National culture and attitudes' impact on diffusion of sustainable new technology-based products

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Abstract

Purpose – Sustainability is increasingly becoming an essential aspect of technological innovations. In addition, the diffusion of sustainable new technology-based products appears to be uneven across the globe. The authors examine the effect of three country-level Hofstede measures of culture and two national-level innovation characteristics on the diffusion of Sustainable New Technology-based Products (SNTP).

Design/methodology/approach – Regression and Necessary Conditions Analysis were used to analyze a panel dataset of electric and hybrid vehicles sales from 2008 to 2017 across 89 countries.

Findings – Results suggest Long-Term Orientation (LTO) was correlated with SNTP diffusion, Indulgence (IVR) was partially correlated with SNTP diffusion and was also a necessary condition. Surprisingly, Uncertainty Avoidance (UAI) was not correlated with SNTP diffusion. In addition, a national proclivity for developing innovations and a history of utilizing prior generic innovations were both correlated and necessary for SNTP diffusion.

Originality/value – This paper measures the impact of several macro-level variables (culture and other innovation related characteristics of countries) on SNTP diffusion. In addition to regression analyses to measure the average effect size, the authors conduct Necessary Conditions Analysis, which assesses the necessity of a variable for the outcome. These insights may help multinational companies better strategize entry decisions for international markets and aid governments in formulating more effective policies by recognizing and accommodating the influences of national culture and innovation attitudes.

Keywords Technology diffusion, Hofstede measures, Innovation, Sustainability

Paper type Research paper

1. Introduction

Innovation has been studied in considerable depth and breadth for the past century or more. Schumpeter defined innovation as new combinations of new or existing knowledge, resources, equipment and other factors (Schumpeter, 1934). Factors that could impact the development of innovations have been studied at the macro level (nation, region level) (e.g. Parwez and Chandra Shekar, 2019), meso level (firm) (e.g. Chatterjee *et al.*, 2002; Lin and Lin, 2008) and micro level (e.g. Mueller *et al.*, 2013; Storey *et al.*, 2016). Similarly, studies assessing the impact of innovations abound (e.g. Ahmed *et al.*, 2018; Maslennikov, 2017; Rosenbusch *et al.*, 2011; Rubera and Kirca, 2012). However, the diffusion of innovations and innovative products is a topic that appears to have fallen in and out of favor over time. Comprehensive cross-national studies of diffusion of innovative products are relatively scarce (for exceptions, see Camerani *et al.*, 2016; Gong, 2009).

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Diffusion studies have been conducted since the 19th century (Kinnunen, 1996). In the US, the study of the adoption of hybrid corn by Ryan and Gross (1943) became a milestone of diffusion research, and Rogers' (2010) work, first published in 1962, is considered a seminal work in the field. In the recent past, studies from marketing and information technology disciplines have analyzed the diffusion of technologies across borders (e.g. Dwyer *et al.*, 2005; Erumban and De Jong, 2006). With regard to international trade, technology diffusion can be a source of significant economic growth, especially for less developed countries (Shikher, 2014). Camerani *et al.* (2016) tested several alternative models of diffusion and called for more comprehensive approaches to the study of diffusion. While past studies have explored the diffusion of technology-based product innovations, usually in similar geographies or regions, we do not fully understand the variables pertinent to the diffusion of *sustainable* new technology-based products and if these variables apply *globally*.

