Technology Analysis & Strategic Management

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ctas20

Asymmetry of the technological cycle of disruptive innovations

Mario Coccia

To cite this article: Mario Coccia (2020) Asymmetry of the technological cycle of disruptive innovations, Technology Analysis & Strategic Management, 32:12, 1462-1477, DOI: 10.1080/09537325.2020.1785415

To link to this article: https://doi.org/10.1080/09537325.2020.1785415

Published online: 03 Jul 2020.

TECHNOLOGY ANALYSIS & STRATEGIC MANAGEMENT
2020, VOL. 32, NO. 12, 1462–1477
https://doi.org/10.1080/09537325.2020.1785415

Routledge
Taylor & Francis Group

Check for updates

Asymmetry of the technological cycle of disruptive innovations

Mario Coccia

CNR – National Research Council of Italy, Real Collegio Carlo Alberto, Moncalieri, Italy

ABSTRACT

A vast literature exists on disruptive technologies. However, some fundamental questions are unknown, such as: *how to measure the growth of disruptive technologies in competitive markets? How is the pathway of technological cycle of disruptive innovations?* The study confronts these questions here by developing a theoretical and empirical analysis, which endeavours to explain the behaviour of disruptive technologies that generate industrial and corporate change. A simple model is proposed to measure the relative growth of disruptive technologies compared to established technologies. This analytical approach is applied on the evolution of technologies in the US sound-recorded music industry. Empirical findings suggest general properties that can expand disruptive innovation theory, namely: (1) disruptive technology has a *disproportionate growth* in markets compared to established technologies; (2) technological cycle of disruptive technology has up wave phase longer than down wave phase (*asymmetric shape of technological cycle*) and (3) disruptive technology has a series of major and minor technological advances of its own that pave the way for dominance on other established technologies in markets. Best practices for management of technology are discussed.

ARTICLE HISTORY
Received 1 October 2019
Revised 12 June 2020
Accepted 15 June 2020

KEYWORDS
Disruptive technology; disruptive innovation; technological cycle; technology change

JEL CODES
O30; O32; O33; B50

Introduction and goals of the investigation

This paper has *two goals*. The *first* is to measure the relative growth of disruptive technology compared to established technologies in markets. The *second* goal is to analyse the technological cycle of disruptive innovations and to suggest properties that can explain and generalise the evolution of disruptive technologies and technological change in markets.

Christensen and Bower (1996) analyse disruptive technologies and argue that in the initial stage of development, they serve niche segments that value their new kinds of characteristics. Subsequently, the evolution of disruptive technologies increases the technical performance to satisfy mainstream customers (cf., Vecchiato 2017). The study by Christensen (1997) identifies specific characteristics of disruptive technology: (a) performance trajectory of disruptive innovation and (b) performance trajectory demanded by mainstream market. Christensen (1997) also states that disruptive innovations generate significant shifts in markets. Moreover, disruptive innovations change habits of consumers in markets and undermine the competences and complementary assets of existing producers (Coccia 2017b, 2018a, 2020e; Markides 2006, 22–23; Zhang et al. 2019). Although several contributions in these fields of research, the patterns of disruptive innovations that generate structural change in markets are hardly known. The main aim of this article is to explain, whenever possible, the behaviour and characteristics of disruptive technologies within the industrial competition. In particular:

CONTACT Mario Coccia mario.coccia@cnr.it CNR – National Research Council of Italy, Real Collegio Carlo Alberto, Via Real Collegio, Moncalieri (Torino), n. 30–10024, Italy

- how to measure the *growth rate of disruptive technologies* that gives a precise evaluation and prediction of the speed of evolution compared to existing technologies?
- what is the *shape of the technological cycle* in disruptive technologies?

Next sections confront these questions here by proposing an analytical approach, which endeavours to explain the relationships underlying the evolution of disruptive technologies in competitive markets and suggest general properties of the technological change.

Theoretical framework

Technological change is driven by different typologies of innovations (Coccia 2005a, 2020c). One of the most important types is disruptive innovations that have a significant and far-reaching impact in markets and society (Coccia 2017b, 2017c, 2018a; Danneels 2006; Yu and Hang 2010). The impact of disruptive innovations in markets is associated with their evolution compared to other innovations. In this context, technological evolution can be explained with theories based on processes of competitive substitution of a new technology for the old one (Coccia 2019a, 2020b; Fisher and Pry 1971; Sahal 1981; Utterback, Pistorius, and Yilmaz 2020).[1] This dynamic competition between technologies can lead to the dominance of a new technology on established technologies in markets (cf., Berg, Wustmans, and Bröring 2019). The history of technology has many examples of competition between technologies, such as the diffusion and dominance of steamship as efficient means of transportation of goods and people compared to sailing ship (Sahal 1981, 79ff). Another example is the diffusion of the Solvay process that in the 1900s destroys the Leblanc process in the manufacturing sector of soda (Freeman 1974). Coccia (2020a) analyses deep learning technology in cancer imaging as a disruptive technology in modern diagnostics compared to current techniques. In general, disruptive technologies have the characteristic of substitutes with a powerful force in markets to generate technical, economic, industrial and social change.

Methodology

Evolutionary model for measuring the growth of creative disruption

The first goal of this study is to measure and analyse the growth rate of disruptive technologies/innovations. This paper here proposes a model of growth of a disruptive technology compared to an established technology. The proposed model is based on the biological principle of allometry that was developed in zoology to study the differential growth rates of the parts of a living organism's body in relation to the whole body (cf., Reeve and Huxley 1945). Sahal (1981) applies this model to explain the diffusion of new techniques in the agriculture, manufacturing, steel production, electricity generation, etc.

The suggested model is based on the following assumptions:

(1) Suppose the simplest possible case of only two technologies, V (*established technology*) and Kl (a *disruptive technology*).
(2) Let $Kl(t)$ be the level of a disruptive technology Kl at the time t and $V(t)$ be the level of an established technology V at the same time.
(3) Suppose that both Kl and V evolve according to an S-shaped pattern of technological growth, which is given by differential equation of the logistic function. For V, *established technology*, the starting equation is:

$$\frac{1}{V}\frac{dV}{dt} = \frac{b_1}{K_1}(K_1 - V]$$

The equation can be rewritten as:

$$\frac{K_1}{V}\frac{1}{(K_1 - V)}dV = b_1 dt$$

The integral of this equation is:

$$\log V - \log(K_1 - V) = A + b_1 t$$

$$\log\frac{K_1 - V}{V} = a_1 - b_1 t$$

$$V = \frac{K_1}{1 + \exp(a_1 - b_1 t)}$$

$a_1 = b_1 t$ and t = abscissa of the point of inflection.

