can be played on a gramophone, to a cassette for a cassette player, and then to a compact disc (CD) for a CD player and then to a compressed MP3 digital music format.

The research in this paper is focused on the distribution and consumption of recorded music, which are again in the middle of a transformation in terms of its underlying technologies business model. Today consumers have the luxury to choose from enormous libraries and to listen to almost any music any time they wish, without any significant delay and continuously. In most cases listeners only need to make a payment if they choose not to be interrupted by advertisements. Changes in the business model from sales of physical media to subscription services have brought new challenges. Sharing profits and capturing value from the subscription model are not clearly settled, as major streaming service firms in the market have not reached profitability yet. Our object in studying the music industry specifically its transition from products to services. Our assumption is that the dynamics in the music case might share features with technological transitions in other industries. Moving to a service based model requires changes not only within the enterprise, but we expect it to result in systemic change in the value chain; in the interactions of stakeholders; and in the ways value is shared by stakeholders.

Figure **3 Phases of the recorded music industry**



Phase transitions in the music industry are defined for our analysis as follows:

• Sales data from the recording industry is divided into four phases, driven by the dominant technologies of each phase. Our data set starts at 1973.
• Sales in each phase are then simulated using the Lotka-Volterra model, and the coefficients and interactions between technologies discussed in detail.
• Using results from the simulations, limited predictions are made and compared to the actual results.

• Phase 1: Starts at 1973, where the earliest data are, available and ends in 1983, when the sales revenue of new Cassette technology surpasses the sales revenue of the incumbent - Vinyl.
• Phase 2: Begins when the CD enters the market and surpasses the sales revenue of the incumbent – the Cassette.
• Phase 3: Begins when the CD sales surpass Cassettes and ends when Cassette sales disappear.
• Phase 4: This phase extends from the end of Phase 3 until to today, during which streaming technologies enter the market, and sales for CD's declines.

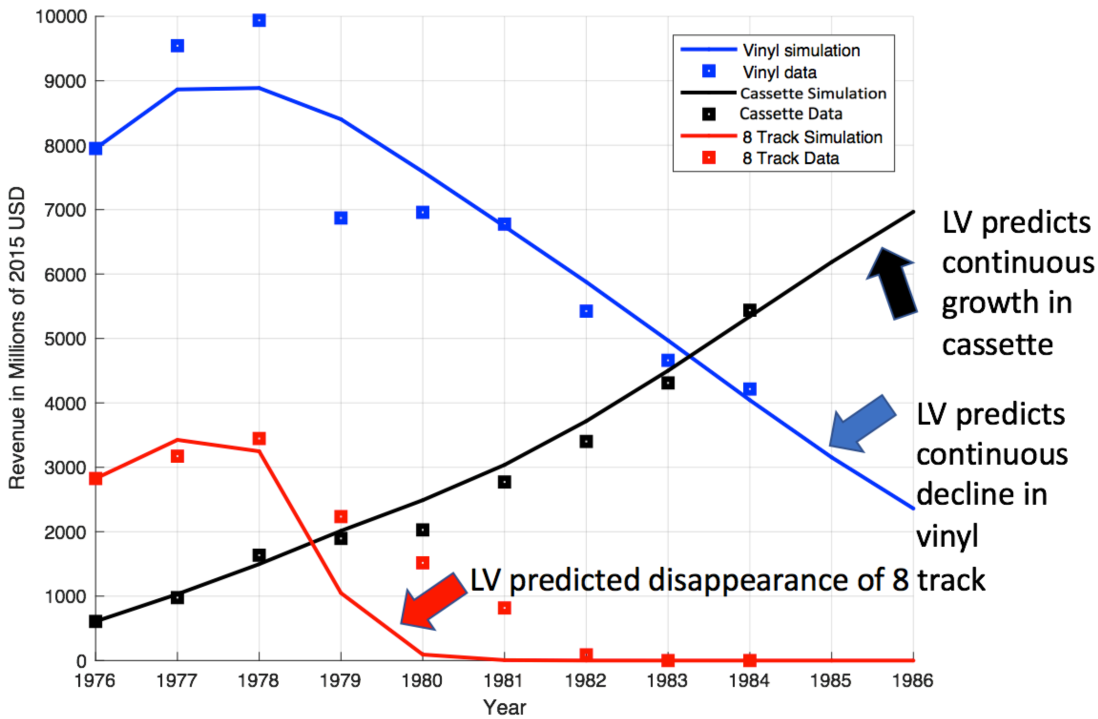


Figure 4: Phase 1 Analysis and Prediction

Analysis of the interaction among recording technologies from 1973 through 1984 shows that:

- 8-Track: Cassettes have a predator-prey relationship, where Cassettes are the predator
- 8-Track: Vinyl has a predator-prey relationship, where Vinyl is the predator
- Cassette: Vinyl has a competitive relationship

On the other hand, the analysis shows 8-Track's sales revenue will become $0. In a true predator-prey relationship, the prey does not entirely disappear but it comes back once the predator population starts to decay. However, it is clear that analysis of product interactions is not exactly analogous to that of the populations of animals.

Here decay in the 8-track's sales revenue results as an increase in Vinyl's and Cassette's sales revenue, and the increase in Vinyl's and Cassette's sales revenue results in a decrease in 8-Track's sales revenue. The analysis indicates that the nature of interaction between Vinyl and Cassette is competition, which would result in Vinyl's sales revenue disappearing at some point. (Optimum parameters found by the optimization engine are given in Appendix 2 for each Phase).

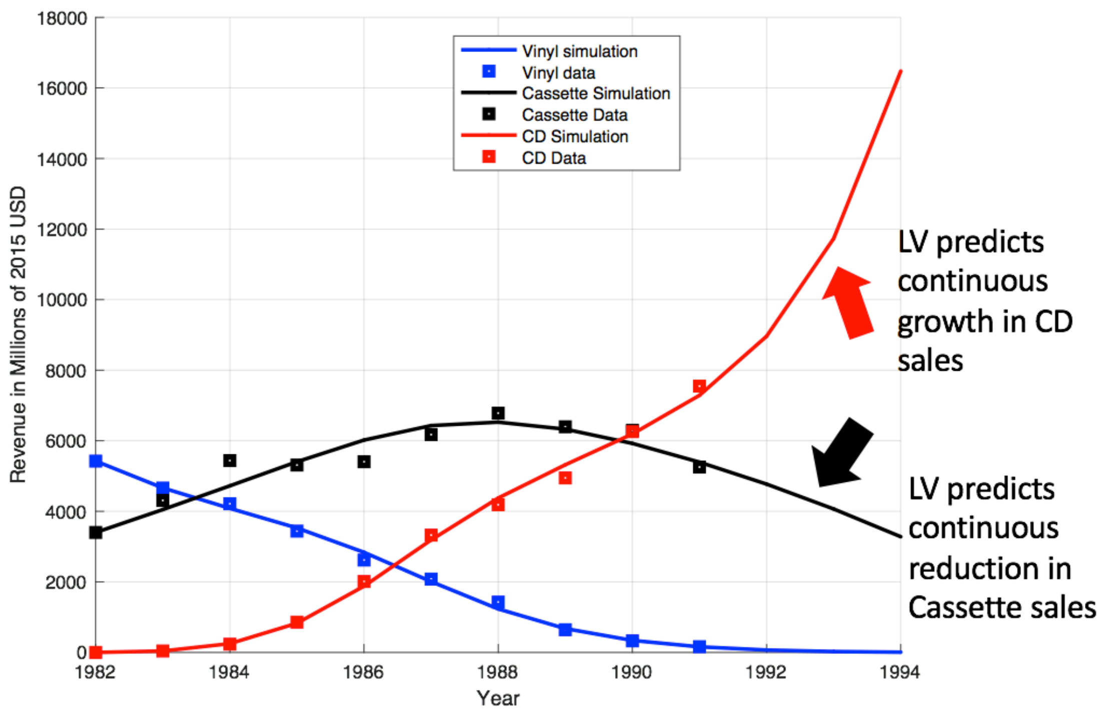


Figure 5: Phase 2 Analysis

In Phase 2, from 1982 – 1990, we encounter an interesting result. Here are the interactions in the early years of cassette sales:

• 8-Track: Cassette has a symbiotic relationship
• 8-Track: Vinyl has a predator-prey relationship, where Vinyl is the predator
• Cassette: Vinyl has a predator-prey relationship, where Vinyl is the predator

One can expect to have changes in the interactions among technologies over time. However, in this analysis, the number of the data points for the Cassette is too limited to arrive at a conclusion.