This study focuses on the diffusion of sustainable new products based on innovative technology rather than the diffusion of new process technologies (Camerani *et al.*, 2016). The study expands past diffusion of technology research on multiple fronts. First, most past diffusion studies are generally limited in scope by focusing on one region or similar economies or similar divisions (e.g. Bailard, 2009; Waarts and Van Everdingen, 2005). The limited scope of prior studies may be due to reasons such as a lack of access to global data, an expectation that results could differ across the globe due to a variety of factors not included in the study (e.g. political, socio-economic and culture), and a paucity of globally available innovative products to study. This study plans to further the conversation using a near-global dataset (89 countries). The expected variability across countries helps the authors investigate a "global" technology diffusion curve, thus addressing a pertinent gap in the diffusion literature. Second, with the world moving towards sustainable and green technologies, it is vital to check whether past findings regarding the diffusion of new products (Dwyer *et al.*, 2005) or generic technologies such as the Internet or cell phones (e.g. Andrés *et al.*, 2010; Bailard, 2009; Wunnava and Leiter, 2009) apply to the diffusion of Sustainable New Technology-based Products (SNTP). The current paper utilizes sales data for electric and hybrid vehicles, technologies considered to be sustainable new technologies, hence widening the scope of technologies studied. Third, we specifically focus on the global impact of pertinent cultural characteristics on SNTP diffusion. In addition to several of Hofstede's measures, this study incorporates two additional national characteristics, Innovation Creation Attitude (ICA), or the propensity for a society to create innovations, and Historical Innovation Diffusion (HID), or the past predilection of a society towards acceptance of generic technologies, to assess their effect on the diffusion of SNTP. Including these new variables furthers our understanding of factors that can impact SNTP diffusion. Finally, the paper incorporates Necessary Conditions Analysis (Dul, 2016), an approach that allows us to ascertain whether the factors are necessary for diffusion. While regression analyses provide us with the average effect of variables, necessary condition analysis (NCA) identifies whether the absence of certain conditions could act as bottlenecks for diffusion.

An investigation along the lines suggested in the paper is warranted since it will help policymakers identify factors correlated with SNTP diffusion. As concerns regarding the planet are taking center stage, this study is a timely contribution to understanding the factors affecting the global diffusion of new sustainable technology-based products. The study should also be helpful to firms in planning international market entry and value capture strategies.

National culture is a set of shared beliefs, attitudes, norms, roles, and values expressed within a society (Triandis, 1995, p. 6). It affects the intentions and actions of people (Rutishauser and Sender, 2019). Research shows that culture has many avenues of affecting business. For example, national culture has consequences for international acquisition performance (Rottig and Reus, 2018) and influences the sustainability beliefs and perceptions of organizations, which in turn affects the quantity and scope of their sustainability initiatives (Tata and Prasad, 2015). Research suggests that some cultures are more receptive to various technologies such as Internet retailing (Gong, 2009).

Regarding entrepreneurship, measures of culture, such as high power distance, have shown a negative association with opportunity evaluation. In contrast, uncertainty avoidance (UAI), collectivism and femininity showed evidence of being positively associated with opportunity evaluation (Goktan *et al.*, 2017). Finally, culture affects national rates of invention (Habib and Coombs, 2001) and trust formation regarding brands and brand loyalty (Hur *et al.*, 2015). Knowledge of local culture can help multi-national corporations better manage their organizations (Romani *et al.*, 2018; Valitova and Besson, 2018) and brand managers to develop and implement strategies to minimize the chances of erroneous decision-making when entering new markets (Banerjee, 2008).

No matter how wonderful, innovations are not beneficial for society unless used. Culture affects the understandings and collective actions of groups of people. Thus, as in Kaasa and Vadi (2010), we argue that culture is appropriate for investigating how human factors influence innovation. Since people's beliefs and resultant actions can contribute to or block the adoption of new technologies, this study seeks to understand the effect of culture on the diffusion of SNTP. Specifically, this research examines the relationships between several national level cultural dimensions and the resultant SNTP diffusion.

Empirically studying the diffusion of SNTP across countries presents a few challenges. Detailed data must be collected on dependent, independent and control variables for multiple national markets. As discussed earlier, past studies have analyzed the diffusion of the Internet, cell phones and consumer durables, amongst other items. However, since the current paper focuses on the diffusion of SNTP, data on older or non-sustainable technology-based products would not suffice. Thus, a sustainable technology context needed to be identified, and global data collected in that context. The current study utilizes electric vehicle (EV) technology as the context for the analyses. Internal combustion engines (ICE) have been a staple for motored transportation on land for more than a century. Although electric vehicles got an early start around the late 1820s (Guarnieri, 2012), they were vanquished by ICE, which became the industry standard (Loeb, 2004). Electric vehicles were thus relegated to the sidelines of transportation. However, they made a comeback in 1996 (Quiroga, 2009) with the advent of hybrid vehicles (Eberle and Von Helmolt, 2010), followed by battery electric vehicles in 2008, and plug-in vehicles around 2010.

A global industry is one "in which a firm's competitive position in one country is significantly influenced by its position in other countries" (Porter, 1986, p. 12). The auto industry and its electric propulsion technologies are global in scope since the research and development (R&D), manufacturing, supply chain and other activities are spread throughout the globe and serve multiple markets with semi-standardized products. As such electric vehicles can be considered a "global emerging technology". Furthermore, they are sustainable and vastly different from the ICE, hence a viable context for the study.

