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The nature, causes, and effects of skepticism on technology diffusion

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A R T I C L E I N F O

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A B S T R A C T

Although skepticism is involved in technical change and scientific revolutions, surprisingly, the literature lacks a systematic analysis of the different forms, causes, and roles of skepticism in the diffusion of innovation.

This paper defines, identifies and models different types and causes of skepticism and their role in technology adoption. The paper identifies and studies: skepticism involving the characteristics of the technology and the producer; skepticism that induces to disbelieve market signal; and comparative skepticism i.e., skepticism produced by an unbalance relationship between the perceived complexity of the problem and the solution.

Among the theoretical findings of the paper and regarding skepticism on market signals, we found that the non-differentiability and oscillation of diffusion rates occur if individuals use the information on diffusion rates as proxy of the probability of technology working and modify this probability according to their skepticism.

1. Introduction

Expensive social campaigns and high R&D investments in new technology for process or product innovation that are designed to improve social well-being or increase the competitiveness of firms often produce late results or fail. Market barriers, e.g., economic, organizational, cultural, technological, political, and infrastructural issues, are recognized as the most significant causes of these failures.

These barriers define the conditions in which the potential adopter will trust the characteristics of the proposed solutions, but these conditions are not in line with the adopter's conditions, wishes, or objectives.

There are also conditions under which the characteristics and promises of the offered technological solutions are not trusted. This paper addresses these types of attitudes, which we refer to as *skepticism*.

Although skepticism is one of the most common attitudes toward innovation and can trigger or brake technical change and scientific revolutions, a systematic analysis of its different forms, causes and roles in innovation adoption and diffusion is lacking.

In Sections 2.1, we discuss the existing definitions and meanings of skepticism, its different origins, how it can be measured. and the general findings on the role of skepticism in product and innovation adoption. Section 2.1.2 explicilty reports the definition of technology skepticism we have adopted in our research.

Section 2.2 proposes a classification of skepticism based on three criteria:

a) the type of objects that are not trusted;
b) the degree of selectivity; and.
c) the degree to which skepticism is planned by the potential adopter.

In terms of the types of objects that are not trusted, the paper focuses on:

1) specific or generic characteristics of the product, the producer, the brand as solutions to a given problem (analyzed in Section 3);
2) market signals (discussed in Section 4);
3) skepticism emerging from the comparison between the perceived complexity of the problem and the perceived complexity of the offered solution (presented in Section 5).

Concerning dimensions b) and c), we focus on a low technological specificity – a low degree of planned skepticism.

Since all types of skepticism may be triggered by communication and advertising, we discuss how skepticism emerges in advertising and offer suggestions to prevent or reduce skepticism through communication strategies (Section 6).

2. Technology skepticism

2.1. Technoskepticism versus technology skepticism

Aside from the definitions of skepticism in the philosophical

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literature (Greco, 2008) and those involving scientific paradigm shifts (i.e., institutional norms, according to which "no claims to truth are held sacred" (Koertge, 2008; Merton, 1973), the literature on innovation diffusion provides no explicit definition of technology skepticism. It is often viewed as a negative reaction to technological stress (i.e., an adaptive response caused by an inability to adapt to new technologies in a healthy manner) (Brod, 1984; Salanova, 2003; Salanova et al., 2013), or as generated by potential threat of technology, e.g., the fear of job loss akin to Luddites (Mellor et al., 2015). This type of reactions are usually named *technoskepticism*.

In our approach, we follow the etymology of skepticism focusing on the semantic dimension of distrust, disbelief, etc., as adopted in the field of consumer behavior. This perspective emphasizes attitudes toward a) overly enthusiastic communication about the benefits and effectiveness of technology; b) some specific charactertistic of the technology that may generate doubts on technology effectiveness, rather than solely focusing on the potential threats posed by the technology. We define these attitudes as *technology skepticism.*

2.1.1. A definition of technology skepticism

The term skepticism originates from *sképsis*—research, or doubt—-with the same root as the Greek verb *sképtesthai*, which means to distinguish, to examine. Doubt and skepticism can thus be seen as oscillation between two opposite poles (e.g., old versus new ideas, known versus unknown solutions) and the lack of correspondence between them. The opposite of skepticism is trust. Trust originates from the proto-Indo-European root *deru*, which means being solid, a generator of comfort, protection, and consolation (etimonline.com/word/trust). Disbelief is the lack of the old English *geleafa* belief, faith, and the old german *ga-laubon*: to hold dear, esteem, and trust. According to these etymologies, disbelief can be seen as an attitude toward somebody or something that is not effective in protecting and solacing. (etimonline.com/word/disbelief).

Morel and Pruyn (2003) developed the concept of consumer skepticism toward new products (CSTNP) as the tendency to question all aspects of a new product. (Hernandez et al., 2019; Morel and Pruyn, 2003). These authors discuss whether skepticism is a personal trait or a context-induced state. Both these hypotheses are plausible. Specific conditions can induce heterogeneous but temporal reactions, triggering different skeptical behaviors.

Morel et al. (2003) also explain the difference between skepticism, doubt, disbelief, and distrust. Doubt originates from insufficient information. Disbelief and distrust do not imply information scarcity but rather attitudes toward the credibility of information.

A more consolidated literature related to advertising (Obermiller et al., 2005; Obermiller and Spangenberg, 2000; Raziq et al., 2018) considers skepticism as synonymous with disbelief. However, disbelief is more definite than skepticism. Distrust is synonymous with cynicism and not with skepticism. However, these definitions are too generic and are not able to characterize the different types of skepticism. Sometimes, without any further investigation of the causes of the low diffusion rates of a technology, skepticism is the label associated with the later adopters (Lemos, 2008).

In this paper we adopt the following general definition of skepticism. In contrast with technoskepticism that collects reactions to technology adoption induced by economic and cultural market barriers, *technology skepticism* regards the lack of trust on or disbelieve toward information concerning, directly or indirectly, the effectiveness of a proposed technology and/or on some of its components.

Following the given definition, while technology skepticism leads to a transformation of the received information on technology performance, technoskepticism induces a rejection without transforming the information about it.

2.1.2. Dimensions of technology skepticism

Inspired by consumer skepticism, technology skepticism can be analyzed considering different types of reaction to information about a technology.

A cognitive response refers to the rational evaluation of information and claims provided by companies. Consumers may be skeptical if they find inconsistencies, lack of evidence, etc.

An affective responses identifies the emotional response of consumers toward marketing messages or brands. Skepticism may arise if consumers feel manipulated or misled by emotional appeals.

Behavioral reactions describes all the actions taken by consumers in response to their skepticism, such as seeking more information about the technology, engaging in extensive research before making a purchase, or avoiding certain brands altogether.

A situational response is a form af skepticism that varies depending on the context or situation. For example, consumers may be more skeptical of new or unfamiliar products compared to well-established brands.

Finally, a socially-inspired response describes social influences that can shape consumer skepticism, hearing negative experiences or reviews from friends or family members.

All the listed reactions describe above can be rearranged into three dimensions:

- the object toward which technology skepticism is directed;
- the degree of specificity of the skepticism;
- the degree of planning.

Form of control, which can vary from low or very high, that inhibits the instinctual acceptance of theories, products, and technologies.

There is, however, skepticism at first sight that is not planned i.e., it is not the effect of the top-down control, and appearing as a reaction induced by conditions of fear or high risk.

The theory of controlled inhibition (Anderson and Weaver, 2009), which increases with age, explains how skepticism evolves and changes.

In childhood, individuals have not learnt how to control over over-reactions. There is no skepticism in children's eyes (see, for instance, Piaget's experiment explained in Houdé and Borst, 2014). Age activates superior cognitive functions, and top-down control inhibits instinctual behaviors. However, it has been observed that elderly people with specific diseases like Alzheimer often show disinhibited cognitive functions (Migliaccio et al., 2020). By contrast, high skepticism toward novelty that is instinctual and not planned increases with age (Behforuzi et al., 2019).

Additionally, intergenerational conflicts often involve skepticism toward novelty and old solutions. This means that skepticism toward novelty or toward old technologies (focused on specific characteristics of technology or facing the technology holistically) are higher than the degree of trust in friendly and family relationships.

2.2. How techno skepticism is measured

Jahanmir and Lages (2016) introduced and measured skepticism to assess the case of late adopters of mobile phones. To characterize late adopters and involve academics and users, the cited authors adopt a confirmatory factorial analysis of 50 items from users' characteristics (Lemos, 2008; Rogers et al., 2014) and other dimensions from the innovation literature. Based on the factorial analysis, these authors developed a nine items questionnaire. Three questions were related to skepticism: SK1 I approach innovations with a skeptical and cautious air. SK2 I often fear high-tech a little bit. SK3 I can be stubborn in resistance to buying new product.

Morel et al. (2003) developed a questionnaire to assess consumer skepticism with 20 items. The questionnaires asks if consumer doubts product performance, ease of use, durability, scarcity, value for money, and novelty.

Obermiller et al. (2005) proposed an advertising skeptical scale (SKEP) consisting of 9 items on a 10-point scale.

An indirect way to assess skepticism is, of course, measuring trust or disbelieve. Yamagishi and Yamagishi (1994) developed a general trust scale of 6 items. However, this questionnaire is too generic and it is not focused on technology, product or advertising (as done by Soh et al., 2009).