Related to the nature of interactions, analysis shows that:

• Vinyl: The CD has a predator-prey relationship, where CD is the predator. The coefficient that determines this interaction is the largest coefficient among the coefficients for CD.
• Cassette: The CD has a predator-prey relationship, where CD is the predator.
• Cassette: Vinyl has a symbiotic relationship.

This result is hardly surprising as the CD took market leadership during the early 1990s, moving revenue away from Cassette and Vinyl. Although the LV model correctly predicts the near future as sales continued to grow for the CD and reduce for Cassette, it is important to emphasize that LV is not a pure forecasting tool but more of a tool that provides insight regarding the nature of interactions among technologies and by creating a set of consistent scenarios.

These results also beg the question: How early can LV predict emergence of a new technology? The answer seems to be in the optimization engine. As shown in Figure 6, if one simulates the very early years of CD, the LV model may not be able to predict the emergence of a new technology. This is not purely due to the limitation of the model but it is also due to the decisions one makes to simulate the model and to find optimum parameters. Since in the solution provided here, the residue for the optimization engine would be much smaller in the case of the CD compared to Vinyl or Cassette (because they have higher sales revenue), the LV model does not predict the emergence of the CD in its first 2-3 years.

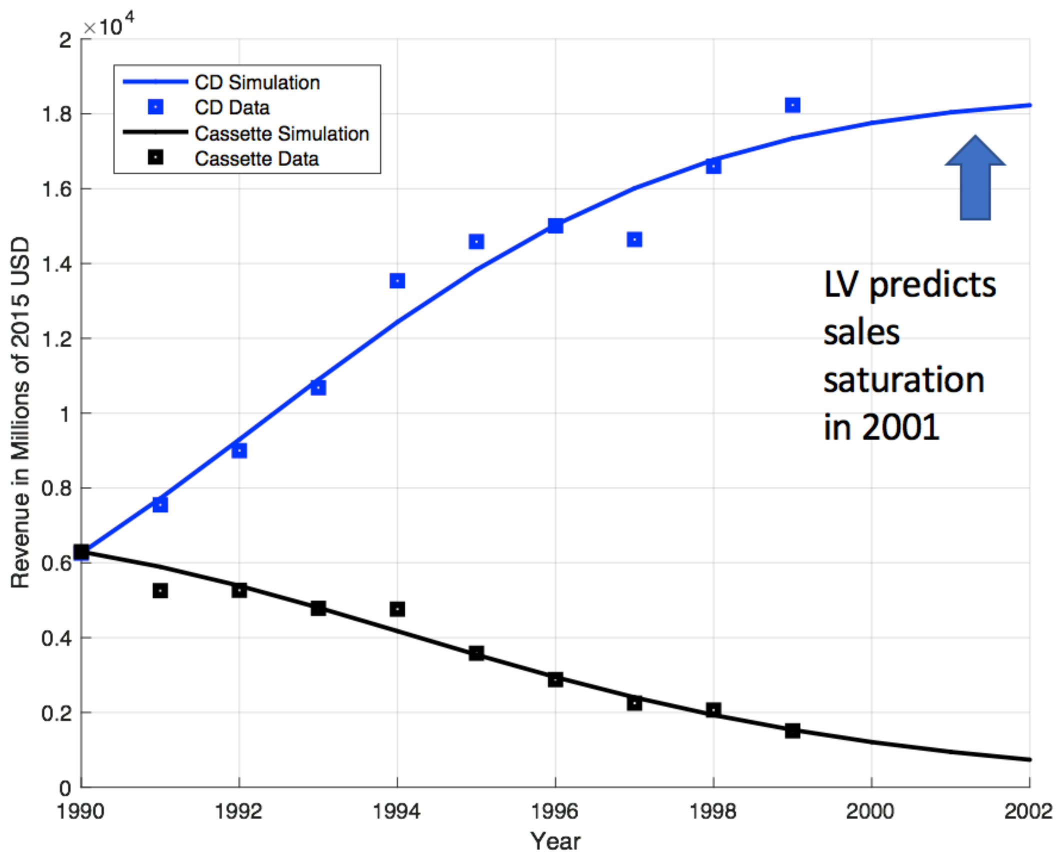


Figure 6: Phase 3 Analysis and Prediction

Phase-3 is not particularly interesting as it has the CD reaching its peak and the cassette's decline. However, it presents an illustration for two technologies competing rather than three as in previous examples.