A 10-year panel of electric car sales data was compiled for analysis. The sales covered 89 nations, representing almost all-known electric autos sales worldwide. Country-level variables were collected from various sources such as the United Nations and World Bank. The rich dataset allowed for the testing of multiple hypotheses and assessment of the necessary conditions.

Regarding the Hofstede's measures, in congruence with past findings of innovation diffusion, Long-Term Orientation (LTO) is positively correlated with the diffusion of SNTP (e.g. Andrijauskienė and Dumčiuvienė, 2017; Dwyer *et al.*, 2005). However, contrary to most past studies, which found a negative relation between UAI and innovation development (e.g. Kaasa and Vadi, 2010; Waarts and Van Everdingen, 2005), we found no such effect. However, we note that innovation development, not diffusion, was the focus of these prior studies. The above-mentioned result is surprising since one would assume that uncertainty would dampen diffusion. Finally, Indulgence (IVR) was partially correlated with sustainable technology diffusion (two of three models in regression). In addition, the ICA of a nation was positively correlated to the diffusion of SNTP, and HID was positively correlated with SNTP diffusion in two of three regression models. Finally, IVR, ICA and HID were necessary conditions for SNTP diffusion.

In section 2, we review the literature and develop the hypotheses. Section 3 discusses the methods, including the data and variables. Section 4 presents the results, while section 5 discusses the implications of the research.

2. Literature review and theory

This study focuses on understanding how culture and related dimensions of society affect the diffusion of SNTP. Specifically, we examine the relationship between the diffusion of SNTP and three Hofstede's cultural dimensions, as well as a society's ability to develop innovations and its proclivity to use innovations in their daily lives. In this paper, diffusion refers to the spread of a new product among the members of a society over time (Camerani *et al.*, 2016). Conversely, innovation adoption by a country is a related yet separate idea. Rogers (2010) posits that adoption is the decision by an organization or group to use an innovation. This idea can be extrapolated to a country as well. To differentiate from diffusion, we define adoption as the decision by a country to use an innovative product (for the first time). Adoption is a binary concept; either the country has adopted the innovative product or not, whereas diffusion measures the proportion of people using an innovative product over time.

Product and technology diffusion has been studied across multiple fields. Ryan and Gross (1950) studied the diffusion of hybrid corn. Rogers' (1962) seminal work developed a model to explain diffusion in the social sciences. Later, Bass (1969) developed a model for assessing product diffusion (widely used in marketing studies). Research has identified multiple macro variables that correlate with product diffusion across countries. Examples include international trade and urbanization (Talukdar *et al.*, 2002), and the isolated nature of economies (Dekimpe *et al.*, 2000). Chinn and Fairlie (2007) and Corrales and Westhoff (2006) found a positive relationship between income per capita, trade openness and years of education, with Internet and computer diffusion. While most past diffusion studies focused on one region or market, some studies focus on cross-border or international diffusion. For example, Frimpong *et al.* (2020) studied mobile-banking adoption across UK and Ghana and found that intrinsic traits of consumers have a more significant impact on adoption in Ghana than in the UK. Similarly, Dwyer *et al.* (2005) and Van den Bulte (2000) found that Hofstede's measures were correlated with technology diffusion in 13 European countries.

Hofstede (2001, p. 9) suggests culture as "the collective programming of the mind which distinguishes the members of one group or category of people from another." To operationalize culture as a variable, Hofstede developed six quantitative dimensions to compare cultures – LTO, UAI, IVR, Power Distance (PDI), Individualism (IDV), and Masculinity (MAS). In this study, we study the first three measures – LTO, UAI and IVR since, as discussed in the following sections, these attributes could be correlated with the diffusion of SNTP. Hofstede's measures encapsulate the differences in cultures across nations along the dimensions mentioned above. These dimensions have been aggregated at the national level (Hofstede Insights, 2020) and provide an index (ratings from 1 to 100) for each dimension (Hofstede, 2001). This indexed nature of the dimensions lends itself to use in quantitative models such as regression analyses. Even though there are criticisms of Hofstede's cultural dimensions approach (McSweeney, 2002), it is generally accepted in disciplines such as international business and marketing (Nakata and Sivakumar, 2001).