2.2.1. General findings

Several studies discuss the role of skepticism on the acceptance of green (green skepticism) and sustainable products (Goh and Balaji, 2016; Kahraman and Kazançoğlu, 2019; Luo et al., 2020; Testa et al., 2021); the detection of barriers to the adoption of innovative technologies and innovative services in the Internet of Things era (Chouki et al., 2019; Mani and Chouk, 2018); brand (Hawass, 2013; Hernandez et al., 2019) and label trust (Aji, 2017; Cho and Taylor, 2020); and food consumption (Činjarević et al., 2018).

All these analyses highlight how the negative effect of skepticism rapidly spreads in the market. Late and skeptical adopters appear to be socially active (Moore-Shay and Lutz, 1988). Induced by skepticism and its correlation with age and gender, word of mouth rapidly reduces innovation diffusion (Obermiller and Spangenberg, 2000). Negative expectations about the efficacy of new solutions spread among similar groups or different generations (Buss and Schaninger, 1987; Childers and Rao, 1992; Moore-Shay and Lutz, 1988). The effect is to block the diffusion of innovation and related information.

However, the literature lacks a general framework for modeling and forecasting the effect of technology skepticism on technology diffusion.

2.3. The three dimensions of technology skepticism

The first classification is based on *the type of objects that are not trusted in*. As mentioned in the introduction, we consider skepticism regarding the characteristics of the technology, skepticism related to the market signals (e.g., diffusion rates as a proxy of the effectiveness of the technology), and comparative skepticism involving the characteristics of the original problem and the technology proposed as the solution. (See Table 1)

The second classification details the *degree of selectivity*. For instance, a high degree describes a “cognitive -rational” skepticism regarding specific subsystems or individual sub-technologies embedded in the proposed solution. A low degree characterizes some of the characteristics of the artifacts, such as age and price.

The third classification involves the degree to which skepticism is planned by the potential adopter. Skepticism can be planned or unplanned depending on potential users’ education (Cottrell et al., 2022), and if planned, it does not necessarily correlate with the personal skills and competencies used in a profession. Planned skepticism may be oriented toward maintaining the status quo and the fear of losing reputation and consensus. However, unconscious or unplanned skepticism can also be observed among professionals. Cognitive biases are observed, for instance, in medical decision-making, such as anchoring (Furnham and Boo, 2011) and priming (Mussweiler and Strack, 1999; Strack and Mussweiler, 1997; Tversky and Kahneman, 1974). Confirmation bias (Cai et al., 2020; Nickerson, 1998) usually originates from a lack of critical judgment. However, a lack of criticism of rooted beliefs leads to skepticism about future solutions and innovation. Confirmation bias induces criticism about new situations and novelty. Observations usually do not confirm new theories which need to be supported by more empirical evidence. A skeptical person will emphasize cases of failure instead of collecting evidence about innovation success.

2.4. Types of skepticism considered here

This paper analyzes skepticism with low degrees of selectivity and planning. In fact, we do not focus on a specific case or technology. This approach is also in contrast to Moore (2003), who assumes a high degree of planned skepticism, as if a skeptical person would deliberately propose more reasons that justify their rejection than those considered by an enthusiastic adopter. Our choice corresponds to the skepticism of a nonexpert technology adopter or a potential final user who is not interested in specific technical problems but rather in whether the technology works for their purposes (see Fig. 1). We plan to analyze other types of skepticism in the future. (See Fig. 1.)

Table. 1
Structure of the paper.

	Arguments	Sections and subsections of the paper
Introduction		Section 1
Preliminaries	Definitions of skepticism	Subsection 2.1, subsub sections 2.1.1
	Definition of technology skepticism adopted int the paper	2.1.2
	Origins of skepticism	2.1.3
	Measuring skepticism	2.1.4
	Empirical findings	2.1.5
	Classifications and types of skepticism covered in the paper	Subsections 2.2- 2.3
		Subsection 3.1, subsubsections 3.1.1, 3.1.2
Skepticism toward characteristics of the technology	Price and quality	Subsection 3.2
	Skepticism on brand and producer reputation	Subsection 3.3
	General skepticism on the probability that the technology works	Subsections 3.4 – 3.5
Skepticism toward market signals		Section 4 and Appendices B, C
Comparative skepticism		Section 5
	Skepticism depending on marketing intensity and technology specific communication i.e., skepticism arising from B2B rather than B2C strategies	Section 6, subsection 6.1 and Appendix A
Skepticism arising from communication ad advertising	Skepticism due to the imbalance in communication between capturing bottom-up attention (which generates surprise) and informing potential adopters (which reduces surprise)	Subection 6.2
	Comparative skepticism	Subsection 6.3
Discussions and conclusions		Section 7

3. Skepticism toward the characteristics of technology (and the producers)

Among the characteristics of a technology that do not require a high degree of skill, we consider the age, price and, in general, the probability that the technology will work, i.e., all the characteristics of the technology that can already be perceived without carrying out any technical or specific tests.

3.1. Age of the technology

One key characteristic of technology involving skepticism is its age. This type of skepticism is affected or triggered by the following:

1) disbelief vs attraction to rare or unexpected events;
2) the paradigm of efficiency vs the strength of old solutions.

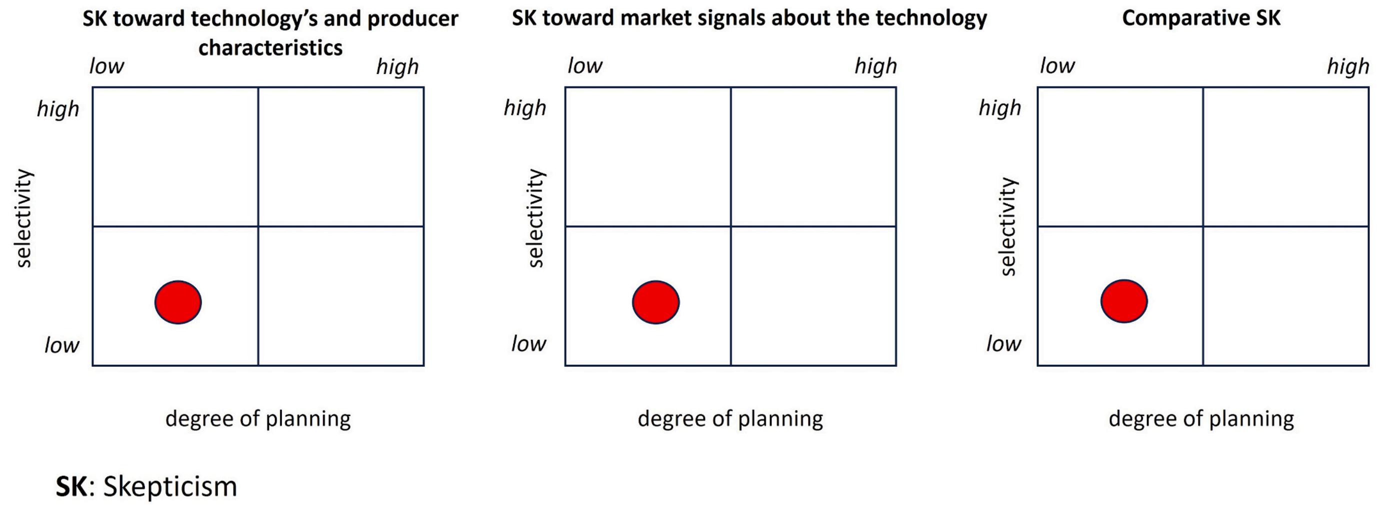

Fig. 1. Types of skepticism (SK) and those analyzed in the present paper (red circles). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3.1.1. Disbelief vs. attraction to rare or unexpected events

Rare and unexpected results trigger bottom-up attention in people. Trust or skepticism results from different types of attention given to novel and rare events. Since skepticism derives from an overcontrol of the characteristics and performance of a technology that initially appear viable, skepticism emerges by controlling and modifying the first positive reaction expressed in bottom-up attention.

Unexpected facts or novelty not necessary come from updated or new technologies.

In fact, if people are attracted to novelty only because an unexpected result triggers bottom-up attention, they may differ in the type of novelty they prefer. Today, old but effective technologies (e.g., the astrolabe, or an automaton of '600) are less commonly observed than the sextant, the GPS, or an advanced robotic solution. Therefore, an old technology may also be a novel for very young generations.

Some people are therefore attracted by the novelty of the future, with less interest and more skepticism toward old technologies (as is typical of young people). On the other hand other people are attracted by the "novelty" of the past and are not interested in and distrust future solutions (as observed in elderly people). Finally, some potential adopters are attracted by novelty, irrespectively of the age of the technology.

3.1.2. The paradigm of efficiency vs the strength of past technologies

It is generally believed that innovation improves the capability of human beings to overcome unsolved problems or to better solve old ones. Therefore, if we believe in technological progress, we should argue that a technology T' improves human needs better than a technology T if T' appears after T'. In other words, there are operations that T' can do that T cannot. We call this assumption "the strength of new technologies" or "the paradigm of efficiency". This assumption is the basis of skepticism toward old technologies.

However, because of the necessity of complementary and updated technologies to work, the new solutions are effective only in restricted scenarios. When external conditions compromise the use of complementary technologies and or specific source of energies, updated technologies does not work. In that conditions we assists to the "revenge" of old technologies that often works independently to the evolution of technological paradigms. This is the "strength" of old technologies.

For instance, let us consider three technologies: an oil lamp, a candle, and an electrical lamp.