As shown in the table in Appendix 2, *a* coefficient for the Cassette is near zero and LV explains the decline with the predator-prey relationship where Cassette is the prey. In general, users will find it easier to simulate the case of two technologies as the optimization engine converges quickly.

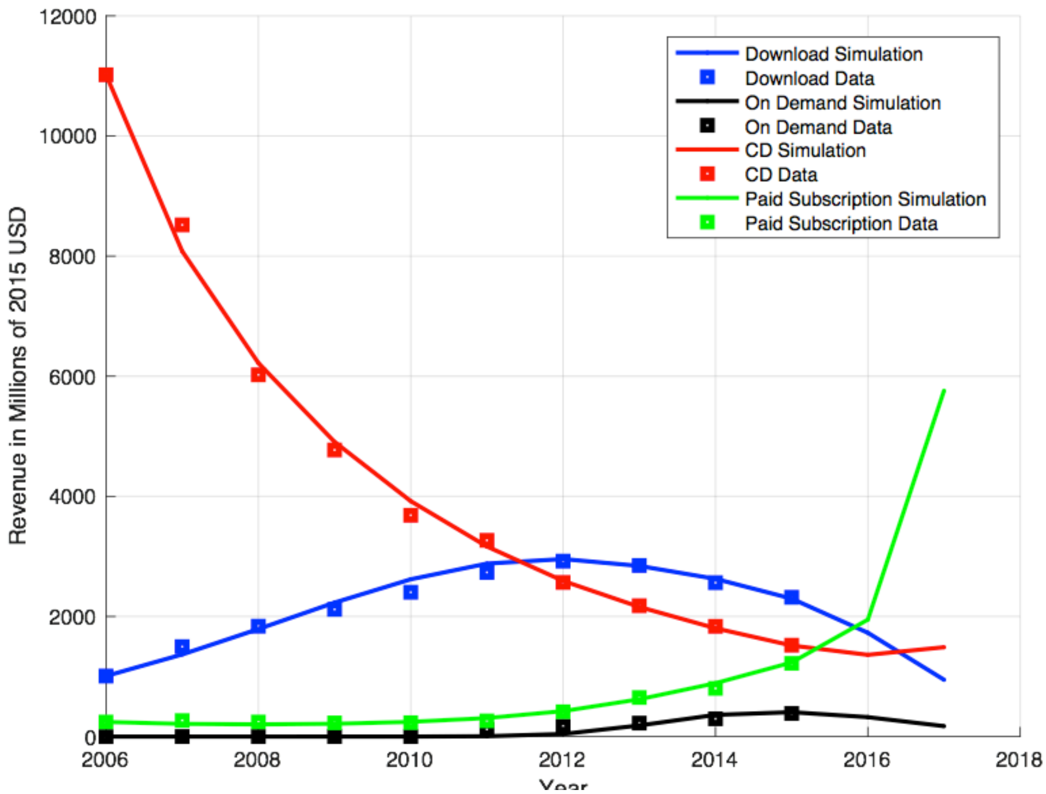


Figure 7: Phase 4 Analysis and Prediction

Phase 4 constitutes a very interesting case as 4 technologies are competing and all of them need to be considered. As explained in the previous chapter, music streaming is taking the market lead in the US and in the world while sales of either the digital format or the CD format are in decline.

The analysis shows the following relationships:

• Paid Subscription – On Demand Streaming has a competitive relationship. These two new technologies compete for sales. The simulation indicates that paid subscription has an advantage over on demand streaming.
• Paid Subscription – The CD has a predator-prey relationship where the CD is the predator. This indicates an interesting case and will be further investigated in the following part.
• Music Downloads – On Demand Streaming has a symbiotic relationship.
• Music Downloads – The CD has a predator-prey relationship where downloads is the predator
• On Demand Streaming – The CD has a predator-prey relationship where On Demand Streaming is the predator.