While the specific cultural dimensions defined by Hofstede (2001) are pertinent, we analyze other relevant characteristics of a society regarding their impact on SNTP.

A society's ability to innovate could be crucial in SNTP since the population could be adept with new technologies, leading to higher levels of comfort and diffusion. Finally, analyzing a society's historical attitude towards the diffusion of new technology should help us better understand and predict the diffusion patterns of SNTP in a nation.

In the following sections, we develop testable hypotheses for each of the characteristics discussed above.

2.1 Long-Term Orientation (LTO) and sustainable new technology diffusion

This dimension reflects a society's predilection to maintain links with the past while facing present and future challenges. Societies with high levels of LTO focus on modern education, are thrifty and efficient with resource use, and view adaptation and pragmatic problem-solving as necessary. Short-term-oriented societies respect tradition, believe in the reciprocation of gifts, and prefer personal stability and steadiness (Hofstede, 2001; Rinne *et al.*, 2012). Short-term-oriented societies expect quick results, whereas long-term oriented societies progress steadily towards a goal.

SNTP usually requires a long-term approach for adoption and diffusion. Examples include solar technologies (Mirzahosseini and Taheri, 2012; Sedghisigarchi, 2009). These technologies often take an extended period to become economically viable. Governments may need to espouse and endorse such technologies, and the nation's society must persevere over sometimes decades for the technology to take root and mature. The outlook towards sustainable technology diffusion is very different from the diffusion of consumer-oriented new products or technologies. In the latter, consumers want instant gratification. They are often driven by materialism, and as such, these new products will diffuse much faster in a short-term-oriented society (Dwyer *et al.*, 2005). In contrast, comparatively, SNTP diffusion should fare better in long-term oriented societies.

As mentioned earlier, long-term oriented societies are focused on modern education. Modern education is usually scientifically oriented (Millar, 1994) and receptive to new approaches. Individuals trained in the scientific approach are more willing to change habits and approaches when convinced using research and data. This notion is supported by Cette and Lopez (2012), who found that higher levels of education led to increased diffusion of information and communication technologies. On the other hand, short-term-oriented cultures may hold onto tradition and the *old ways* even when faced with logic and facts that point towards adopting different habits and approaches. Modern education should equip society to appreciate the linkages between nature and humans. Sometimes, sustainable technologies may require more effort to adopt (e.g. sorting trash for recycling or understanding the differences between an ICE and an electric motor). Modern education would provide individuals with the tools to understand, appreciate and use sustainable technologies.

Finally, long-term oriented societies are thrifty with resources. It does not matter whether a resource is abundantly available in their country or is easily accessible to them through suppliers outside the country. A long-term oriented society believes in using resources wisely so that they can last longer. Such cultures will take a structured, well-planned and methodical approach to solve problems (Prim *et al.*, 2017). One of the most significant issues facing countries worldwide is natural resource conservation and the protection of the environment. As discussed earlier, sustainable technologies generally require a long temporal runway, thus lending themselves to long-term oriented societies being relatively more predisposed to widely accepting and using them. Hence, contrary to past studies (e.g. Dwyer *et al.*, 2005) that find LTO is detrimental to new product diffusion, we argue that LTO should benefit the diffusion of sustainable new technologies.

The arguments above lead to the following hypothesis:

H1. Ceteris paribus, a country's level of LTO will be positively correlated with the diffusion of SNTP in the country.

2.2 Uncertainty Avoidance (UAI) and sustainable new technology diffusion

The UAI dimension of culture expresses the degree to which a society is uncomfortable or feels threatened by unfamiliar or ambiguous situations (Hofstede, 2001). Societies that score high on this dimension eschew uncertainty and are anxious towards ambiguous situations. Conversely, cultures scoring low on this dimension espouse variety in life and are more tolerant towards new and unknown ideas, people, and situations (Hofstede *et al.*, 2010, p. 188).

Tellefsen and Takada (1999) find that high UAI cultures view new products suspiciously and are slow to adopt them. Krishnan and Lymm (2016) report that UAI negatively moderates the diffusion of virtual social networks. Likewise, Tellis *et al.* (2003) found that new products diffuse faster in cultures with low UAI. According to Rogers (2010), an important reason for the diffusion of new products is *relative advantage* – the degree to which an innovation is seen as better than the extant product or service it replaces. It takes time to assess and validate the various advantages and disadvantages of an innovation; thus, high UAI cultures may view innovations with suspicion and pessimism. However, low UAI societies may view the same innovation as an opportunity to explore and be curious (Hofstede, 2001).