An oil lamp (T) would have also worked in the era of the candle and electrical lamps. This was also the case for a candle in the early era of oil lamps and electric lamps. However, the electrical lamp could not have been produced or work in the eras of early oil lamps and candle production.[1]

The paradigm of efficiency triggers skepticism of old technologies, the strength of old technologies supports skepticism of the new ones.

3.2. Price and quality

Price is one of the most important factors that induces skepticism. Here, skepticism works in the opposite direction to economic barriers: too low prices reduce adoption. Ashraf et al. (2010) show how, in a lower-income country, higher prices of a solution for disinfecting water stimulate product use. Hardesty et al. (2002) demonstrate that a high price positively influences highly skeptical advertising consumers. Yin et al. (2020) show that consumers are more skeptical of hotels that adopt low-price green practices, than of hotels adopting high-price images. Skepticism may emerge whenever the price is not proportional to the complexity and quality of the solution and the importance/complexity of the problem.

As a technology becomes more common, reduced purchasing prices may also induce skepticism in late adopters if they believe in the superiority of a costly but updated new version of the original product. This is not always the case. For instance, the paradigmatic case of Windows XP and Windows Vista. Relatively low-quality packaging can induce skepticism regarding the ability of the solution to work. Therefore, investing

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[1] From the suggested perspective a current technology T' can be effective in a past scenario S of technology T, only if T' is an incremental innovation with respect to the past technology T. Otherwise, T' is a radical innovation, if compared with T.There are, of course, some exceptions that strongly depend on the availability of complementary technologies. It is the case of past technologies that do not work in current scenarios such as old TVs that need a specific tuner to capture the digital signal. However, it is also the case of digital TVs that do not work in an analogical signal scenario.

in industrial design is essential not only to improve ergonomic and easy-to-use technologies but also to reduce skepticism. Concerning price promotion, de Pechpeyrou and Odou (2012) observe how skepticism produces discounted savings and the reduced purchase intention of promotional offers.

We suspect that the observed incongruity between the price and quality of technology design triggers skepticism - however this needs empirical validation.

3.3. Skepticism about a technology depending on the producer and brand reputation

The reputation of producers and brands plays a fundamental role in triggering or reducing skepticism toward technology.

Vanhamme and Grobben (2009) assessed how consumers perceive the effort of corporate communication aimed at restoring reputation. They conclude that corporate social responsibility (CSR) claims induce skepticism, i.e. these claims are “too good to be true”, in the case of companies with a short CSR history.

Reputation is a challenge for young, smart and innovative companies such as university spin-offs that develop new technologies. The mechanism through which a company, by transferring its reputation to its technology, brand, or technologies, prevents skepticism is not clear, and there is not a unique solution. The complexity of the problem is increased by the nonlinearity between the effort to increase credibility and the reaction of potential adopters. It seems that if companies make too much effort to improve their reputation, then the level of consumer skepticism increases. For instance, marketing intensity is negatively related to reputation for technological innovation (Hoflinger et al., 2018). However, technology-specific communication may increase market barriers (see Section 6).

3.4. Skepticism and the probability that the technology will work

All the conditions under which potential users distrust the characteristics of a solution, we can consider the following implicit question: considering the characteristics, or considering the technology holistically, will it work? This question depends on the expected surprise of the technology’s outcome.

A general way to model skepticism as a function of technology characteristics is to focus on the degree of surprise embedded in the transferred information, i.e., considering the technology as a random variable X of its outcomes and the expected surprise that the technology will work as the entropy associated with X.

3.4.1. Technology representation

To model technology, we can use its description offered through advertising or described in the user’s manual, or detailed in a registered patent, or alternatively, we can consider its ability to solve problems or both. Therefore, we can represent a technology X using the frequency of linkages among words that describe it or using probabilities associated with the technology’s outcomes. We follow the second case. For simplicity, we consider a simple technology that produces a single outcome k, solving a specific problem with probability p, i.e., k is the given outcome if X solves the problem. The expected value of X is $EV(X) = pk$.

3.4.2. How a skeptic transforms the declared probability that the technology will work

Let p be the declared probability that technology X will solve the problem or, rather, it is the probability of observing an expected outcome. In line with definition of skepticism proposed in 2.1.2, a skeptical subject will modify p, obtaining $Sk(p,s)$ as a function of her degree of skepticism s:

$$Sk(p,s) = p(1-s) \tag{1}$$

and the expected value of X for a skeptic $(s > 0)$ is $EV(X,s) = kp(1-s)$.

The fact that skeptical people will start from p to evaluate X can be considered the effect of anchoring. s can be exogenous to the information received or dependent on it. Instead of a direct and subjective evaluation of the technology, the idea of an original transformation of p is explained by considering that people process the information coming from direct communication such as advertising, or through their social network.

In this latter case, let us consider a particular value of s. When $s = p$, the skeptical evaluation of X decreases with p. If p is 1, i.e., certainty, the skeptical evaluation is $Sk(1) = 0$. When the probability of observing the outcome is relatively low, skeptical people accept p. The difference between the probability that X will solve the problem and subjective judgment is small. When $s = p$, the effect of an increase in probability p on Sk is $1\text{-}2p$. That is, it is negative for $p > 1/2$. This radical skepticism (when $p = 1$, $Sk = 0$) can be too strong, and we can generalize Sk as:

$$Sk(p,\alpha,\sigma,m) = p(\alpha - \sigma p^m) \tag{2}$$

For $\alpha = 1$, $\sigma = s$, and $m = 0$, expression (2) is reduced to (1), and skepticism does not depend on the original probability, i.e., probability is scaled by a factor $(1-\sigma)$.

For $\sigma \neq 0$, $m \neq 0$, the subjective transformation of the original probability is not linear. Therefore, σ and m control the non-linear component of skepticism in modifying probability p.

Fixing $\alpha = 1$, the expected subjective value of technology X is $EV(X,1,\sigma,m) = kp(\alpha - \sigma p^m)$, and for $\alpha > 0$, it is sufficient $p > \sqrt[m]{\frac{\alpha}{\sigma(1+m)}}$ to observe a decrease in Sk induced by a p increase.

Therefore, given the degree of skepticism expressed by parameters p, α,σ,m, the subjective expected value of the technology can be expressed as:

$$EV(p,\alpha,\sigma,m,k) = k\,p(\alpha - \sigma p^m) \tag{3}$$

3.4.3. Negative probabilities

When $\sigma p^m > \alpha$, the subjectively transformed probability $p(\alpha - \sigma p^m)$ is negative.

The analysis can be reduced by considering only probabilities in the traditional 0–1 range. However, negative probabilities can be considered, as in the case of quantum dynamics (Dirac, 1942; Feynman, 1991). We follow the subjective interpretation of probability according to De Finetti (Cifarelli and Regazzini, 1996).

From this perspective, the probability of an event x is the price a person will consider fair to pay a ticket of a lottery that gives $1 if x occurs; otherwise, $0. Therefore, a negative probability means that the subject asks for money for participating in the lottery, e.g., to compensate for time lost waiting for x. A greater than one probability can be associated with an agent that assigns a greater than $1 value to the time necessary to observe x. This interpretation solves interesting paradoxes such as the penny auction (Shubik, 1971).

3.4.4. Skepticism and expected surprise

We can reformulate the analysis conducted in the above section in terms of entropy – expected surprise.

In effect, Shannon’s quantitative measure of information *H(X)* also relies on entropy of a random variable that can be interpreted as expected surprise. The expected surprise associated with a technology X is given by $H(X) := -\sum_{x\in X} p(x) log\, p(x)$. Tsallis (2022) introduced a generalized formula for entropy – expected surpise: $S_q \equiv k\,\frac{1-\sum_{i=1}^{W} p_i^q}{q-1}$. For $\sum_{i=1}^{W} p_i = 1$,

$$S_q \equiv \frac{k}{q-1} \sum_{i=1}^{W} p_i \left(1 - p_i^{q-1}\right) \tag{4}$$

The maximum entropy corresponds to the highest level of ignorance of the outcome of a random variable, i.e., the maximum expected surprise. For instance, the entropy associated with tossing a fair coin is $-(0.5\log(0.5)+0.5\log(0.5))$, which is greater than that in any other case of unfair coins. Consumers tend to trust products that do not imply too much uncertainty about future outcomes. However, in a complex and uncertain world, consumers are skeptical of offers that are too optimistic, i.e., a condition of very low entropy.

Note that, putting $m = q\text{-}1$, $\alpha = \sigma = 1$ in (3) we obtain expression (4), i.e., how skeptics transform information regarding technology outcomes is a function of the expected surprise and influences the subjective expected value of the technology. See Fig. 2.

Consumers therefore usually consider prices and the other characteristics of the product as a function of the product's capacity to reduce the expected surprise when it appears under a personal threshold and over the level of too low entropy. Over a declared probability p^* that the technology works (p^* is an internal cut-off) or a characteristic of the product that induces a specific level of entropy, the subject transforms $p' > p^*$ as a function *Sk* of the subject's skepticism, obtaining $p'' < p^*$. At p'', however, it is associated the *expected surprise* $H(p'')$. If $H(p'') > H^*$ (H^* is an internal threshold), the technology is not adopted. Fig. 3 represents the process.

4. Skepticism toward market signals

The above sections have analyzed the effect and causes of skepticism as the means through which potential adopters weigh up the probability that the technology will work in relation to some of the product's characteristics. In this section we consider how skepticism involves the transformation of received market signals about the technology. The market signal we consider is the diffusion rate of the technology as a proxy of its effectiveness. We study the effects of skepticism (transforming market signals) on the diffusion rates of a given technology.