The growth of $V(t)$ can be described, respectively, as:

$$\log\frac{K_1 - V}{V} = a_1 - b_1 t \qquad [1]$$

Mutatis mutandis, for disruptive technology $KI(t)$ the equation is:

$$\log\frac{K_2 - KI}{KI} = a_2 - b_2 t \qquad [2]$$

The logistic curve is a symmetrical *S*-shaped curve with a point of inflection at 0.5 K, with $a_{1,2}$ = constants depending on initial conditions, $K_{1,2}$ = equilibrium levels of growth, and $b_{1,2}$ = rate-of-growth parameters (1 = established technology = V; 2 = disruptive technology = KI).

Solving Equations (1) and (2) for t, the result is:

$$t = \frac{a_1}{b_1} - \frac{1}{b_1}\log\frac{K_1 - V}{V} = \frac{a_2}{b_2} - \frac{1}{b_2}\log\frac{K_2 - KI}{KI}$$

The expression generated is:

$$\frac{V}{K_1 - V} = C_1\left(\frac{KI}{K_2 - KI}\right)^{\frac{b_1}{b_2}} \qquad [3]$$

In Equation (3), $C_1 = exp[b_1(t_2 - t_1)]$ with $a_1 = b_1 t_1$ and $a_2 = b_2 t_2$ (cf. Equations (1) and (2)); applying mathematical transformations, the evolutionary growth of disruptive technology compared to established technology is given by:

$$KI = A(V)^B \qquad [4]$$

where $A = \frac{K_2}{(K_1)^{\frac{b_2}{b_1}}} C_1$ and $B = \frac{b_2}{b_1}$

The logarithmic form of the Equation (4) is a simple linear relationship:

$$\log KI = \log A + B \log V \qquad [5]$$

B is the coefficient of growth that measures the evolution of disruptive technology KI compared to established technology V.

This model [5] has linear parameters that are estimated with the ordinary least squares (OLS) method. The value of B in model [5] measures the relative growth of KI compared to the growth of V. The coefficient of regression $\boldsymbol{B}$ indicates different patterns of technological evolution in markets, namely:

- ☐ $B < 1$, whether new technology KI destroys at a *lower* relative rate of change established technology V (*low growth of disruptive technology*);
- ☐ $B = 1$, disruptive technology KI substitutes established technology V at a *proportional* rate of change (*proportional growth of disruptive technology*);
- ☐ $B > 1$, whether disruptive technology KI destroys established technology V at *greater* relative rate of change over the course of time (*acceleration of disruptive technology in markets*).

Data and their sources

The empirical analysis is based on data of technologies in sound-recorded music industry (e.g. vinyl, 8 track, cassette, Compact Disc and streaming technology) in the USA, 1973–2019 period. The US national system of innovation is a vital case study to analyse general patterns of the evolution of new technologies in advanced economies. Source of data for sound-recorded music technology is Recording Industry Association of America (RIAA), which provides data on US sound-recorded music revenues and music sales volumes from 1973 to 2019 (RIAA 2019, 2020). Note that the first year under study here, it is not the year of invention of these technologies (cf., RIAA 2019).

Measures

Measures for competition between Compact Disc (CD) and cassette technology in US sound-recorded music industry are:

- Sound -recorded music revenues in millions $ (adjusted for inflation, 2018 Dollars) of CD technology is a measure of the evolution of this disruptive technology (KI) in period t
- Sound -recorded music revenues in millions $ (adjusted for inflation, 2018 Dollars) of cassette technology is a measure of the evolution of established technology (V)

Measures for competition between streaming and CD technology in US sound-recorded music industry are:

- Sound -recorded music revenues in millions $ (adjusted for inflation, 2018 Dollars) of streaming technology is a measure of the evolution of this disruptive technology (KI'). Note that streaming technology is measured here including different modes: paid subscription, on-demand streaming, other Ad-supported streaming, sound exchange distributions and limited tier paid subscription.
- Sound -recorded music revenues in millions $ (adjusted for inflation, 2018 Dollars) of CD technology is a measure of the evolution of this technology (V'), considered established technology in the period t+1.

Data analysis procedure for investigating the growth of disruptive technologies and the shape of technological cycle

The operationalisation of the proposed model [5] in the case study here is specified as follows:

$$\log KI_t = \log a + B \log V_t + u_t \qquad [6]$$

where a is a constant; *log* has base $e = 2.7182818$; $t =$ time; $u_t =$ error term; KI_t is a measure of the growth of disruptive technology in US sound-recorded music industry; V_t is a measure of the growth of established technology in US sound-recorded music industry.

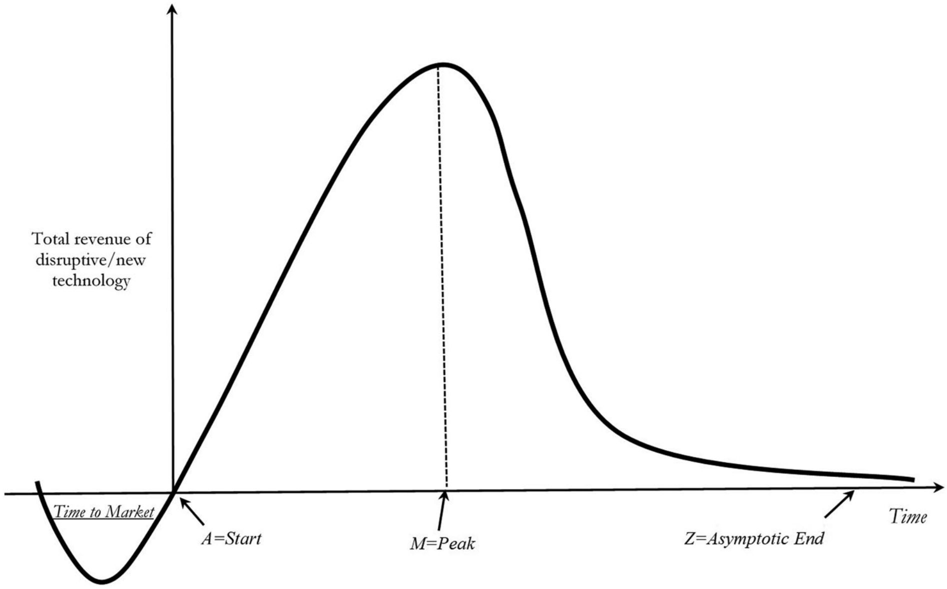

Figure 1. Technological cycle.

The relationship [6] is analysed using OLS method for estimating the unknown parameters in a linear regression model. Statistical analyses are performed with the Statistics Software SPSS® version 26.

This study also proposes some equations for technology analysis of the technological cycle of disruptive technologies (Figure 1).

Let

i be the technology *i*;

A , the year of the starting of revenues of technology *i* in market;

M, year of the peak of revenues of technology *i* in market;

Z, the year of ending of revenues of technology *i* in market.