Dominant design is another aspect of innovations that may dissuade SNTP diffusion in high UAI cultures. A dominant design signifies the emergence of a dominant technology in an industry (Suarez, 2004; Utterback and Abernathy, 1975). Potential customers may wait for a dominant design to emerge before purchasing a product (Utterback, 1994). It alleviates the customer's concerns regarding follow-up services such as maintenance and availability of spare parts for the new product. The emergence of a dominant design will also motivate suppliers and vendors to get behind the product, leading to benefits such as the ubiquity of service and a secondhand sales market. High UAI societies may wait for a dominant design to emerge before purchasing new technologies. Hence, low UAI societies may possess a higher propensity to embrace a non-dominant design technology. They may view this as an opportunity to experience the various new designs.

Finally, characteristics of a technology may further lead to ambiguity and caution amongst potential customers. For example, when using electric vehicle technology, it may be hard to predict the actual miles an automobile may travel since inaccuracies may creep up in predicting potential travel range as the battery discharges. Similarly, electric charge stations are not as common as gas stations, thus leading to concerns of range anxiety – a worry that the battery may run out before reaching a charging point or the destination. These uncertainties should further reduce the rate of diffusion of innovations in high UAI societies.

The above arguments lead to the hypothesis:

H2. Ceteris paribus, a country's level of UAI will be negatively correlated with the diffusion of SNTP in the country.

2.3 Indulgence (IVR) and sustainable new technology diffusion

IVR measures the degree to which individuals in a culture control their human desires and urges for gratification related to enjoying life. Hofstede *et al.* (2010) added this dimension in 2010. Members of an indulgent society believe in enjoying life, while a less indulgent society tends to limit such enjoyment through strict social norms (Hofstede, 2010). Prim *et al.* (2017) argue that indulgent organizations are more open to trying out new ideas and experimenting, thus leading to higher levels of innovation. Openness to experience is correlated with creativity in organizations (George and Zhou, 2001). We argue that a similar logic should apply to the diffusion of SNTP in societies. Individuals of indulgent societies should have a higher predisposition to experiment with new technologies.

Khan and Cox (2017) argue that highly indulgent societies are generally optimistic, whereas low indulgent societies are more pessimistic and cynical. Optimistic individuals may be more amenable to trying new technologies since they might have faith in the technology's efficacy. On the other hand, pessimistic and cynical individuals may worry that their investments may not work out, avoid new technologies at their inception, and generally take a more cautious approach of waiting until a technology is proven.

As demonstrated by the growth of ecotourism, which is growing at almost three times the rate of general tourism (Hultman *et al.*, 2015), the world's population is getting progressively more eco-friendly. Populations enjoy immersing themselves in nature and outdoor activities such as hiking and camping. People also understand that clean natural resources such as water, air and Earth will help lead to a better quality of life. More indulgent societies, which are simultaneously eco-friendly, should have a higher interest in sustainable innovations that could help them enjoy nature as well as healthy and longer lives.

The above arguments lead to the following hypothesis:

H3. *Ceteris paribus,* a country's level of IVR will be positively correlated with the diffusion of SNTP in the country.

2.4 Innovation Creation Attitude (ICA) of a country and sustainable new technology diffusion

Innovative nations usually possess higher levels of absorptive capacity. Cohen and Levinthal (1990) describe absorptive capacity as a firm's ability to understand new and external information and apply it to commercial ends. Studies have found that levels of innovation and absorptive capability are correlated in firms (Fosfuri and Tribó, 2008; Ritala and Hurmelinna-Laukkanen, 2013; Van Den Bosch *et al.*, 1999). This study proposes that the theory of absorptive capacity can be applied at the national level (e.g. Huebler and Lontzek, 2012). More innovative nations should also possess higher levels of absorptive capacity. These higher levels of absorptive capacity of a nation should allow it to be more comfortable with new technologies. The populations of these nations should be better able to understand and assess new technologies. Lin *et al.* (2004) report that absorptive capacity helps transfer technology within firms. By extension, a nation with higher levels of absorptive capacity should assimilate and utilize new technologies relatively quickly.