As far as we are aware, this analysis is one of very few cases where 4 technologies are used within LV modeling. As the optimization engine was tasked with finding 20 parameters, one can expect some level of computational errors in the model. However, given the current state of competition and the market capitalization of the companies in the business, the future of music streaming is the most sought after information. Our model shows that the model of paid subscription for streaming will take off where the other technologies in the model, except the CD, will lose sales.

The predator-prey relationship reported by the analysis for CD and Paid Subscription is of streaming services, one can expect popular artists to continuously take larger parts from the pie. An important idea to explain this phenomenon is the “paradox of choice” (Schwartz, 2004). According to Schwartz, the efforts needed to understand the available offers and to arrive at a reasonable conclusion are too overwhelming, that people either choose what they already know or follow the popular choice. As the number of choices increases with streaming, the effort to make a choice also increases.

The four transitions discussed above affected not only a limited number of stakeholders (artists, labels), but each changed the value chain in the industry creating new major stakeholders and diminishing the power of some of the existing ones. In the traditional music industry, record selling was the main source of revenue, hence the production and distribution of music was coordinated around this core activity. As a result, for a singer or song writer, finding a label to work with to produce and sell music records was most important. One can see from Figure 3 that revenues for all recordings sold in the United States were fairly flat at about six billion dollars per year during the first half of the four decades covered here. The advent of more compact analog and then digital recordings read by means of coherent light nearly tripled sales through the next decade to 18 billion in 1998.

The transition to music downloads and now streaming services has made it is nearly impossible for an artist to make a living solely based on an income from the music he or she creates and records. Today a consequence of the transition to streaming, the leading source of revenue for singers is not album or single sales, but live demonstrations and tours. In 2013, all of the 10 artists who made the list of highest earning singers had more than 60% of their income from touring (Tschmuck, 2012).

Another major impact of the transition is seen in the accessibility and availability of music. As the world becomes increasingly connected with smartphones and internet access, music streaming services will continue to expand and reach more consumers. Soon every smartphone owner will have access to at least one form of a free streaming service, meaning virtually everyone will have access to almost every song ever produced. Today there are tens of millions of songs available *via* streaming.

Ubiquitous availability introduces a fundamental question: who will benefit? One possibility is suggested by the “long tail” theory (Anderson, 2006) in which the future of the music business is selling less of more. Anderson argues that with improved ability for finding products closely tailored to their specific needs, consumers would migrate from popular products to custom ones. The opposite possibility is suggested by *The Winner Take-All Society* (Frank & Cook 1995). Frank and Cook argue that with broad communication and easy replication, consumers are more likely to converge in their habits and tastes. Anita Elberse (2008), using data from the home-video and the music industries, showed that increasingly with digital content sales skewed towards the most popular titles.

With wide adaptation of streaming services, one can expect popular artists to continuously take larger parts from the pie. An important idea to explain this phenomenon is the “paradox of choice” (Schwartz, 2004). According to Schwartz, the efforts needed to understand the available offers and to arrive at a reasonable conclusion are too overwhelming, that people either choose what they already know or follow the popular choice. As the number of choices increases with streaming, the effort to make a choice also increases.

Following the shift of revenue sources, once a business of domestic markets, promotion and organization of concerts and tours have become a multi-billion-dollar industry, creating opportunities for new organizations to thrive. These dynamics changed the content of the agreements that artists made with labels. Now arrangements are made between musicians and labels that allow labels to not only collect income from record or digital music sales but also from artists' concert income. Indeed, Pine and Gilmore (1999) suggest that products that become commodities may be revitalized by being transformed first into services and further when consumed as experiences. The music business provides a good example starting as live performances, moving to commodity recordings, becoming a streaming service and coming full-circle back to live performances on the stage.

6. Implications for strategy and future research

The authors suggest that this work is of more than academic interest, and has significant implications for innovation strategy. The theory and findings can useful for the developers of new, emerging and "disruptive" technologies as well as the defenders of mature technologies in understanding how the interactions of the various technologies influence the trajectories of others. An important aspect of innovation strategy pertains to the decisions of when to adopt a new technology, abandon the old or pursue an interim approach.

Strategies are invariably based on underlying assumptions, often implicit. If innovation strategies and strategic decisions are based on invalid assumptions regarding the way technologies interact, one should not be surprised if results ranging from "less than ideal" to catastrophic follow. Should, for example, management not appreciate that the nature of the interaction among technologies is multi-modal and furthermore that the modes change dynamically, it is foreseeable that they will deploy a 'constant' strategy, which may be 'perfect' for the presumed assumptions, but not for the actual modes their technology is in interacting with others.