The technology analysis of the cycle of disruptive innovation is given by following equations:

AZ_i is the length of the cycle of technology *i*

$$\mathrm{AZ}_i = Z_i - A_i \quad [7]$$

AM_i is the length of the up wave phase of technological cycle *i*

$$\mathrm{AM}_i = M_i - A_i \quad [8]$$

ZM_i is the length of the down wave phase of technological cycle *i* (also called disruption period DP_i of technology *i*)

$$\mathrm{ZM}_i = Z_i - M_i \quad [9]$$

$\mathbf{ZM}_i = \boldsymbol{DP_i}$ = Disruption period of technology $i = \mathbf{Z}_i\_\mathbf{M}_i$.

Results

A short background of technologies for sound-recorded music is useful to clarify the findings here. From 1930 to 2020, technological trajectories for delivering sound-recorded music have had radical changes (cf., RIAA 2019, 2020). In the 1930s, the Radio Corporation of America launched the first commercially-available vinyl long-playing record. Vinyl had lower playback noise level than shellac (Mudg and Hoek 2000). Since 1939, Columbia Records continued the development of this technology and in 1948 released their 33 ⅓ RPM (Revolutions per Minute), which is made from polyvinyl chloride and pressed on a 12″ diameter flexible plastic disc. The sound is recorded in the grooves in the vinyl and while the record spins, the needle runs along the grooves and passes the information to the electromagnetic head (Read 1952). After vinyl, the 8-track tape (formally Stereo 8) was a magnetic tape sound-recording technology popular in the United States from the mid-1960 to be used in cars. Subsequently, during the 1970s and 1980s, the most common technological device to deliver music was compact cassettes based on analog magnetic tape for audio recording and playback. This product innovation was developed by Philips company, released in 1962 and introduced in the US market in 1964. Ray Dolby develops in 1968, a technology called Dolby noise reduction to increase the sound quality of cassette tapes. These technological advances led cassette tapes to be a dominant technology on 8-track tapes in the mid-1970s and in the early 1980s. The emerging technology of compact audio disc (CD), co-developed by Philips and Sony corporations and launched in 1982, generates a further technological and industrial change (BBC News 2007). CD technology is a digital optical disc originally developed to store and play only sound recordings but it was later also adapted for storage of other data (Coccia 2018a). In the mid-1990s and in the early 2000s, the high sound quality of CD led this technology to be the dominant one in markets, overtaking cassette sales from 1991 to 2005 period (cf., RIAA 2019). The revolution of Information and Communication Technologies (ICTs) has generated other new technologies for market of sound-recorded music, based on transmission of video/audio information over the Internet, such as:

Download mode. The content file is completely downloaded and then played. This mode requires long downloading time for the whole content file and needs a large hard disk space (a consequential problem that supports technical advances towards streaming mode, cf., Coccia 2017a).

Streaming mode. The content file is not required to be downloaded completely and it plays while parts of the content are being received and decoded. Files can be inserted in favourite items of video-sharing platforms for future necessities and desires. In particular, video streaming technology delivers audio and video over the Internet network to reach many customers having personal computers, personal digital assistants, smartphones and/or other ICT devices. The growth of streaming technology is due to broadband networks, efficient techniques of video and audio compression, a high r quality and variety of audio and video services over Internet, etc. A streaming media player can be either an integral part of a browser, a plug-in, a separate program, or a dedicated device, such as Apple TV, iPod, etc. For streaming technology, the UDP/IP (User Datagram Protocol/ Internet Protocol) is used to deliver the multi-media flow as a sequence of small packets. The application of layer protocol RTP/RTSP (Real-time Transport Protocol /Real-Time Streaming Protocol), which is implemented on top of UDP/IP, provides an end-to-end network transport for video streaming.

Different modes of streaming video content distribution are (cf., RIAA 2019):

- *Sound Exchange Distributions* based on payments to performers and copyright holders for digital radio services under statutory licenses
- *Paid Subscription* includes streaming, tethered, and other paid subscription services not operating under statutory licenses
- *Limited Tier Paid Subscription* includes streaming services with interactivity limitations by availability, device restriction, catalog limitations, on demand access, or other factors
- *On-Demand Streaming* includes Ad-supported audio and music video services not operating under statutory licenses
- *Other Ad-supported Streaming* includes revenues paid directly for statutory services that are not distributed by Sound Exchange and not included in other streaming categories.

Coelho and Mendes (2019) argues that new technology of digital distribution is revolutionising the pop-rock music market. Lee et al. (2016) claim that the Internet has changed the media contents industry from records to online digital products. Aguiar (2017) points out that the growth in interactive music streaming is raising questions about its effects on music industry, such as if streaming enhances product discovery and if free streaming stimulates the use of channels that allow mobile consumption (cf., Cavazos and Szyliowicz 2011). Wlömert and Papies (2016) argue that on-demand streaming services, which rely on subscription fees or advertising as a revenue source (e.g. Spotify), are topics of on-going controversial debate in music industry. Many studies suggest that online streaming generates a positively impact on music record sales.

The growth of disruptive technologies in sound-recorded music industry in the USA is analysed as follows:

- CD as disruptive technology of cassette technology in the period *t*;
- Streaming technology as disruptive technology of CD technology in the period *t*+1.

The estimated relationship in Table 1 shows that the significance of coefficient and explanatory power of model are high. The coefficient of R^2 adj. is also high and the proposed model of the evolution of CD (as disruptive technology) compared to established cassette technology explains more than 50% variance in the data (Table 1). In particular, results suggest that in the USA, CD technology has $B = 2.1$ (i.e. $B > 1$), suggesting a destruction of cassette technology with a *high relative rate of change* (period 1984–2008).

Table 2 shows results of streaming technologies from 2004 to 2018 = 14 years. Streaming technology in this period is still in the phase of development with $B = -1.28$. In particular, the study shows that US sound-recorded music revenues of streaming technologies have overtaken CD technology in 2015 with \$2400 millions compared to \$1400 millions. The period 2015–2018 under study here may explain low relative rate of change of streaming technology compared to CD technologies in markets (that is $B < 1$). Instead, the long period under study for CD technology – started in 1991 with sound-recorded music revenues of \$7800 million of CD compared to \$5400 millions of cassette – explains high relative rate of substitution of CD as disruptive technology compared to cassette as established technology (i.e. $B > 1$). In the context of streaming technology, Lee et al. (2016) find that online streaming services positively impact music record sales. In addition, Naveed, Watanabe, and Neittaanmäki (2017) point out that the co-evolutionary pathways of increasing popularity of streaming services and resurgence of live music are sustaining music industry.

Technological cycle of disruptive innovations

The second goal of this study stated in the introduction is to analyse technological cycle of disruptive innovations in industrial competition. Sound-recorded music industry has different new technologies with different evolutionary pathways (beginning-ending of revenue) in markets, as follows (cf., Table 3):

Vinyl technology (1930s-residual trend of revenue)⇒*8-track technology* (1965–1982)⇒*cassette technology* (1964–2008)⇒*CD technology* (1983–2018)⇒*Download technology* (2004-in progress)⇒*streaming technology* (2005–in progress).