A high rate of innovation in a culture also reduces the population's anxiety towards new technologies and products since they are used to experimenting with new products and innovations given their innovative culture. In addition, countries with innovative cultures should have business models, communication channels and other auxiliary services in place for an innovative technology or product to be marketed and sold in the country. This availability of an ecosystem, which can support innovation, should make a nation receptive to and propagate new technologies.

The above arguments lead to the following hypothesis:

H4. *Ceteris paribus,* a country's level of ICA will be positively correlated with the diffusion of SNTP in the country.

2.5 Historical Innovation Diffusion (HID) of a country and sustainable new technology diffusion

The historical attitude of the population towards the diffusion of generic innovations should be a good predictor of the diffusion of SNTPs in a country. The technology acceptance model (TAM), developed by Davis (1985), has been used to predict and evaluate the adoption of new technological tools. The TAM model proposes a sequence of causal relationships among what individuals believe about using a system and its actual use. Fundamentally, users' beliefs influence the attitude, which in turn modifies the intention to use a particular technology. The intention is the primary determinant of actual use. The main components of TAM are perceived usefulness and perceived ease of use. The TAM theory's validity has been confirmed in sectors such as wearable technologies (Chuah *et al.*, 2016), among others. In other words, if members of society believe that technology is useful and is easy to use, their intention to use the technology increases.

Based on an extrapolation of TAM theory, it could be expected that as the population of a country utilizes major innovations such as the Internet, their perceptions of new technology, in general, should lean toward believing these technologies are both useful and easy to use, thus leading to an increased intention to use new technologies. Hence, the propensity of a country's population to utilize innovations could correlate with innovation diffusion of new technologies.

A population that is amenable to trying innovations would be better positioned than a *non-trier* population to understand the benefits of innovation. It is akin to someone owning automobiles. A person who has owned various kinds of automobiles in the past will be better able to appreciate and learn about the features and benefits of a new automobile that comes to market. This built-up absorptive capacity regarding automobiles will then lead to maximizing the utilization of new features by the person. Similarly, suppose the population of a country is used to trying innovations. In that case, they will be able to extract the benefits of the innovation–increasing the quality of service or reducing costs, or both. Such populations, which have a high HID, should also adopt SNTPs faster.

The above arguments lead to the following hypothesis:

H5. *Ceteris paribus,* a country's level of HID will be positively correlated with the diffusion of SNTP in the country.

2.6 Necessary conditions for sustainable new technology diffusion

Most empirical analyses such as regression assess the average effect or correlation of a variable to the outcome. A relatively new approach has been developed (Dul, 2016), which analyzes whether a condition is necessary for an outcome. It could be the case that a variable has a small correlation with the outcome (sufficient condition), but without it, the outcome is not possible (necessary condition). Conversely, a variable may demonstrate a sizable effect via correlation but not be a necessary factor, meaning that its effect can be replaced by substituting one or more other variables. The NCA approach is discussed in the methodology section, and the arguments for hypotheses are presented in this section.

While we expect regression analyses to show a significant effect size for one or more of the Hofstede's measures (LTO, UAI and IVR), these analyses will not inform as to their necessity. For example, what if the effects of UAI can be substituted with more marketing and high levels of trialability (the ease with which a customer can try a product or service)? According to West (2020), social pressures can affect the speed of innovation adoption in rural areas. These countermeasures might blunt a country's high levels of UAI and build trust regarding the product. Similarly, governments can provide incentives to persuade people to use a new technology even when such technologies need a long-term approach for payback (Guo *et al.*, 2017). Thus, this paper investigates whether the Hofstede's measures are necessary for SNTP diffusion. It should be noted that hypotheses 1 to 3 are for sufficiency and the necessary analysis is exploratory.

These arguments lead to the following exploratory hypothesis:

H6a. One or more of the Hofstede's measures – LTO, IVR and UAI – will be sufficient but not necessary for SNTP diffusion.

The innovativeness of a country's populace (ICA) and their predilection for trying innovations (HID) should be necessary conditions for the diffusion of SNTP. These two characteristics would be difficult to replace or be substituted for by other variables. Suppose a country is not innovative or its population is not inclined towards trying out new technologies. In that case, there are not many approaches short of government regulations that could lead to the widespread diffusion of new technology. When new technologies are not tried, people do not become familiar with them and may not understand the potential benefits, thus leading to a lower diffusion rate.