Consider for example, the case where a mature product starts to experience a growth spurt, while at the same time the managers detect the emergence of a potentially threatening technology. One can easily see that a 'single and constant mode' mindset of management may assume that the growth may be due to other causes (which of course it may) and merely relish the new growth, or that the new technology is nothing to worry about. In fact, as our analysis shows, the growth spurt may be a lead indicator that what is now a symbiotic relationship may soon change to predator-prey and then to pure competition. Had the management realized this, they would (or should) probably adopt a very different strategy.

It is tempting to think that strategic challenges will come from familiar sources and competitors, but truly transforming innovations are much more likely to appear from unfamiliar sources such as newly formed firms and established firms diversifying from an unexpected quarter (Sosa, 2009). Challenges may also come from emerging fields of science or technology, and especially potent challenges from confluences of new fields (Maine, *et al*., 2014). One may wish that the path ahead will be placid and free of surprises, but that is seldom the case. Change seems to occur in multiple waves often in quick succession after a period of stability.

New entrants look at competition as symbiotic and enter un-served or underserved niches, while incumbents view completion as a stable game of predator-prey or win-lose battles for share. Incumbents spend far too much incrementally defending the old or at best embracing hybrids of new and old far beyond the time that those investments make economic sense Suarez, *et al*., 2018). Venerable firms seem to resist new ideas and opportunities, and they seem consistently to underestimate the rate of technological change and adoption of new ideas (Foster, 1986). At the same time new entrants almost never seek to compete in the traditional product or service but consistently to champion new ideas. New entrants offer new technology or product architectures and expect rapid change (Christensen, 1997). Evidence seems pervasive in support of these points, and it is probably true of all sorts of organizations and decisions not just confined to firms or products.

It seems only human to seek information that reinforces our values and experiences, and that if a threat that comes from innovation is presented as an existential challenge it may only be natural that it be resisted. Resistance would particularly ensue if no path for change seems available, in which case firms may resort to political means to defend themselves (Thompson, 1967).