Table 1. Parametric estimates of the model of disruptive CD technology on established cassette technology, 1984–2008 period in US market.

Dependent variable: *log* annual sound-recorded music revenues of disruptive CD technology (value adjusted for inflation, 2018 Dollars)				
	Constant a (St. err.)	*Coefficient β = B (St. err.)*	*R^2 adj. (St. err. of the estimate)*	*F (sign.)*
CD *vs.* cassette technology	−9.80* (4.72)	2.10*** (0.55)	0.51 (0.64)	14.38**

Notes: ***significant at *p*-value < .001; **significant at *p*-value < .01; *significant at *p*-value < .05; Explanatory variable is *log* annual sound-recorded music revenues of cassette as established technology (value adjusted for inflation, 2018 Dollars).

Table 2. Parametric estimates of the model of disruptive streaming technology on CD technology, 2004–2018 period in US market.

Dependent variable: *log* annual sound-recorded music revenues of disruptive streaming technology (value adjusted for inflation, 2018 Dollars)

	Constant a (St. err.)	*Coefficient β=B (St. err.)*	*R^2 adj. (St. err. of the estimate)*	*F (sign.)*
Streaming technology *vs.* CD technology	17.22*** (0.67)	−1.28*** (0.08)	0.95 (0.27)	240.01***

Notes: ***significant at *p*-value < .001; Explanatory variable is *log* annual sound-recorded music revenues of CD technology as established technology (value adjusted for inflation, 2018 Dollars). Streaming technology is measured here including sound-recorded music revenues of different modes: paid subscription, on-demand streaming, other Ad-supported streaming, sound exchange distributions and limited tier paid subscription.

Technology analysis of these disruptive technologies suggests the following theoretical and empirical properties:

- *The property of average disruption period* states that a new technology destroys the established technology, overtaking total revenue in markets, in an average period of 13 years.

Remarks. Results in Table 3 (last rows) support this property showing the average duration of disruption period of established technologies in sound-recorded music market.

The analysis of data by RIAA (2019, 2020) also shows different *technological cycles* driven by new disruptive innovations in US sound-recorded music market.

The *first technological cycle* under study is by Vinyl records. The introduction of vinyl is in the 1930s and the peak of revenues by vinyl single in US sound-recorded music market is in 1979 with €353.6M. In that year, the sales volume for vinyl single format equalled 212.0M units, representing 31% of total sales volumes of 682.8M units for all formats that year. The introduction of cassette, CD and other technologies, as will be explained later, has almost destroyed this technology, such that in 2019 revenues by vinyl single are a mere €6.8M, representing a small niche within US sound-recorded music market. In addition, the vinyl format in 2019 is made up 0.1% of the total sales volumes of 453.3M units for all formats (RIAA 2020). Some scholars analyse the diffusion of retro-technologies, such as vinyl record that is making a comeback, for rethinking the potential exploitation of their value and

Table 3. Disruption period of established technology because of new disruptive innovation in sound-recorded music industry of the US market

.

Established Technology in market of sound-recorded music	Year of the introduction of *established* technology	*New* disruptive innovation in market of sound-recorded music	Year in which new technology destroys more than 50% of the revenue of *established* technology	% of sound-recorded music revenues of *established* technology	Peak of revenues by *established* technology	Ending of revenues by *established* technology	Disruption Period (*DP*) in years of *established* technology *via* new disruptive innovation
Established		*Disruptive innovation*			M	Z	$DP_i = Z_i - M_i$
Vinyl	1930	*8-Track*	n.a.	n.a.	1979		
8-Track	1965	*Cassette*	1980	42.80 in 1980	1978	1982	**4**
Cassette	1964	*CD*	1991	41.00 in 1991	1990	2008	**18**
CD	1983	*Download*	2012	45.20 in 2012	2000	2018	**18**
CD	1983	*Download + Streaming*	2011	46.60 in 2011			
Download	2004	*Streaming*	2015	49.98 in 2015			
		Average values (Mean)		45.12%	Average values (Mean)		13 years
		Standard Deviation (SD)		3.47%		SD	8.8 years

Notes: Elaboration on data by RIAA (2019, 2020); years are based on data concerning values not adjusted for inflation. Disruption Period of established technology *i* is $\boldsymbol{DP_i = Z_i - M_i}$ ($\mathbf{Z}_i$ is the year of the ending of revenues of technology *i*–$\mathbf{M}_i$ is the year of the peak of revenues in technology *i*); n.a. = not available data.

supporting value-creating strategies of physical retails in the digital age (cf., Hracs and Jansson 2017; Sarpong, Dong, and Appiah 2016).

The *second technological cycle* is by 8-track tape having the peak, measured with US sound-recorded music revenues, in 1978 (RIAA 2019). In 1964, the cassette technology is introduced in US-recorded market. This new technology has destroyed 8-track tape in 1982 with a disruption period of 4 years, given by difference between year of the ending of revenues of 8-track tape and year of the peak of its revenues (i.e. 1982–1978 = 4 years; cf., Table 3). The overall length of technological cycle of 8-track tape is 17 years (from 1965 to 1982; cf., Table 4).

The *third technological cycle* of cassette technology started, as said, in US sound-recorded music market in 1964 and achieved the peak of revenue in 1990. Subsequently, cassette technology is destroyed in 2005 by (*new*) disruptive CD technology. The overall length of technological cycle of cassette technology is about 41 years, from the year of the starting of revenues to the year of the ending of revenues (cf., Table 4). Some scholars argue the re-emergence of near-obsolete technologies, supporting a culture of vintage-technologies, such as vinyl records and cassettes (cf., Eley 2016; Sarpong, Dong, and Appiah 2016). However, data show that technological cycles of these old-technologies are almost finishing, except small niches of market associated with customers attached to vintage technologies.

The *fourth technological cycle* is given by CD technology that achieved the peak in 2001, after 18 years from its introduction in 1983. In 2018, this technology is almost destroyed by new technologies of download and video streaming. In fact, CD technology in 2018 has a mere \$698.4 million of revenue on a total of \$9846 million in US sound-recorded music market. Moreover, sales volume for CD format is made up 9.8% of the total volume of 532.3M units for all formats in 2018 (CD format had 91.1% of the total sales volumes of 968.5M units for all formats in 2001). The overall length of technological cycle of CD technology is about 35 years, whereas the disruption period is about 17 years (cf., Tables 3–4).

The *on-going technological cycles* in sound-recorded music market are driven by download and streaming technology introduced in the mid-2000s. Download mode has had the peak in 2012, after 8 years from its introduction in 2004, and now it has a phase of decline, because of streaming technology that is growing over time, with many technical advances, such as growing video-sharing websites (cf., Table 4).

These empirical results in Table 4 suggest another main property for disruptive technologies.

- The property of the *asymmetry of technological cycle* states that technological cycle of disruptive technologies has up wave phase longer than down wave phase: *Negative asymmetry of technological cycle* (Figure 2).