Therefore, while in the previous section, p was the declared probability that the technology will work, in the following sections p is the rate of technology adoption.

4.1. Models of innovation diffusion

The simplest way of modeling innovation diffusion derives from studies on contagion diffusion.

(Rubinow, 1975).

Let us consider virus contagion in a population of N individuals. There is no recovery time. Once infected, agents do not change their health condition or social habits. In the unit time, new infections are proportional to the number of interactions between infected $I(t)$ and not infected $N(t) = N\text{-}I(t)$, given the probabilities of contagion c and interaction l.

$$\frac{dr(t)}{dt} = ar(t)r(t) = cI(t)N(t) = aI(t)(N - I(t)) \tag{5}$$

with $a = cl$.

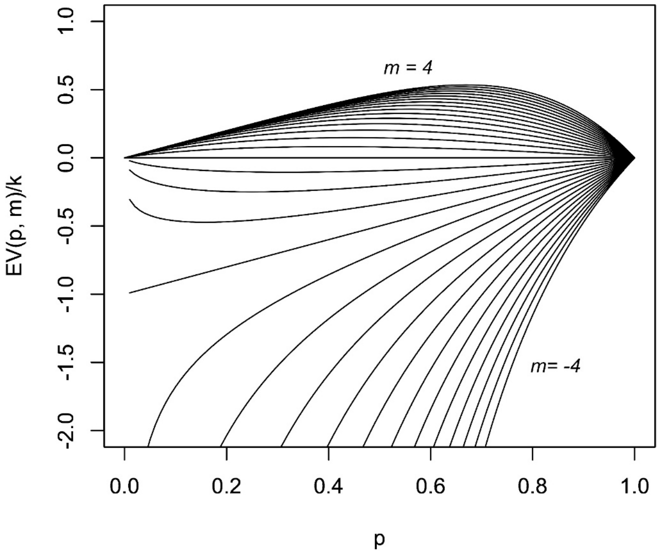

Fig. 2. Diffusion of innovation and subjective evaluation.

Integrated with the separation of variables, the ordinary nonlinear differential equation in (1) shows the logistic behavior for the rate of contagion $i(t) = I(t)/N$ over time.

Now, we replace contagion with technology adoption, and we obtain the simplest model to mimic innovation diffusion. The model expressed in (5) is the continuous analogue of the discrete process of a binary decision (to adopt or not).

N does not change during the process, i.e., the sum of adopters and potential adopters is constant (Sharif and Ramanathan, 1981).

To forecast the sales of products such as televisions, and inaugurating a growing literature and different applications (Lawton and Lawton, 1979; Lekvall and Wahlbin, 1973; Mahajan and Muller, 1979; Webber et al., 1972; Peres et al., 2010; Ratcliff and Doshi, 2012; Sidorov et al., 2021) Bass (1969) divided potential adopters N-r(t) into two subgroups: innovators and followers. In the group of innovators, new adoption depended only on interactions between other innovators (i.e., external influence is zero). New adoptions from the group of followers depended on interactions with both innovators (Coleman et al., 1966; Hamblin et al., 1973) and followers (Mahajan and Peterson, 1978; Sharif and Ramanathan, 1981; Griliches, 1957; Mansfield, 1961), which are related to the Gompertz function, as observed by Martino (1987). In different approaches, there is a time lag between interaction and adoption (Murray, 2002). Additionally, the total number of adopters N can change over time (Mahajan and Peterson, 1978; Sharif and Ramanathan, 1981). Jain et al. (1991) modified Bass's model by considering supply restrictions. Bayus (1993) and Peterson and Mahajan (1978) investigated the generation and management of technology-substituted and subsequent product generations. Narasimhan (1989) integrated diffusion models with pricing expectations. Other authors added profitability as a diffusion driver (Davies et al., 1979). In the early 1980s, other scholars complicated the Bass's original model with stochastic behaviors.

Advanced diffusion models have included micro-behaviors such as awareness and the decision-making stage (Kumar et al., 2022; Yu and Wang, 2006). However, Bass's model is still the most adopted and empirically tested in the case of durable goods diffusion. However, the models mimic single-product diffusion, while the decision to adopt is usually comparative (comparing alternatives), or sequential (new technologies replace old ones). A coevolution following Lotka-Volterra (Lotka, 1956; Rubinow, 1975) applied models of technology substitutions. Models with multiple substitutions have been proposed (the related literature started with Marchetti and Nakicenovic, 1979).

Arthur et al. (1994) introduced technology diffusion with increasing returns. This approach adopts the Polya-urn model and its extensions (Dosi et al., 2019). At time t, the probability that a technology (a ball of a given color i) will be adopted (i.e., it is drawn and a new one is added to the urn) is a (non-linear) function of the distribution of colors in the urn at time $t\text{-}1$. Non-linearity produces unbalanced and unpredictable market dynamics. To the best of our knowledge, there are no models of innovation diffusion and skepticism.

4.2. A dynamic model of technology diffusion and skepticism

In the unit time, new adoptions depend on two factors: (1) potential adopters $N\text{-}P(t)$ that meet adopters $P(t)$. They can be informed of the value of technology by interaction; (2) potential adopters that search for global information on the probability that the technology will solve a given problem. They adopt the rate of diffusion as a proxy of this

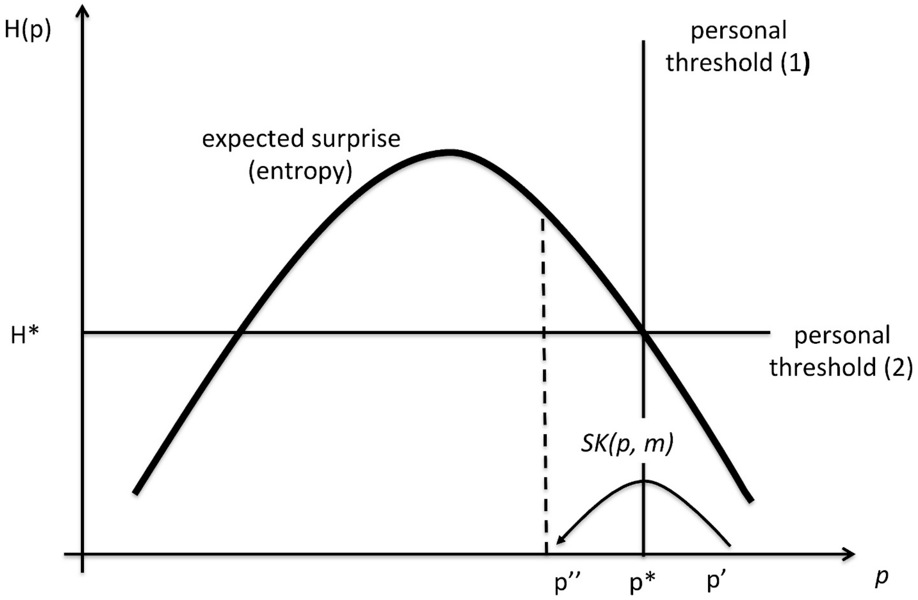

Fig. 3. Decision-making process for skeptical subjects.

probability. They also modify information (market signals) according to their skepticism and adopt the technology if the subjective evaluation exceeds a personal benchmark B. This is the case for adoption without interaction.

The first-order nonlinear differential equation that explains p as the rate $P(t)/N$ of adoption in the interval time is:

$$\frac{dp(t)}{dt} = \gamma(1-p)(ap+(1-a)\Phi(p,dt)) \tag{6}$$

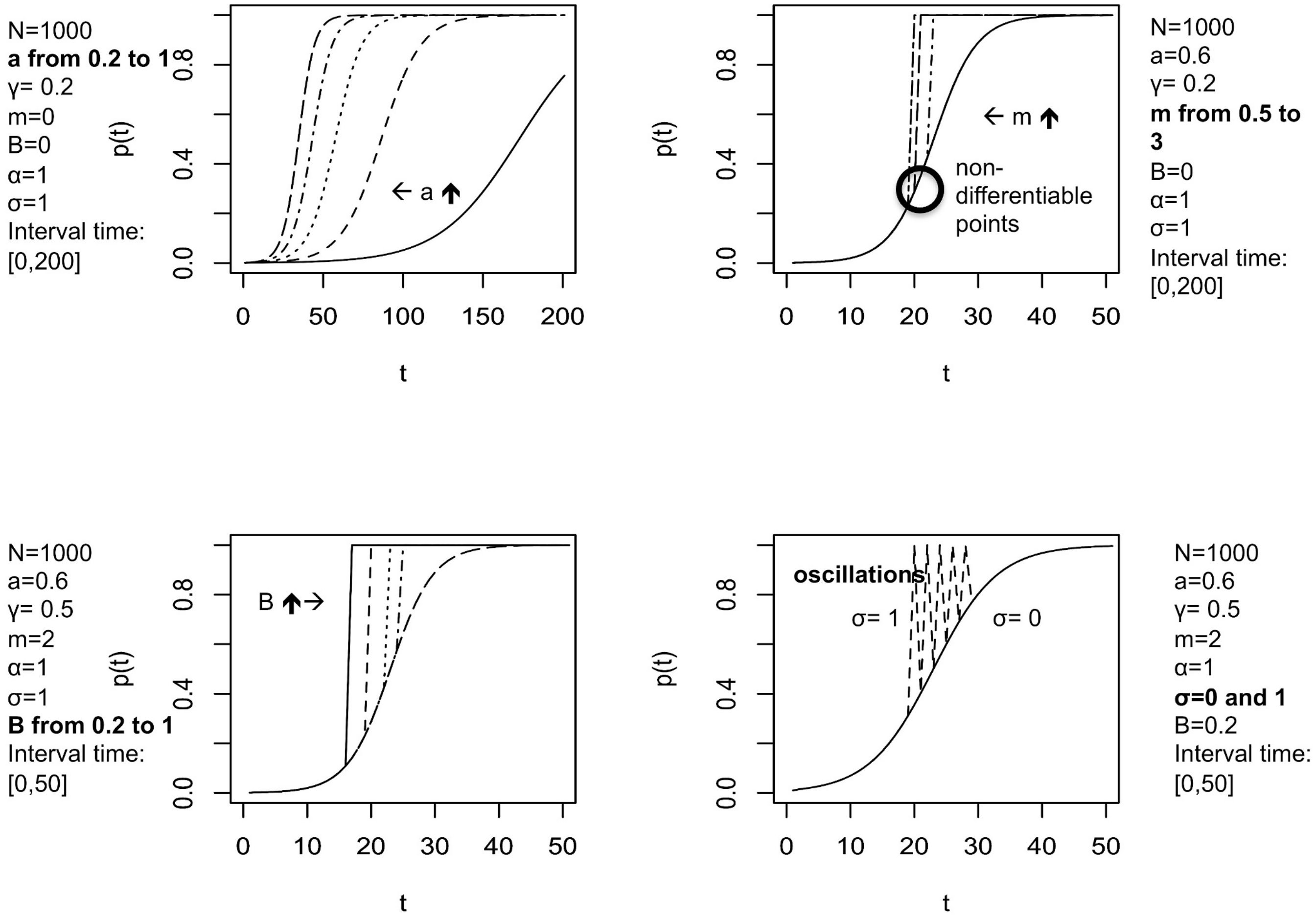

Fig. 4. Impact of skepticism on innovation diffusion.

where $\Phi(\mathrm{p}, \mathrm{dt})\{1\ \mathrm{p}(\alpha - \sigma \mathrm{p}^{\mathrm{m}}) > \overline{B}$, 0 otherwisewhere Φ(p,dt){1 p (α-σpm) > B; otherwise 0, and $\overline{m}, B$ are the minimum values of m_i and the minimum level of B_i for $i \in a(N - P(t))$.

Therefore, considering $t_0 = 0$ and by the separation of variables, we obtain the rate of technology diffusion $p(t)$ when $\Phi(p, dt) = 1$ as:

$$p(t) = 1 - \frac{1}{\left(\frac{N}{1-N} - a\right)e^{\gamma t} + a} \tag{7}$$

And, of course,

$$p(t) = \frac{1}{1 + (N-1)e^{-\gamma a t}} \tag{7'}$$

when $\Phi(p, dt) = 0$.

See Appendix B for the detailed steps from Eqs. (6) to (7).

4.3. *Innovation diffusion and skepticism: how to observe the logistic curve*

4.3.1. *Initial observations*

A first qualitative analysis of the effect of skepticism induced by the model expressed in Eq. (7) is the presence of non-differentiable points in the diffusion rate curve. It is, of course, related to the benchmark $B < 1$ that triggers adoption without interaction.

The second effect of skepticism depends on the magnitude of parameter a, i.e., the percentage of potential adopters that make decisions influenced by their interaction with adopters. Skepticism induces a long gestation and duration of the first phase of technology uptake (as also done by parameter γ). See Fig. 4.

4.3.2. *Skepticism, non-linearity and oscillation of diffusion rates*

Comparing the two cases of $\sigma = 0$ and $\sigma = 1$ with m varying from 0.5 to 5, in expression (6), we can observe the linear and non-linear effects of skepticism on diffusion rates.

When a skeptic interiorizes the received market signals *p(t)* (i.e., the diffusion rate) and according to the benchmark *B* he decides to adopt, he modifies the diffusion rate $p(t+1)$. A new skeptic and potential adopter will interiorize $p(t+1)$, but the transformed value could be lower than *B* so that she does not adopt the technology. Therefore, skepticism can produce oscillations (i.e., delays) in diffusion rates. As observed, when $p > \sqrt[m]{\frac{\alpha}{\sigma(1+m)}}$, $p(\alpha - \sigma p^m)$ decreases as p increases. Therefore, for a sufficiently low benchmark *B*, the subjective transformation of the probability could be lower than *B*. This, of course, reduces the diffusion rates, restoring conditions for adoption. Therefore, oscillations emerge when:

$$B < \frac{dSk(p)}{dt} = \frac{dSk(p)}{dp}\frac{dp}{dt} = (\alpha - \sigma(1+m)p^m)\gamma(1-p)(ap + (1-p)) \tag{8}$$

There is no oscillation when *B* is greater than the above formula and, in general, for $p = p_0 = 1/N$ in Eq. (8).

Fixing a threshold *B*, oscillation is induced by the non-linear effect of skepticism ($m = 1$). Oscillation also emerges in diffusion models with delay. They are of type $\frac{dp}{dt} = ax(-x(t - t^*))$ and involve *sine* and *cosine* functions as solutions. In these models, oscillation depends on the fixation of t^* instead of the probability that the technology effectiveness will meet a given threshold.

The observed effects suggest how to detect skepticism from data on technology diffusion. See Fig. 4.

4.4. *Model limitations*

The most important limitation of the model proposed in Section 4 is the overly strong assumption that a potential adopter can observe global market signals. According to a more realistic hypothesis, potential adopters obtain only local information. Agent-based models can overcome this limitation. However, skeptics prefer personal research on global signals rather than local information obtained through interactions with adopters. They do not trust such information, and skeptics subjectively transform market information quite independently of such interactions. Another limitation of this approach is that market properties are considered "on average" as the mean or the sum of individual behaviors. However, market properties may reflect individual behaviors only for those decision-makers that evaluate technology without interaction. However, this might not be the case for subjects influenced by their networks. The complexity of the interaction induced a rejection of the equilibrium hypothesis. Therefore, global properties cannot be ex ante deduced by observing micro behaviors (Kirman, 2010).

4.5. *Model extensions*

This section discusses how diffusion models can integrate users' characteristics and skepticism.

Let us consider the relationship between skepticism and age. This correlation is paradigmatic of the approach to follow when integrating the model with the personal characteristics of the potential adopters. To model the relationship between skepticism and age, it is sufficient to operate on the form of Sk (expression 2) and/or expression (6), e.g., *m (t)* = *E-t*, where E is the life expectancy.

Therefore, in the last case, expression (6) is a starting point for modeling variables that affect skepticism over time and their indirect impact on technology diffusion expressed in (6). Skepticism can also modify the internal benchmark, which can increase over time according to age. The empirical analysis suggests which sources of skepticism the models should include.

5. Comparative skepticism

Returning to the question in Section 3.4 about whether the technology will work, this is more targetted at engineers. An end user is likely to answer another question. Will the technology solve my problem? If we extend the analysis from the technology characteristics as a solution to the problems that the technology is trying to solve, another type of skepticism arises. Trieste et al. (2022) describe the skepticism that emerges when one compares the perceived complexity of the problem and the complexity of the proposed solution.

Irrespectively of their effectiveness, new theories, approaches, technologies, etc., may be perceived as being too simple or too complex compared with the perceived complexity of the problem. This is the case for Columbus's egg and the engineer's effect, respectively (Trieste et al., 2022).

Technology complexity is defined according to four dimensions: knowledge quantity, quality, heterogeneity and scarcity embedded in the artifact.

Jahanmir and Lages (2016) found a positive correlation between skepticism and the need for product simplicity. In elderly people, smartphones diffuse slowly not only because of the expected learning curve, but also because elderly people and younger people have different perceptions of the problems that smartphones can solve. If Jahanmir et al. (2016) had analyzed or asked respondents to describe the problems a smartphone could solve, they would have understood the importance of comparative skepticism. For elderly people, smartphones are more complex than the degree of complexity they assign to the original problem solved by traditional mobile phones (Yap et al., 2022). Younger people have different problems e.g., connectivity and memory capacity for navigating the internet. Therefore, insisting on smartphone performance and functions triggers more skepticism since the gap between the complexity of the problem and the solution increases for elderly people.

Miscommunication can increase adoption barriers rather than convince potential adopters, compromising the diffusion of viable solutions. This type of communication trap is described by Watzlawick et al. (2011).

5.1. Comparative skepticism and technology adoption

The perceived difference between the complexity associated to a problem and the proposed solution is a source of skepticism. Parameter *m* of the expression (2) can embed this difference.

$$Sk = p\left(\alpha - \sigma p^{\frac{1}{d(P,S)}}\right)$$

where *d(P,C) is* the distance between the complexity associated to problem P and solution S. As this difference goes to zero (problem and solution complexity are balanced), the non-linear component of skepticism disappears.

Empirical analysis is necessary to evaluate, through questionnaires. The complexity associated to problem and solution and forecast the defree of skepticism associated with *p*.

6. Skepticism and communication

Adopting the general idea that communication is related with all the dimensions of technology characteristics, market signals and comparison between problem' and solution's complexity, the three kinds of skepticism are triggered by communication and through communication we may prevent or reduce skepticism.

6.1. Skepticism depending on marketing intensity and technology-specific communication

Aside from personal perceptions of product characteristics, skepticism is related to the reactions to advertisements regarding the technology's characteristics and strengths.

However, defining the right amount of marketing intensity and technology communication is not easy. A very simple model can explain this problem.