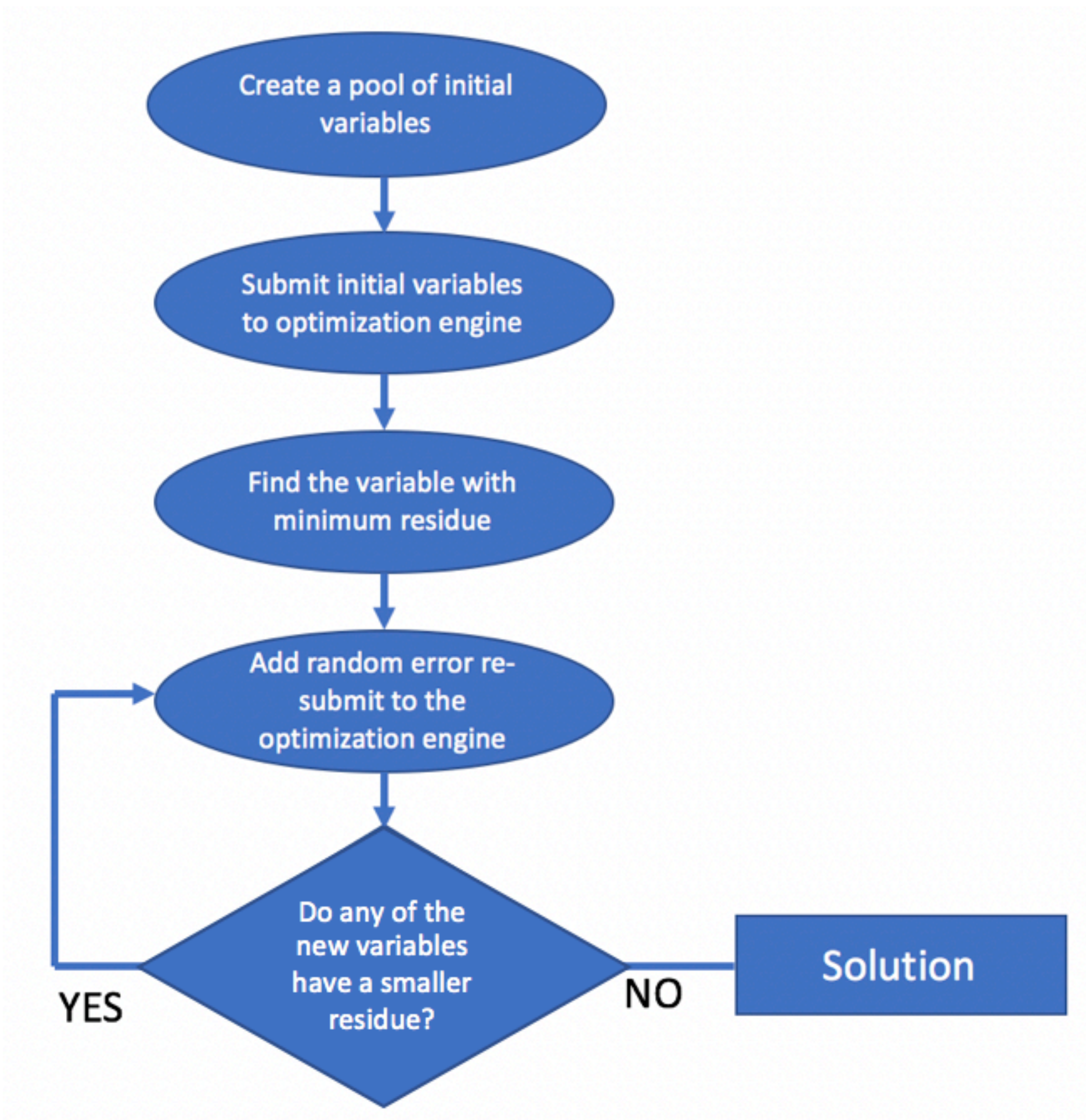
The central problem then, as we see it is that new and rather hysterically termed “disruptive innovations,” often make the world better for established practice, at least for a substantial time, reinforcing conservative arguments that the new idea is no threat (Christiansen, Suarez and Utterback, 1998). Our research shows that, at least in the cases examined, a trajectory of competitive modes from symbiosis to zero-sum competition with predator-prey modes during the transition tends to be the dynamic norm. New practice usually begins in market niches not served or occupied, or even feasible for the established practice and may spread from there to direct confrontation in established niches. Well-established products may keep growing for a substantial time before declining and even continuing to prosper in some niches while the newer practice captures the premium growth in the market.

Is the assumption then that all competitive races are zero-sum games, if I win you must lose, the reason for so many erroneous forecasts and missed investment decisions? Our socialization through competitive games and sports, in addition to selective perception of contrary evidence, might certainly cause us to make so many egregious errors of both excessive defense and postponed offense. We believe the root cause may well be that symbiosis may be the usual expectation at the beginning of competitive races. We expect the strengths of highly evolved practices to prevail and new ideas to fail when we are confronted by competitive threats. Surely no one saw that the pixilated black and white images produced by Sony’s *Mavica* electronic digital still camera would compete with the beauty of silver halide images on film when it was introduced, and hugely expensive in August of 1981. As with our other examples though digital still photography filled an unoccupied niche in sports and news photography and relentlessly improved from there to become the pervasive success we see more than 40 years later, making ubiquitous the use of photography in the process.

The model we have presented requires no simplifying assumptions. All variables and coefficients can be computed from primary data. Analysis of diffusion can be done not simply of one new product (N) contending with one established product (M), but rather for multiple M_i and N_j. We have shown that competitive modes are dynamic probably moving in most cases from symbiotic, through predator and prey modes and finally evolving into pure competition, and finally that the coefficients of the competitive mode can be calculated directly as it evolves. The next logical step in this work is simulation of a competitive race among products using calculated dynamic c coefficients rather than as here breaking the analysis up into distinct phases.

The next logical topic for research could be, how might we consider the measurement of a product or service when the very boundaries of a product are constantly variable? What shall we consider the product or service definition or the units of measure to be when a cell phone evolves to become multi-purpose remote device with hundreds of functions embedded in it? This is truly a difficult conundrum to resolve!

Appendix 1: Flow Chart for the Optimization Software



Details are provided in Yilmaz, 2017.