Remarks. The analysis of technological cycles (vinyl, 8-track tape, cassette and CD technology) shows that up wave phase has an average duration of about 23 years (SD = 16.8 years), whereas down wave phase has an average duration of roughly 19 years (SD = 15.1 years). Overall, average duration of a technological cycle in sound-recorded music market is about 46 years (Table 4). In particular, results suggest that technological cycles have an average duration of up wave phase equal to 61.24% of overall wavelength, whereas the average duration of down wave phase is shorter (it is about 38.76% of overall wavelength). Coccia (2010) showed that economic long waves have asymmetric paths with longer periods of *up wave* than *down wave* phase over time. A similar result seems to be also present in evolutionary cycle of research fields based on scientific production over time (cf., Coccia 2020b). In general, this finding reveals an analogy of the dynamics of evolutionary cyclesin long waves, in scientific and technological trajectories that seem to have general socio-economic factors determining a longer phase of up wave than down wave over time.

This technological behaviour of disruptive technology can be due to ambidexterity learning processes, given by:

Table 4. Technological cycles in the US sound-recorded music industry.

Technological cycles in US recorded music market	*Up wave of cycle*		*Down wave of cycle*	Duration of technological cycle in years				
	A = begin of revenues of technology	*M* = peak of revenues of technology	*Z* = end of revenues of technology	AM length up wave years = *M-A*	MZ length down wave years[a] = *Z-M*	AZ length cycle years = *Z-A*	(AM/AZ) %	(MZ/AZ) %
1 Vinyl technology	1930	1979	2019	49	40	89	55.06	44.94
2 8-track tape technology	1965	1978	1982	13	4	17	76.47	23.53
3 Cassette technology	1964	1990	2005	26	15	41	63.41	36.59
4 CD technology	1983	2001	2019	18	18	36	50.00	50.00
5 Download technology	2004	2012	∼	8	–	–	–	–
6 Streaming technology	2005	∼	∼	–	–	–	–	–
Arithmetic mean, years				22.80	19.25	45.75	61.24%	38.76%
Standard Deviation (SD), years				16.08	15.09	30.63		

Notes: ∼ is the technology in progress; elaboration on data by RIAA (2019).

[a]Disruption period of established technology *i* is MZ_i = year of the ending of revenues of technology_i (Z_i) – year of the peak of revenues of technology_i (M_i); length of technological cycle of technology *i* is AZ_i = year of the ending of revenues of technology_i (Z_i) – year of the starting of revenues of technology_i (A_i).

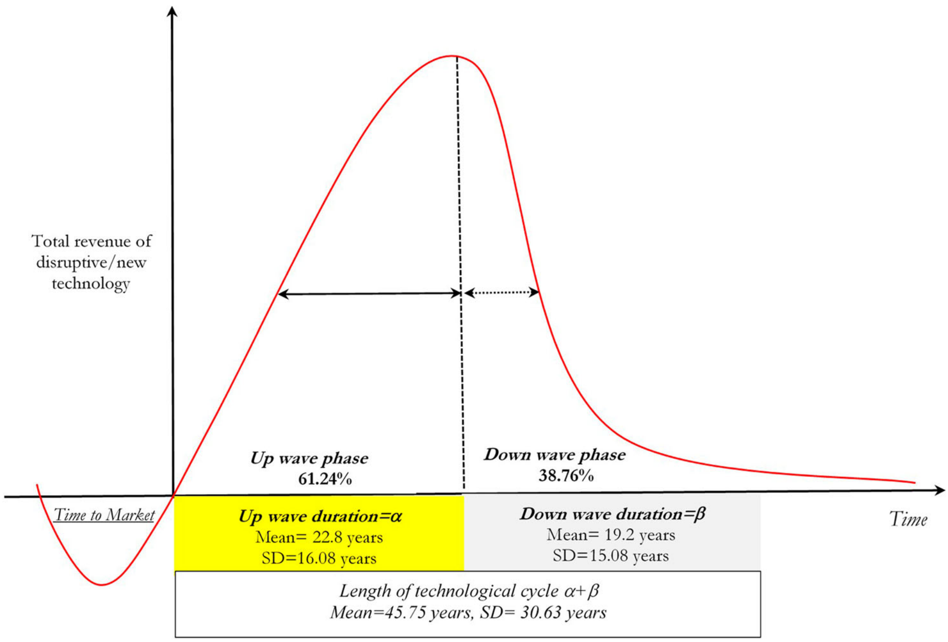

Figure 2. Negative asymmetry of technological cycle of disruptive innovations having up wave phase longer than down wave phase.

Notes: Mean is the arithmetic mean based on historical data on the evolution of example technologies in sound-recorded music industry of US market; SD is the standard deviation.

- '*learning via diffusion*' (Sahal 1981, 114, italics added) in which the increased adoption of a technology supports the path for improvement in its technical characteristics (i.e. technological advances).
- '*diffusion by learning*' that improvement in the technical characteristics of a technology enhances the scope for its adoption over the course of time (Sahal 1981, 114, italics added).

Discussion and implications of strategic management

Results of proposed theoretical and empirical analyses here are:

(1) The growth of disruptive technology is generally an allometric process of *a disproportionate growth* of (new) disruptive technology compared to the established technology;
(2) The technological cycle of disruptive innovations has up wave phase longer than down wave phase (*asymmetry of technological cycle*);
(3) Finally, new technologies can have a higher capacity of disruption if they are inter-related with other technologies in function of host or parasitic technologies, such as streaming technologies inter-related with other ICTs (cf., Coccia 2018b; Coccia 2019a, 2019b, 2019c; Coccia and Watts 2020).

To our knowledge, this study is the first attempt to develop a specific model that measures the growth rate of (new) *disruptive technologies* in markets during a competition with existing technologies. This approach and results can extend the theory of disruptive technologies with new properties (cf., Christensen 2006). In addition, results here can provide best practices of strategic management to predict the directions and pathways of disruptive technologies based on *estimated relative growth rate* **B** of the proposed technological disruption model. In fact, estimated coefficient **B** can support innovation strategy of firms on critical decisions, such as investing in new technologies if

B>1, for sustaining and safeguarding competitive advantage in turbulent markets. Christensen (1997) observes that established firms face an *innovator's dilemma* concerning internal resource allocation that leads to systematically underinvest in disruptive technologies (cf., Coccia 2018d). Kapoor and Klueter (2015) confirm that incumbents tend to not invest in disruptive technological regimes and maintain a competence-enhancing approach. However, research alliances and acquisitions are strategies that may help incumbents to overcome this *inertia* both in the initial stage of research and in the later stage of development of disruptive technologies (cf., Radnejad and Harrie 2019). A main example is represented by strategic alliance between AstraZeneca (incumbent) and Amgen (a leader in biotechnology) to co-develop and commercialise five monoclonal antibodies from Amgen's clinical portfolio: the strategy is the improvement of the expertise of AstraZeneca in respiratory and gastrointestinal diseases, whereas Amgen improves commercial experience in rheumatologic and dermatologic diseases. These strategic alliances are designed to share risk and leverage each partner's functional and geographic strengths (Coccia 2014a, 742).