The probability of technology adoption depends on marketing intensity M and technology communication T. However, market intensity can generate skepticism Sk(M), and technology communication produces market barriers *MB(T)*.

$$\mathrm{p(M,T) = M - Sk(M) + T - MB(T)}$$

We model the skepticism that arises from M and market barriers from T as follows:

$$\mathrm{Sk(M) = (M - m)^2}$$

$$\mathrm{MB(T) = 1 - (T - t)^2}$$

where m and t represent two thresholds. Over them, skepticism increases with M (it is the effect of marketing intensity on skepticism) and market barriers decrease with T because of learning, respectively.

Therefore, the critical point of *p(M, T) (½ + m, t -½)* is a saddle point (see appendix A).

One solution is a strong differentiation of B2B and B2C strategies in which technology communication is the only considered strategy (B2B) or is completely avoided and replaced by market intensity in B2C strategies.

6.2. Surprise, communication strategies, and skepticism: a suggested interpretation

According to the AIDA model (Iwamoto, 2023), the purpose of advertising is to stimulate attention (A), provoke interest (I), create desire (D) in the consumer for the product, and activate a purchasing action (A). New stimuli, or information-inducing surprises, can trigger bottom-up attention. Great surprises or storytelling that postpones or delays the use of a product as the solution to the represented needs can be very engaging (Storr, 2020). However, between engaging attention to adopting the technology, some steps require the opposite strategy, i.e., reducing the expected surprise of the technology's characteristics. The adopter, however, is not memoryless, so he compares the information that was used to attract and engage them with the information that was used to convincing them to adopt. A strong imbalance between these opposite strategies can lead to skepticism. Increasing the credibility and reputation of the sender of the message and/or of the communication channels may prevent this imbalance and increase the chances of adopting the technology.

6.3. Comparative skepticism and communication strategies

To prevent or neutralize comparative skepticism and boost technology adoption, we need to reduce the gap between the perceived complexity of the problem (P) and the perceived complexity of the solution (S). The related communication strategy depends on the skills and competences of the market target.

Fig. 5 reports a taxonomy of communication strategies depending on a) the type of the Columbus egg and the engineer's effect and b) the type of market target.

7. Discussion and conclusions

This paper offers a general framework for taking into account the different forms of technology skeptics, and offers some criteria of skepticism detection and mitigation (see Section 6 and Fig. 5). Howeverwe consider skepticism involving nonspecific technological characteristics and naive consumers. Future analyses will suggest how the personal characteristics of potential adopters, product stimuli and market signals generate specific kinds of skepticism, how they affect technology adoption and diffusion, and how to tackle them.

The framework and presentation of different kinds of skepticism should therefore be of interest to academics, technology developers and evaluators, as well as product and marketing managers.

CRediT authorship contribution statement

Leopoldo Trieste: Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Conceptualization. **Giuseppe Turchetti:** Writing – review & editing, Writing – original draft.

Data availability

Appendix C of the paper reports instructions for reproducing the simulated data.

Appendix A. Critical points for the probability of technology adoption as a function of market intensity, technology communication, and their side effects (skepticism, and market barriers)

The critical points of:

$$p(M,T) = M - (M - m)^2 + T - 1 + (T - t)^2$$

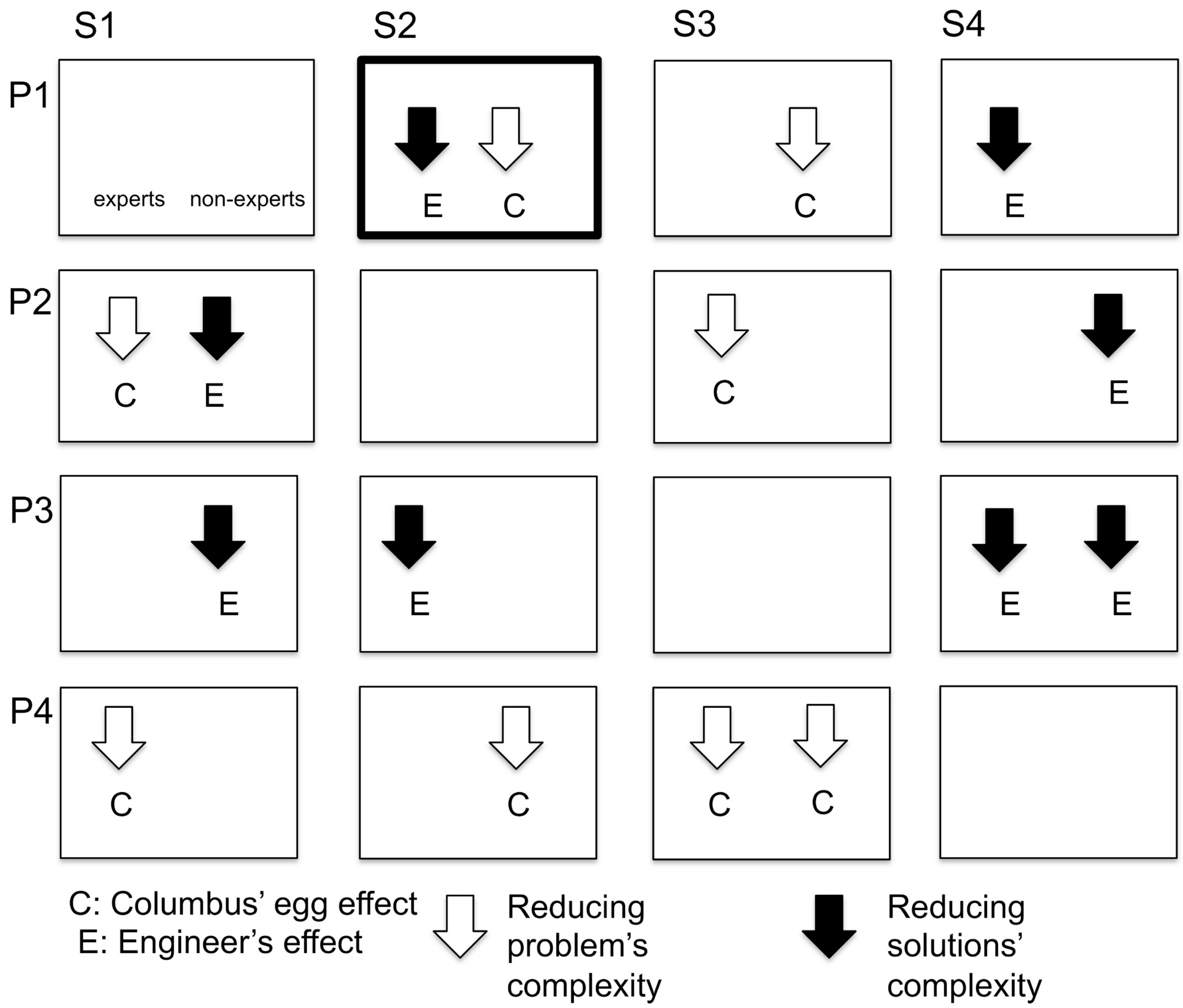

Fig. 5. Communication strategies for preventing comparative skepticism.

are obtained under the conditions that the first partial derivatives of p go to zero.

$p_M(M,T) = 0 \Rightarrow 1 - 2(M - m) = 0 \Rightarrow M = m + 1/2$

$Sk_T(M,T) = 0 \Rightarrow 1 + 2(T - t) = 0 \Rightarrow T = t - 1/2$

The Hessian matrix of the second partial derivatives is indefinite (the determinant is negative).

-2	0
0	2

Therefore, m + ½, t-½ is a saddle point of p.

Appendix B. Derivation of expression (7)

From (6) and by separating the variables, we obtain:

$$\int \frac{dp}{(1-p)(ap+1-a)} = \int \gamma dt$$

Now, the indefinite integrals expressed above are: $\int \frac{dp}{(1-p)(ap+1-a)} = log\left(p + \frac{1-a}{a}\right) - log(1-p) + c1$ and $\int \gamma dt = \gamma t + c2$.

The definite integrals are given by:

$$\int_{p_0}^{p}\frac{ds}{(1-s)(as+1-a)}=\int_{t_0}^{t}\gamma df \tag{1}$$

Considering the indefinite integrals above, we obtain:

$$\left[\log\left(s+\frac{1-a}{a}\right)-\log(1-s)\right]_{p_0}^{p}=[\gamma f]_{t_0}^{t}$$

We obtain:

$$\log\left(p+\frac{1-a}{a}\right)-\log\left(1-p\right)=\gamma t+c_0$$

where $\log\left(p_0+\frac{1-a}{a}\right)-\log\left(1-p_0\right)+\gamma t_0\ =\ -c_0$.

Taking the exponentials, we obtain:

$$\frac{p+\frac{1-a}{a}}{1-p}=c_1e^{\gamma t} \tag{2}$$

where $c_1\ =e^{c_0}$.