Appendix 2: Lotka-Voltera Coefficients Calculated for each Phase

Template

LV Coefficients

c Coefficient	*Technology 1*	*Technology 2*
Technology 1	c(1,1)	c(1,2)
Technology 2	c(2,1)	c(2,2)
s Coefficient	*Technology 1*	*Technology 2*
Technology 1	s(1,1)	s(1,2)
Technology 2	s(2,1)	s(2,2)
a Coefficient	*Technology 1*	*Technology 2*
	a(1)	a(2)

Coefficient Parameter Details

Parameter	Explanation
c(1,1)	Self coupling coefficient for Technology 1
c(1,2)	Coupling of Technology 2 to Technology 1 (Technology 2's impact on Technology 1)
c(2,1)	Coupling of Technology 1 to Technology 2 (Technology 1's impact on Technology 2)
c(2,2)	Self coupling coefficient for Technology 2
s(1,1)	Self coupling sign for Technology 1*
s(1,2)	Sign for coupling of Technology 2 to Technology 1
s(2,1)	Sign for coupling of Technology 1 to Technology 2
s(2,2)	Self coupling sign for Technology 1*
a(1)	Growth coefficient for Technology 1
a(2)	Growth coefficient for Technology 2

Although the table presents the format for a 2-technology case, it is easy to develop intuition for more technology cases as well. Even though in some of the previous work the self-coupling coefficient has been determined to be exclusively positive, here relaxing this criterion improves the understanding of the competitive behavior and yields better agreement between the data and the model.

Model Parameters Phase 1

LV Coefficients

c	*Vinyl*	*Cassette*	*8 Track*
Vinyl	8.70E-05	1.92E-04	8.83E-06
Cassette	1.81E-03	2.62E-03	5.18E-04
8 Track	8.56E-04	3.15E-03	3.15E-03
s	*Vinyl*	*Cassette*	*8 Track*
Vinyl	-1	-1	1
Cassette	-1	-1	1
8 Track	-1	-1	1
a	*Vinyl*	*Cassette*	*8 Track*
	9.430E-01	2.467E+01	1.796E-09

Model Parameters for Early Interactions in Phase 1

LV Coefficients

c	*Vinyl*	*Cassette*	*8 Track*
Vinyl	1.45E-04	9.73E-04	2.66E-04
Cassette	1.28E-03	2.55E-03	2.80E-03
8 Track	2.21E-04	8.84E-04	2.53E-04
s	*Vinyl*	*Cassette*	*8 Track*
Vinyl	-1	1	1
Cassette	-1	1	1
8 Track	-1	1	1
a	*Vinyl*	*Cassette*	*8 Track*
	1.855E-08	1.461E+00	6.626E-01

Model Parameters Phase 2

LV Coefficients

c	Vinyl	Cassette	CD
Vinyl	3.29E-05	4.85E-06	1.86E-04
Cassette	2.68E-05	4.54E-06	2.14E-05
CD	2.38E-04	3.16E-04	2.44E-05
s	Vinyl	Cassette	CD
Vinyl	-1	1	-1
Cassette	1	1	-1
CD	1	-1	-1
a	Vinyl	Cassette	CD
	7.549E-05	4.495E-06	2.330E+00

Model Parameters Phase 3

LV Coefficients

c	CD	Cassette
CD	1.30E-05	8.94E-06
Cassette	1.60E-05	4.99E-06
s	CD	Cassette
CD	-1	1
Cassette	-1	1
a	CD	Cassette
	2.379E-01	2.333E-10

Model Parameters Phase 4

LV Coefficients

c	Download	On Demand Stream	CD	Paid Subscription
Download	9.66E-05	8.05E-04	9.47E-06	8.91E-04
On Demand Stream	2.89E-04	8.70E-04	2.58E-05	9.28E-04
CD	6.09E-05	3.70E-04	3.14E-05	1.81E-04
Paid Subscription	8.68E-05	6.85E-04	3.04E-05	3.98E-04
s	Download	On Demand Stream	CD	Paid Subscription
Download	-1	1	1	-1
On Demand Stream	1	-1	1	-1
CD	-1	-1	-1	1
Paid Subscription	1	-1	-1	1
a	Download	On Demand Stream	CD	Paid Subscription
	5.515E-01	4.739E-01	3.198E-05	1.153E-04

Details are provided in Yilmaz, 2017.

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