In general, disruptive technologies compete with other technologies to achieve the dominance in markets, generating industrial and corporate change. Adner and Zemsky (2005) argue that social welfare can increase because prices for products fall with disruption and that concentration tends to increase with disruption. For scholars, disruptive technologies highlight the question of the boundaries of technology competition and how those boundaries change over time (Adner 2002). For managers, disruptive technologies highlight the danger posed to incumbent firms from too quickly dismissing new technologies as inferior and therefore irrelevant to their market positions. However, we know, *de facto*, that other things are often not equal over time and space in the domain of these disruptive technologies. The study here may encourage further theoretical exploration of the competition between technologies that generates a disruptive creation for technological and economic change in society. Future efforts in this research field will be also directed to provide additional empirical evidence to better explain the behaviour of disruptive technologies in different markets. To conclude, identifying a generalisable theory of disruptive technologies for prediction of the technological change in the presence of rapid industrial competition is a non-trivial exercise. In fact, Wright (1997, 1562) properly claims that: 'In the world of technological change, bounded rationality is the rule'.

Note

1. For other detailed studies on disruptive technological change, source, evolution and diffusion of innovations and technologies, see also Christensen and Overdorf (2000); Christensen and Raynor (2003); Christensen, Raynor, and McDonald (2015); Coccia (2005b, 2005c, 2006, 2008, 2012, 2014a, 2014b, 2015a, 2015b, 2016a, 2016b, 2016c, 2017d, 2017e, 2018c, 2019d, 2020d); Hall and Martin (2005); Li, Porter, and Suominen (2018); Love, Matthews, and Jingyang (2020); Mahto, Belousova, and Ahluwalia (2017); Park (2018); Reinhardt and Gurtner (2018); Schmidt and Druehl (2008); Schuelke-Leech (2018); Tripsas (1997).

Acknowledgement

The author gratefully acknowledges financial support from National Research Council of Italy–Direzione Generale Relazioni Internazionali for funding this research project developed at Yale University in 2019 (Grant-CNR n. 62489-2018).

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The financial support was provided by National Research Council of Italy–Direzione Generale Relazioni Internazionali for developing this research project at Yale University in 2019 [grant-CNR n. 62489-2018].

Notes on contributor

Mario Coccia is a social scientist at the National Research Council of Italy (CNR) and visiting scholar at Yale University School of medicine. He has been research fellow at the Max Planck Institute of Economics and visiting professor at the Polytechnics of Torino and University of Piemonte Orientale (Italy). He has conducted research work at the Georgia Institute of Technology, United Nations University-Maastricht Economic and Social Research Institute on Innovation and Technology (UNU-MERIT), RAND Corporation (Washington D.C.), University of Maryland (College Park), Bureau d'Économie Théorique et Appliquée (Strasbourg), Munk School of Global Affairs (University of Toronto) and Institute for Science and Technology Studies (University of Bielefeld). He leads the CocciaLAB to investigate, with interdisciplinary scientific approaches the determinants of socioeconomic and technological phenomena associated with economic growth and wellbeing of people, such as new technology, evolution of scientific fields, higher performance and efficiency of public research organisations, technology transfer, etc. He has written more than three hundred international papers in several disciplines.

ORCID

Mario Coccia http://orcid.org/0000-0003-1957-6731

References

Adner, R. 2002. "When Are Technologies Disruptive: A Demand-Based View of the Emergence of Competition." *Strategic Management Journal* 23 (2002): 667–688.

Adner, R., and P. Zemsky. 2005. "Disruptive Technologies and the Emergence of Competition." *The RAND Journal of Economics* 36 (2), Summer: 229–254.

Aguiar, L. 2017. "Let the Music Play? Free Streaming and its Effects on Digital Music Consumption." *Information Economics and Policy* 41: 1–14.

BBC News. 2007. "Compact Disc Hits 25th Birthday." August 17. Accessed June 18, 2017. http://news.bbc.co.uk/2/hi/technology/6950845.stm.

Berg, S., M. Wustmans, and S. Bröring. 2019. "Identifying First Signals of Emerging Dominance in a Technological Innovation System: A Novel Approach Based on Patents." *Technological Forecasting and Social Change* 146, September: 706–722. doi:10.1016/j.techfore.2018.07.046.

Cavazos, D. E., and D. Szyliowicz. 2011. "How Industry Associations Suppress Threatening Innovation: The Case of the US Recording Industry." *Technology Analysis & Strategic Management* 23 (5): 473–487.

Christensen, C. 1997. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Cambridge, MA: Harvard Business School Press.

Christensen, C. 2006. "The Ongoing Process of Building a Theory of Disruption." *Journal of Product Innovation Management* 23: 39–55.

Christensen, C. M., and J. L. Bower. 1996. "Customer Power, Strategic Investment, and the Failure of Leading Firms." *Strategic Management Journal* 17 (3): 197–218.

Christensen, C. M., and M. Overdorf. 2000. "Meeting the Challenge of Disruptive Change." *Harvard Business Review* 78 (2): 66–77.

Christensen, C., and M. Raynor. 2003. *The Innovator's Solution*. Boston, MA: Harvard Business School Press.

Christensen, C., M. Raynor, and R. McDonald. 2015. "What is Disruptive Innovation?" *Harvard Business Review* 93 (12): 44–53. December.

Coccia, M. 2005a. "Measuring Intensity of Technological Change: The Seismic Approach." *Technological Forecasting & Social Change* 72 (2): 117–144. doi:10.1016/j.techfore.2004.01.004.

Coccia, M. 2005b. "Metrics to Measure the Technology Transfer Absorption: Analysis of the Relationship Between Institutes and Adopters in Northern Italy." *International Journal of Technology Transfer and Commercialization* 4 (4): 462–486. doi:10.1504/IJTTC.2005.006699.

Coccia, M. 2005c. "A Taxonomy of Public Research Bodies: A Systemic Approach." *Prometheus – The Journal of Issues in Technological Change. Innovation. Information Economics, Communications and Science Policy* 23 (1): 63–82. doi:10.1080/0810902042000331322.

Coccia, M. 2006. "Analysis and Classification of Public Research Institutes." *World Review of Science, Technology and Sustainable Development* 3 (1): 1–16. doi:10.1504/WRSTSD.2006.008759.

Coccia, M. 2008. "Science, Funding and Economic Growth: Analysis and Science Policy Implications." *World Review of Science, Technology and Sustainable Development* 5 (1): 1–27. doi:10.1504/WRSTSD.2008.01781.

Coccia, M. 2010. "The Asymmetric Path of Economic Long Waves." *Technological Forecasting & Social Change* 77 (5): 730–738. doi:10.1016/j.techfore.2010.02.003.