We can multiply both sides of (2) by (1-p). Alternatively, we can change the variable $u=1-p$ so that $p=1-u$. (B2) becomes:

$$\frac{1-u+\frac{1-a}{a}}{u}=\frac{1}{au}-1=c_1e^{\gamma t} \tag{3}$$

Therefore:

$$\frac{1}{au}=c_1e^{\gamma t}+1 \tag{4}$$

So that:

$$u=\frac{1}{a(c_1e^{\gamma t}+1)}. \tag{5}$$

Since $p = 1\text{-}u$, we obtain:

$$p=1-\frac{1}{a(c_1e^{\gamma t}+1)}. \tag{6}$$

To obtain c_1, we consider the value of p at $t = 0$:

$$p_0=1-\frac{1}{a(c_1+1)}$$

so that:

$$c_1=\frac{1}{a(1-p_0)}-1=\frac{1-a(1-p_o)}{a(1-p_0)} \tag{7}$$

Substituting c_1 expressed in (7) in (6), we obtain:

$$p(t)=1-\frac{1}{\frac{1-a(1-p_o)}{(1-p_0)}e^{\gamma t}+a}. \tag{8}$$

Finally, assuming that $p_0\ =\frac{1}{N}$, we obtain:

$$c_1=\frac{1-a(1-p_o)}{(1-p_0)}=\frac{\frac{N-aN+a}{N}}{\frac{N-1}{N}}=\frac{N-a(N-1)}{N-1}=\frac{N}{N-1}-a$$

and (8) becomes:

$$p(t)=1-\frac{1}{\left(\frac{N}{N-1}-a\right)e^{\gamma t}+a}. \tag{9}$$

Appendix C. Function of R to generate Figs. 2 and 4, based on expressions (6), (7) and (7’)

```
# modification of market signals (See Fig. 2.)
pp<-function(p,p_1,p_2,m){
p*(p_1-p_2*p^m)}
```

```
# case of m as a function of age; see section.
pp2<-function(p,p_1,p_2,t){
p*(p_1-p_2*pˆ(80-t)}
# expression for p(t) as reported in (7)
f1<-function(N, a, g,t,t1){
1-1/((N/(1-N) -a)*exp(g*t)+a)}
# expression for p(t) as reported in (7')
f2<-function(N,a,g,t,t1){
1/(1+(N-1)*exp(-a*g*t))}
# function of p(t) over time:
# differences between simulation parameters and model parameters: g=γ, p1=α, p2=σ
# t₁ = t₀, where t2 is the right bound of the interval time considered.
PL<-function(N,a,g,m, B, p_1, p_2,t1,t2, h, r){
tt<-seq(t1: t2)
b<-seq(t1: t2)
b[1]<-1/N
for(i in 1:(length(tt)-1)){
if(pp(b[i],m,p_1,p_2)<B){
b[i+1]<-f2(N, a,g, tt[i+1], t1)}
else {
b[i+1]<-f1(N, a,g, tt[i+1], t1)}
}
plot(b~tt, type="l", ylim=c(0,1), xlab="t", ylab="p(t)", xlim=c(t1, t2), lty=h, col=r)}
#Fig. 2
prob<-seq(0,1, by=0.01)
q<-seq(-4,4,by=0.25)
m<-seq(1: length(prob))
for(i in 1: length(q)){
for(j in 1: length(prob)){
m[j]<-pp(prob[j], 1,1,q[i])}
plot(m~prob, type="l", xlim=c(0,1), ylim=c(-2, 1), main="", xlab="p", ylab="EV(p, m)/k")
par(new=TRUE)}
#Fig. 3.
par(mfrow=c(2,2))
#basic model without skepticism
#effect of a on diffusion
a<-seq(0.2,1, by=0.2)
for(i in 1: length(a)){
PL(1000, a[i], 0.2, 0, 1, 1,0,0, 200,i,1)
par(new=TRUE)}
par(new=FALSE)
# effect of m on diffusion with benchmark B=0.5
m<- seq(0.5, 3, by=0.5)
for(i in 1: length(m)){
PL(1000, 0.6, 0.5, m[i], 0.6, 1, 1,0, 50,i,1)
par(new=TRUE)}
par(new=FALSE)
###### Effect of B
B<- seq(0.2, 1, by=0.2)
for(i in 1: length(B)){
PL(1000, 0.6, 0.5, 2, B[i], 1, 1,0, 50,i,1)
par(new=TRUE)}
par(new=FALSE)
#oscillation
PL(100, 0.4, 0.5, 1, 0.2, 1, 0,0, 200,1,1)
par(new=TRUE)
PL(100, 0.4, 0.5, 1, 0.2, 1, 1,0, 200,2,1)
```

References

Aji, H.M., 2017. Does skepticism toward halal label exist? The empirical evidence from Indonesia, in: Advances in Islamic Business. A Book Based on Proceedings of the 8th Global Islamic Marketing Conference. pp. 3–5.

Anderson, M.C., Weaver, C., 2009. Inhibitory control over action and memory. Encyclopedia Neurosci. 5, 153–163.

Arthur, W.B., et al., 1994. Increasing Returns and Path Dependence in the Economy. University of Michigan Press.

Ashraf, N., Berry, J., Shapiro, J.M., 2010. Can higher prices stimulate product use? Evidence from a field experiment in Zambia. Am. Econ. Rev. 100, 2383–2413. https://doi.org/10.1257/aer.100.5.2383.

Bass, F.M., 1969. A new product growth for model consumer durables. Manag. Sci. 15, 215–227.

Bayus, B.L., 1993. High-definition television: assessing demand forecasts for a next generation consumer durable. Manage. Sci. 39 (11), 1319–1333.

Behforuzi, H., Feng, N.C., Billig, A.R., Ryan, E., Tusch, E.S., Holcomb, P.J., et al., 2019. Markers of novelty processing in older adults are stable and reliable. Frontiers in Aging Neurosc. 11, 165.

Brod, C., 1984. Technostress: The Human Cost of the Computer Revolution. Addison-Wesley, Reading, MA, USA.

Buss, W.C., Schaninger, C.M., 1987. An overview of dyadic family behavior and sex roles research: a summary of findings and an agenda for future research. Rev. Mark. 293–324.

Cai, H., Yao, T., Zhang, X., 2020. Confirmation Bias in Analysts' Response to Consensus Forecasts, in: 2020 CIRF \& CFRI Joint Conference.

Childers, T.L., Rao, A.R., 1992. The influence of familial and peer-based reference groups on consumer decisions. J. Consum. Res. 19, 198–211.

Cho, Y.-N., Taylor, C.R., 2020. The role of ambiguity and skepticism in the effectiveness of sustainability labeling. J. Bus. Res. 120, 379–388.

Chouki, M., Talea, M., Okar, C., Chroqui, R., 2019. Barriers to information technology adoption within small and medium enterprises: a systematic literature review. Int. J. Innov. Technol. Manag. 17, 2050007. https://doi.org/10.1142/S0219877020500078.

Cifarelli, D.M., Regazzini, E., 1996. De Finetti's contribution to probability and statistics. Stat. Sci. 11, 253–282.

Činjarević, M., Agić, E., Peštek, A., 2018. When consumers are in doubt, you better watch out! The moderating role of consumer skepticism and subjective knowledge in the context of organic food consumption. Zagreb. Int. Rev. Econ. Bus. 21, 1–14.

Coleman, J.S., Katz, E., Menzel, H., 1966. Medical Innovation. Bobbs-Merrill, Indianapolis.

Cottrell, S., Torres, E., Harris, P.L., Ronfard, S., 2022. Older children verify adult claims because they are skeptical of those claims. Child Dev. https://doi.org/10.1111/cdev.13847.

Davies, S., et al., 1979. The Diffusion of Process Innovations. Cambridge University Press, Cambridge.

Dirac, P.A.M., 1942. Bakerian Lecture. The Physical Interpretation of Quantum Mechanics. Proc. Math. Phys. Eng. Sci. 180 (980), 1–39.

Dosi, G., Moneta, A., Stepanova, E., 2019. Dynamic increasing returns and innovation diffusion: bringing Polya urn processes to the empirical data. Ind. Innov. 26, 461–478.

Feynman, R., 1991. Negative Probability 235–248 in Quantum Implications: Essays in Honour of David Bohm Eds. Hiley B, Bohm D, Peat D.

Furnham, A., Boo, H.C., 2011. A literature review of the anchoring effect. J. Socio-Econ. 40, 35–42.

Goh, S.K., Balaji, M.S., 2016. Linking green skepticism to green purchase behavior. J. Clean. Prod. 131, 629–638.

Greco, J., 2008. The Oxford Handbook of Skepticism. Oxford University Press.

Griliches, Z., 1957. Hybrid corn: an exploration in the economics of technological change. Econom. J. Econom. Soc. 501–522.

Hamblin, R.L., Jacobsen, R.B., Miller, J.L.L., et al., 1973. A Mathematical Theory of Social Change. Wiley, New York.

Hardesty, D.M., Carlson, J.P., Bearden, W., 2002. Brand familiarity and invoice Price effects on consumer evaluations: the moderating role of skepticism toward advertising. J. Advert. 31, 1–15. https://doi.org/10.1080/00913367.2002.10673663.

Hawass, H.H., 2013. Brand Trust: Implications from Consumer Doubts in the Egyptian Mobile Phone Market. J. Islam, Mark.

Hernandez, J.M. da C., Wright, S.A., Affonso, F.M., 2019. The importance of advertising skepticism for brand extension appeals. Psychol. Mark. 36, 687–699.

Hoflinger, P.J., Nagel, C., Sandner, P.S., 2018. Reputation for technological innovation: does it actually cohere with innovative activity? J. Innov. Knowl. 3, 26–39.

Houdé, O., Borst, G., 2014. Measuring inhibitory control in children and adults: brain imaging and mental chronometry. Front. Psychol. 5, 616. https://doi.org/10.3389/fpsyg.2014.00616.

Iwamoto, A., 2023. The Origin of AIDA: Who Invented and Formulated the AIDA Model?, in: Proceedings of the Conference on Historical Analysis and Research in Marketing.