These arguments lead to the following exploratory hypothesis:

H6b. One or both of ICA and HID will be necessary for SNTP diffusion.

3. Methods

3.1 Data

Electric cars have generally been categorized as hybrid electric vehicles (HEVs), plugin hybrid electric vehicles (PHEVs) and fully battery-operated electric vehicles (Bev). As per AFDC (2020a), ICE is the prime propulsion provider in HEV, whereas the electric motor provides extra power when needed, such as when driving up an incline. While outside sources cannot charge an HEV battery, a PHEV battery is charged using plugin chargers. The PHEVs derive their propulsion primarily from the electric motor, and the ICE acts as a backup for extra power requirements (AFDC, 2020b). The BEVs rely on an electric motor as they do not have an ICE (AFDC, 2020c). As with PHEVs, the battery of the BEVs can be charged using plugin chargers. The PHEV and Bev technologies are much closer to each other than the HEV technology since the electric motor is the prime mover, whereas, in the latter, the ICE is the prime mover. Hence, as in past studies (Silvia and Krause, 2016; Rezvani *et al.*, 2015), the HEVs are treated as one group and the PHEVs and BEVs have been combined into another group referred to as plug-in electric vehicles (PEV).

A panel dataset of the sales of electric cars from 2008 to 2017 was developed for 89 countries. A few countries had sales only in one of the categories – HEVs or PEVs. A total of 1,710 rows of country-year sales data have been recorded in the dataset. The sales data were provided by EV-Volumes, a website focusing on data regarding electric vehicles. The website has provided data to sources such as the Wall Street Journal in the past (Foldy, 2020; Wilmot, 2019). Data about the cultural dimensions of a nation were collected from Hofstede's website. Data for other variables were collected from sources such as the United Nations, World Intellectual Property Organization and World Bank websites. While every effort was made to collect independent and control variables data for all years of the panel, it was not possible to obtain data for all years. Data from the closest preceding or succeeding years were used in such situations. Furthermore, all Hofstede's measures were collected for the year 2019. Given that the data are at the national level, it has been assumed that national-level characteristics such as cultural dimensions do not change significantly over a decade, thus justifying the abovementioned approach.

3.2 Statistical methods

Pooled ordinary least squares was used to analyze the data. Panel data analysis methods such as fixed effects or random effects require that the dependent and independent variables vary over time (Wooldridge, 2016). However, the country-level independent and control variables such as population, number of patents, cultural dimensions will not vary significantly in a decade. Hence, the use of panel regression models is not justified.

Data on charging stations were only available for 2015, 2016 and 2017. Hence, three regression models were employed. The first analysis utilized PEVs and HEVs combined (but without the charging station control), while the second model only used HEV data. Both the abovementioned models utilized the entire ten years of data. Finally, the third model used only the PEV data for 2015–2017 and controlled for charging stations.

3.2.1 Necessary Condition Analysis (NCA). NCA as a technique was introduced by Dul (2016). The technique has been utilized in various disciplines such as entrepreneurship (Arenius *et al.*, 2017), strategy (Tho, 2018) and international business (Richter *et al.*, 2020). NCA evaluates whether the absence or presence of a condition is necessary for the outcome. For example, applying to a university is necessary for getting admitted. However, it does not guarantee admission (it is not sufficient). Regression analyses such as ordinary least squares generally tell us about one variable's *average* effect on another, holding all other variables constant. On the other hand, NCA helps us understand whether the absence of a variable would lead to the non-attainment of the result. For example, minimal amounts of salt may be required in food (a small regression point estimate); however, the absence of salt may make some foods bland. NCA helps us understand this relationship.

The NCA is conducted using one independent variable at a time. Furthermore, linear transforms of variables are preferred over non-linear transforms. NCA has parameters – the size effect is like the point estimate of the coefficient in regressions. The *p*-value in NCA has a similar interpretation of significance as in regression analysis.

3.2.2 Dependent variables. Sales per capita of PEVs and HEVs for a country each year, calculated as (sales/population)*1,000,000. Used for NCA.

Log of sales of PEVs or HEVs for a country for a given year. Due to the wide variation of sales across countries, a log transformation was undertaken for sales. Used for regression analyses.