Coccia, M. 2012. "Evolutionary Growth of Knowledge in Path-breaking Targeted Therapies for Lung Cancer: Radical Innovations and Structure of the New Technological Paradigm." *International Journal of Behavioural and Healthcare Research* 3 (3–4): 273–290. doi:10.1504/IJBHR.2012.051406.

Coccia, M. 2014a. "Converging Scientific Fields and New Technological Paradigms as Main Drivers of the Division of Scientific Labour in Drug Discovery Process: The Effects on Strategic Management of the R&D Corporate Change." *Technology Analysis & Strategic Management* 26 (7): 733–749. doi:10.1080/09537325.2014.882501.

Coccia, M. 2014b. "Path-breaking Target Therapies for Lung Cancer and a Far-sighted Health Policy to Support Clinical and Cost Effectiveness." *Health Policy and Technology* 3 (1): 74–82. doi:10.1016/j.hlpt.2013.09.007.

Coccia, M. 2015a. "Technological Paradigms and Trajectories as Determinants of the R&D Corporate Change in Drug Discovery Industry." *International Journal of Knowledge and Learning* 10 (1): 29–43. doi:10.1504/IJKL.2015.071052.

Coccia, M. 2015b. "Spatial Relation between Geo-Climate Zones and Technological Outputs to Explain the Evolution of Technology." *International Journal of Transitions and Innovation Systems* 4 (1–2): 5–21. doi:10.1504/IJTIS.2015.074642.

Coccia, M. 2016a. "The Relation Between Price Setting in Markets and Asymmetries of Systems of Measurement of Goods." *The Journal of Economic Asymmetries* 14, part B, November: 168–178. doi:10.1016/j.jeca.2016.06.001.

Coccia, M. 2016b. "Radical Innovations as Drivers of Breakthroughs: Characteristics and Properties of the Management of Technology Leading to Superior Organizational Performance in the Discovery Process of R&D Labs." *Technology Analysis & Strategic Management* 28 (4): 381–395. doi:10.1080/09537325.2015.1095287.

Coccia, M. 2016c. "Problem-driven Innovations in Drug Discovery: Co-evolution of the Patterns of Radical Innovation with the Evolution of Problems." *Health Policy and Technology* 5 (2): 143–155. doi:10.1016/j.hlpt.2016.02.003.

Coccia, M. 2017a. "Sources of Technological Innovation: Radical and Incremental Innovation Problem-Driven to Support Competitive Advantage of Firms." *Technology Analysis & Strategic Management* 29 (9): 1048–1061. doi:10.1080/09537325.2016.1268682.

Coccia, M. 2017b. "Sources of Disruptive Technologies for Industrial Change." *L'industria –rivista di economia e politica industriale* 38 (1): 97–120. ISSN: 0019-7416. doi:10.1430/87140.

Coccia, M. 2017c. "The Fishbone Diagram to Identify, Systematize and Analyze the Sources of General Purpose Technologies." *Journal of Social and Administrative Sciences* 4 (4): 291–303. doi:10.1453/jsas.v4i4.1518.

Coccia, M. 2017d. "Varieties of Capitalism's Theory of Innovation and a Conceptual Integration with Leadership-Oriented Executives: The Relation Between Typologies of Executive, Technological and Socioeconomic Performances." *International Journal of Public Sector Performance Management* 3 (2): 148–168. doi:10.1504/IJPSPM.2017.084672.

Coccia, M. 2017e. "Disruptive Firms and Industrial Change." *Journal of Economic and Social Thought* 4 (4): 437–450.

Coccia, M. 2018a. "Disruptive Firms and Technological Change." *Quaderni IRCrES-CNR* 3 (1): 3–18. doi:10.23760/2499-6661.2018.001.

Coccia, M. 2018b. "Theorem of not Independence of any Technological Innovation." *Journal of Economics Bibliography* 5 (1): 29–35. doi:10.1453/jeb.v5i1.1578.

Coccia, M. 2018c. "The Origins of the Economics of Innovation." *Journal of Economic and Social Thought* 5 (1): 9–28. doi:10.1453/jest.v5i1.1574.

Coccia, M. 2018d. "Optimization in R&D Intensity and tax on Corporate Profits for Supporting Labor Productivity of Nations." *The Journal of Technology Transfer* 43 (3): 792–814. doi:10.1007/s10961-017-9572-1.

Coccia, M. 2019a. "Comparative Theories of the Evolution of Technology." In *Global Encyclopedia of Public Administration, Public Policy, and Governance*. First., edited by A. Farazmand, 1–8. Cham: Springer Nature Switzerland AG.doi:10.1007/978-3-319-31816-5_3841-1.

Coccia, M. 2019b. "A Theory of Classification and Evolution of Technologies Within a Generalized Darwinism." *Technology Analysis & Strategic Management* 31 (5): 517–531. doi:10.1080/09537325.2018.1523385.

Coccia, M. 2019c. "The Theory of Technological Parasitism for the Measurement of the Evolution of Technology and Technological Forecasting." *Technological Forecasting and Social Change*. doi:10.1016/j.techfore.2018.12.012.

Coccia, M. 2019d. "Comparative Institutional Changes." In *Global Encyclopedia of Public Administration, Public Policy, and Governance*. First., edited by A. Farazmand, 1–6. Cham: Springer Nature Switzerland AG.doi:10.1007/978-3-319-31816-5_1277-1.

Coccia, M. 2020a. "Deep Learning Technology for Improving Cancer Care in Society: New Directions in Cancer Imaging Driven by Artificial Intelligence." *Technology in Society* 60, February: 1–11. doi:10.1016/j.techsoc.2019.101198.

Coccia, M. 2020b. "The Evolution of Scientific Disciplines in Applied Sciences: Dynamics and Empirical Properties of Experimental Physics." *Scientometrics*. doi:10.1007/s11192-020-03464-y.

Coccia, M. 2020c. "Comparative Concepts of Technology for Strategic Management." In *Global Encyclopedia of Public Administration, Public Policy, and Governance. Springer Nature Switzerland AG 2020*, edited by A. Farazmand. Cham: Springer. doi:10.1007/978-3-319-31816-5_3970-1.

Coccia, M. 2020d. "Comparative Hypotheses for Technology Analysis." In *Global Encyclopedia of Public Administration, Public Policy, and Governance*. First., edited by A. Farazmand, 1–8. Cham: Springer Nature Switzerland AG.doi:10.1007/978-3-319-31816-5_3973-1.

Coccia, M. 2020e. "Destructive Technologies for Industrial and Corporate Change." In *Global Encyclopedia of Public Administration, Public Policy, and Governance*. First., edited by A. Farazmand, 1–7. Cham: Springer Nature Switzerland AG.doi:10.1007/978-3-319-31816-5_3972-1.

Coccia, M., and J. Watts. 2020. "A Theory of the Evolution of Technology: Technological Parasitism and the Implications for Innovation Management." *Journal of Engineering and Technology Management* 55, S0923-4748(18)30421-1: 101552. doi:10.1016/j.jengtecman.2019.11.003.