Jahanmir, S.F., Lages, L.F., 2016. The late-adopter scale: a measure of late adopters of technological innovations. J. Bus. Res. 69, 1701–1706. https://doi.org/10.1016/j.jbusres.2015.10.041.

Jain, D., Mahajan, V., Muller, E., 1991. Innovation diffusion in the presence of supply restrictions. Mark. Sci. 10 (1), 83–90.

Kahraman, A., Kazançoğlu, I., 2019. Understanding consumers' purchase intentions toward natural-claimed products: a qualitative research in personal care products. Bus. Strateg. Environ. 28, 1218–1233.

Kirman, A., 2010. Complex Economics: Individual and Collective Rationality. Routledge, London.

Koertge, N., 2008. New Dictionary of Scientific Biography. Charles Scribner & Sons, New York.

Kumar, R., Sharma, A.K., Sahu, G.P., 2022. Dynamical behavior of an innovation diffusion model with intra-specific competition between competing adopters. Acta Math. Sci. 42, 364–386. https://doi.org/10.1007/s10473-022-0120-1.

Lawton, S.B., Lawton, W.H., 1979. An autocatalytic model for the diffusion of educational innovations. Educ. Adm. Q. 15, 19–46.

Lekvall, P., Wahlbin, C., 1973. A study of some assumptions underlying innovation diffusion functions. Swed. J. Econ. 362–377.

Lemos, N. 2008. Moore and Skepticism', in John Greco (ed.), The Oxford Handbook of Skepticism, (online edn, Oxford Academic, 2 Sept. 2009).

Lotka, A.J., 1956. Elements of Mathematical Biology. Dover, New York.

Luo, B., Sun, Y., Shen, J., Xia, L., 2020. How does green advertising skepticism on social media affect consumer intention to purchase green products? J. Consum. Behav. 19, 371–381.

Mahajan, V., Muller, E., 1979. Innovation diffusion and new product growth models in marketing. J. Mark. 43, 55–68.

Mahajan, V., Peterson, R.A., 1978. Innovation diffusion in a dynamic potential adopter population. Manag. Sci. 24, 1589–1597.

Mani, Z., Chouk, I., 2018. Consumer resistance to innovation in services: challenges and barriers in the internet of things era. J. Prod. Innov. Manag. 35, 780–807. https://doi.org/10.1111/jpim.12463.

Mansfield, E., 1961. Technical change and the rate of imitation. Econom. J. Econom. Soc. 741–766.

Marchetti, C., Nakicenovic, N., 1979. The Dynamics of Energy Systems and the Logistic Substitution Model.

Martino, J.P., 1987. Recent developments in technological forecasting. Clim. Chang. 11, 211–235.

Mellor A, Mobilia M, Redner S, Rucklidge AM, Ward JA., 2015. Influence of Luddism on innovation diffusion. Phys. Rev. E Stat. Nonlinear Soft Matter Phys. 92(1):012806. doi: https://doi.org/10.1103/PhysRevE.92.012806. Epub 2015 Jul 10. PMID: 26274224.

Merton, R.K., 1973. The Sociology of Science: Theoretical and Empirical Investigations. University of Chicago press.

Migliaccio, R., Tanguy, D., Bouzigues, A., Sezer, I., Dubois, B., Le Ber, I., et al., 2020. Cognitive and behavioural inhibition deficits in neurodegenerative dementias. Cortex 131, 265–283.

Moore-Shay, E.S., Lutz, R.J., 1988. Intergenerational Influences in the Formation of Consumer Attitudes and Beliefs about the Marketplace: Mothers and Daughters. ACR North Am, Adv.

Morel, K.P.N., Pruyn, A.T.H., 2003. Consumer Skepticism toward New Products. ACR Eur, Adv.

Murray, J.D., 2002. Mathematical Biology: I. An Introduction. Springer.

Mussweiler, T., Strack, F., 1999. Hypothesis-consistent testing and semantic priming in the anchoring paradigm: a selective accessibility model. J. Exp. Soc. Psychol. 35, 136–164.

Narasimhan, C., 1989. Incorporating consumer price expectations in diffusion models. Mark. Sci. 8, 343–357.

Nickerson, R.S., 1998. Confirmation bias: a ubiquitous phenomenon in many guises. Rev. Gen. Psychol. 2, 175–220.

Obermiller, C., Spangenberg, E.R., 2000. On the origin and distinctness of skepticism toward advertising. Mark. Lett. 11, 311–322. https://doi.org/10.1023/A:1008181028040.

Obermiller, C., Spangenberg, E., MacLachlan, D.L., 2005. Ad skepticism: the consequences of disbelief. J. Advert. 34, 7–17.

de Pechpeyrou, P., Odou, P., 2012. Consumer Skepticism and Promotion Effectiveness. Rech. Appl. en Mark. (English Ed. 27, 45–69. https://doi.org/10.1177/205157071202700203.

Peres, R., Muller, E., Mahajan, V., 2010. Innovation diffusion and new product growth models: a critical review and research directions. Int. J. Res. Mark. 27, 91–106. https://doi.org/10.1016/j.ijresmar.2009.12.012.

Peterson, R.A., Mahajan, V., 1978. Multi-Product growth models. Research in Marketing: An Annual Compilation of Research 201–231.

Ratcliff, R., Doshi, K., 2012. Using the Bass model to analyze the diffusion of innovations at the base of the pyramid. Bus. Soc. 55 https://doi.org/10.1177/0007650313479529.

Raziq, M.M., Ahmed, Q.M., Ahmad, M., Yusaf, S., Sajjad, A., Waheed, S., 2018. Advertising skepticism, need for cognition and consumers' attitudes. Mark. Intell. Plan. 36, 678–693. https://doi.org/10.1108/MIP-11-2017-0273.

Rogers, E.M., Singhal, A., Quinlan, M.M., 2014. Diffusion of innovations, in: An Integrated Approach to Communication Theory and Research. Routledge, pp. 432–448.

Rubinow, S.I., 1975. Introduction to Mathematical Biology. Wiley.

Salanova, M., 2003. Trabajando con tecnologías y afrontando el tecnoestrés: el rol de las creencias de eficacia. Rev. Psicol. Trab. Organ. 19, 225–246.

Salanova, M., Llorens, S., Cifre, E., 2013. The dark side of technologies: technostress among users of information and communication technologies. Int. Jour. of Psych. 48 (3), 422–436.

Sharif, M.N., Ramanathan, K., 1981. Binomial innovation diffusion models with dynamic potential adopter population. Technol. Forecast. Soc. Change 20, 63–87.

Shubik, M., 1971. The dollar auction game: a paradox in noncooperative behavior and escalation. J. Confl. Resolut. 15, 109–111.

Sidorov, S., Faizliev, A., Balash, V., Balash, O., Krylova, M., Fomenko, A., 2021. Extended innovation diffusion models and their empirical performance on real propagation data. J. Mark. Anal. 9, 99–110.

Soh, H., et al., 2009. Measuring Trust in Advertising: development and validation of the ADTRUST scale. J. Advert. 38, 3–103.

Storr, W., 2020. The Science of Storytelling: Why Stories Make us Human and how to Tell them Better. Abrams.

Strack, F., Mussweiler, T., 1997. Explaining the enigmatic anchoring effect: mechanisms of selective accessibility. J. Pers. Soc. Psychol. 73, 437.

Testa, F., Pretner, G., Iovino, R., Bianchi, G., Tessitore, S., Iraldo, F., 2021. Drivers to green consumption: a systematic review. Environ. Dev. Sustain. 23, 4826–4880.

Trieste, L., Geisler, E., Turchetti, G., 2022. Columbus' egg and the engineer's effect in forecasting solutions adoption. Technol. Forecast. Soc. Change 183, 121892. https://doi.org/10.1016/j.techfore.2022.121892.

Tsallis, C., 2022. Enthusiasm and skepticism: two pillars of science-a nonextensive statistics case. Physics (College. Park. Md). 4, 609–632. https://doi.org/10.3390/physics4020041.

Tversky, A., Kahneman, D., 1974. Judgment under uncertainty: heuristics and biases: biases in judgments reveal some heuristics of thinking under uncertainty. Science 80-.). 185, 1124–1131.

Vanhamme, J., Grobben, B., 2009. "Too good to be true!". The effectiveness of CSR history in countering negative publicity. J. Bus. Ethics 85, 273–283.

Watzlawick, P., Weakland, J.H., Fisch, R., 2011. Change: Principles of Problem Formation and Problem Resolution. WW Norton & Company.

Webber, M.J., et al., 1972. Impact of Uncertainty on Location. Australian National University Press.

Yamagishi, T., Yamagishi, M., 1994. Trust and commitment in the United States and Japan. Motiv. Emot. 18, 9–66.

Yap, Y.-Y., Tan, S.-H., Choon, S.-W., 2022. Elderly's intention to use technologies: a systematic literature review. Heliyon 8, e08765. https://doi.org/10.1016/j.heliyon.2022.e08765.

Yin, C.-Y., Du, F., Chen, Y., 2020. Types of green practices, hotel price image and consumers' attitudes in China: the mediating role of consumer skepticism. J. Hosp. Mark. Manag. 29, 329–357. https://doi.org/10.1080/19368623.2019.1640162.

Yu, Y., Wang, W., 2006. Global stability of an innovation diffusion model for n products. Appl. Math Lett. 19 (11), 1198–1201.

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