Coelho, M. P., and Z. J. Mendes. 2019. "Digital Music and the "Death of the Long Tail"." *Journal of Business Research* 101: 454–460.

Danneels, E. 2006. "Dialogue on the Effects of Disruptive Technology on Firms and Industries." *Journal of Product Innovation Management* 23 (1): 2–4.

Eley, C. 2016. "Technostalgia and the Resurgence of Cassette Culture." In *The Politics of Post-9/11 Music: Sound, Trauma, and the Music Industry in the Time of Terror*, edited by Brian Flota and Joseph P. Fisher, 63–74. Farnham, United Kingdom: Routledge.

Fisher, J. C., and R. H. Pry. 1971. "A Simple Substitution Model of Technological Change." *Technological Forecasting & Social Change* 3 (2-3): 75–88.

Freeman, C. 1974. *The Economics of Industrial Innovation*. Harmondsworth: Penguin.

Hall, J. K., and M. J. C. Martin. 2005. "Disruptive Technologies, Stakeholders and the Innovation Value-Added Chain: a Framework for Evaluating Radical Technology Development." *R and D Management* 35: 273–284.

Hracs, B. J., and J. Jansson. 2017. "Death by Streaming or Vinyl Revival? Exploring the Spatial Dynamics and Value-Creating Strategies of Independent Record Shops in Stockholm." *Journal of Consumer Culture*. doi:10.1177/1469540517745703.

Kapoor, R., and T. Klueter. 2015. "Decoding the Adaptability-Rigidity Puzzle: Evidence from Pharmaceutical Incumbents' Pursuit of Gene Therapy and Monoclonal Antibodies." *Academy of Management Journal* 58: 1180–1207.

Lee, M., H. B. Choi, D. Cho, and H. Lee. 2016. "Cannibalizing or Complementing? The Impact of Online Streaming Services on Music Record Sales." *Procedia Computer Science* 91: 662–671.

Li, M., A. L. Porter, and A. Suominen. 2018. "Insights Into Relationships Between Disruptive Technology/Innovation and Emerging Technology: A Bibliometric Perspective." *Technological Forecasting and Social Change* 129: 285–296.

Love, P. E. D., J. Matthews, and Z. Jingyang. 2020. "Is it Just too Good to be True? Unearthing the Benefits of Disruptive Technology." *International Journal of Information Management* 52: 102096. doi:10.1016/j.ijinfomgt.2020.102096.

Mahto, R. V., O. Belousova, and S. Ahluwalia. 2017. "Abundance – A new Window on how Disruptive Innovation Occurs." *Technological Forecasting and Social Change*: 119064.

Markides, C. 2006. "Disruptive Innovation: In Need of Better Theory." *Journal of Product Innovation Management* 23: 19–25.

Mudg, S., and D. J. Hoek. 2000. "Describing Jazz, Blues, and Popular 78 RPM Sound Recordings: Suggestions and Guidelines." *Cataloging & Classification Quarterly* 29 (3): 21–48. Accessed March 16, 2020. https://web.library.yale.edu/cataloging/music/historyof78rpms.

Naveed, K., C. Watanabe, and P. Neittaanmäki. 2017. "Co-evolution Between Streaming and Live Music Leads a way to the Sustainable Growth of Music Industry – Lessons From the US Experiences." *Technology in Society* 50: 1–19.

Park, C. 2018. "Incumbents as Disruptor and Their Disruptive Behaviour Enabling Disruptive Innovation: Case Study of High Performance and low Cost CPU and Foundry Market." *Technology Analysis & Strategic Management* 30 (12): 1437–1454.

Radnejad, A. B., and V. Harrie. 2019. "Disruptive Technological Process Innovation in a Process-Oriented Industry: A Case Study." *Journal of Engineering and Technology Management* 53: 63–79. doi:10.1016/j.jengtecman.2019.08.001.

Read, O. 1952. *History of Acoustical Recording. The Recording and Reproduction of Sound*. Indianapolis: Howard W. Sams.

Reeve, E. C. R., and J. S. Huxley 1945. "Some Problems in the Study of Allometric Growth." In *Essay on Growth and Form*, edited by W. E. LeGros Clark and P. B. Medawar, 121–156. Oxford: Oxford University Press.

Reinhardt, R., and S. Gurtner. 2018. "The Overlooked Role of Embeddedness in Disruptive Innovation Theory." *Technological Forecasting and Social Change* 132: 268–283.

RIAA. 2019. "Recording Industry Association of America." U.S. Sales Database. Accessed July 15, 2019. https://www.riaa.com/u-s-sales-database/.

RIAA. 2020. "Recording Industry Association of America." U.S. Sales Database. Accessed March 9, 2020. https://www.riaa.com/u-s-sales-database/.

Sahal, D. 1981. *Patterns of Technological Innovation*. Reading, MA: Addison-Wesley Publishing Company, Inc.

Sarpong, D., S. Dong, and G. Appiah. 2016. "'Vinyl Never say Die': The re-Incarnation, Adoption and Diffusion of Retro-Technologies." *Technological Forecasting and Social Change* 103: 109–118.

Schmidt, G. M., and C. T. Druehl. 2008. "When is a Disruptive Innovation Disruptive?" *Journal of Product Innovation Management* 25 (4): 347–369.

Schuelke-Leech, B.-A. 2018. "A Model for Understanding the Orders of Magnitude of Disruptive Technologies." *Technological Forecasting and Social Change* 129: 261–274.

Tripsas, M. 1997. "Unraveling the Process of Creative Destruction: Complementary Assets and Incumbent Survival in the Typesetter Industry." *Strategic Management Journal* 18 (Summer Special Issue): 119–142.

Utterback, J. M., C. Pistorius, and E. Yilmaz. 2020. "The Dynamics of Competition and of the Diffusion of Innovations." MIT Sloan School of Management Working Paper-6054-20. https://hdl.handle.net/1721.1/124369.

Vecchiato, R. 2017. "Disruptive Innovation, Managerial Cognition, and Technology Competition Outcomes." *Technological Forecasting and Social Change* 116 (2017): 116–128.

Wlömert, N., and D. Papies. 2016. "On-demand Streaming Services and Music Industry Revenues – Insights From Spotify's Market Entry." *International Journal of Research in Marketing* 33 (2): 314–327.

Wright, G. 1997. "Towards A More Historical Approach to Technological Change." *The Economic Journal* 107, September: 1560–1566.

Yu, D., and C. C. Hang. 2010. "A Reflective Review of Disruptive Innovation Theory." *International Journal of Management Reviews* 12 (4): 435–452.

Zhang, K., J. Wang, L. Feng, and Y. Cheng. 2019. "The Evolution Mechanism of Latecomer Firms Value Network in Disruptive Innovation Context: a Case Study of Haier Group." *Technology Analysis & Strategic Management* 31 (12): 1488–1500.