3.2.3 Independent variables. LTO – a Hofstede measure that quantifies the LTO of a society. The scores range from 0 to 100, with low-scoring countries more focused on the short term.

UAI – a Hofstede measure that quantifies the society's attitude towards uncertainty and ambiguity. The scores range from 0 to 100, with countries scoring high on this measure being more intolerant of uncertainty and ambiguity.

IVR – a Hofstede measure that quantifies a society's acceptance of the pursuit of basic and natural human drives. The scores range from 0 to 100, with high-scoring countries being more accepting than low-scoring countries.

ICA – the propensity for a society to create innovations. ICA is operationalized via a count of the number of patents granted in a country each year (*Log of Patent Grants*). Patent data were obtained from the World Intellectual Property Organization database. Due to the wide variation of patent grants across countries, a log transformation was undertaken.

HID – the predilection of society towards the acceptance of generic new technologies. HID is operationalized via the percentage of the population in a society using the Internet *(Internet Use)*. Internet usage data were collected from the World Bank.

3.2.4 Control variables. As per past studies, the control variables included the country's population, GDP (from World Bank) and the index of economic freedom (from The Heritage Foundation) (Ford *et al.*, 1998; Li *et al.*, 2017; Lin and Wu, 2018). Due to the wide variation of population and GDP across countries, a log transformation was undertaken for both variables. A dummy control variable for technology was included to differentiate between HEVs and PEVs (HEV dummy is 0, PEV dummy is 1). A log of charger stations in a country and year effects were also controlled in regressions.

4. Results

Table 1 presents the summary statistics. Nations are generally high on UAI, with a mean score of 67.68 and a standard deviation of 21.09. However, the LTO and IVR scores are closer to the middle. The mean score for LTO is 48.72 with a standard deviation of 22.79, while the

	N	Mean	SD	Min	Max
Log Sales	1,710	3.00	3.70	0.00	13.91
Sales Per Capita	1,660	162.41	726.10	0.00	11981.88
LTO	1,340	48.72	22.79	7.00	100.00
UAI	1,450	67.68	21.09	8.00	100.00
IVR	1,300	44.88	21.04	0.00	99.00
ICA (Log Patent Grants)	1,520	6.60	2.36	1.39	12.95
HID (Internet Use)	1,630	60.42	24.25	1.12	100.00
Economic Freedom	1,640	66.74	8.77	43.20	89.80
Log Population	1,660	16.36	1.88	10.46	21.05
Log GDP Per Capita	1,650	9.62	1.01	6.68	11.85
Technology Dummy	1,710	0.50	0.50	0.00	1.00
Log Number of Chrg Stns	513	3.02	3.19	0.00	11.69

Table 1.
Summary statistics

mean score for IVR is 44.88 with a standard deviation of 21.04. Regarding annual patent data (ICA /Log Patent Grants), close to 735 patents are issued by a country on average every year (e^6.6). The average level of HID of new technology represented by worldwide Internet Use is a robust 60.42%. Of note is the volatility of Sales Per Capita with a mean of 162.41 and a standard deviation of 726.1.

Table 2 shows the correlation table. A significant correlation can be observed between the dependent variable (Log sales) and the independent variables. Some of the control and independent variables are also correlated. Hence the variables of interest were checked for signs of multicollinearity. The variable inflation factor (VIF) for each item was under 4, indicating multicollinearity is not a major concern and is reported with the regressions (see Table 3).

The regression results are presented in Table 3. Models 1–1, 1–2 and 1–3 show the regression results with only the controls included. The dependent variable is Log sales of electric cars. The first model (1–1) includes data for HEVs and PEVs, while model 1–2 only evaluates data for HEVs. Both 1–1 and 1–2 utilize data for ten years (2008–2017). These models do not include charger density as a control (since this is a valid control primarily for PEVs). Model 1–3 utilizes data for only the PEVs, is limited to 2015–2017, and incorporates the charger density control variable. The regressions show that control variables impact the diffusion of electric vehicles as expected. The population of a country and its GDP should be important factors correlated with the increased diffusion of electric vehicles. All models control for year effects, and charger density significantly impacts PEV sales, as expected. Finally, the technology dummy has a negative coefficient indicating that sales of HEVs are higher than sales of PEVs, which makes logical sense since HEVs are relatively older technology and hence more established.

H4 and H5 hypothesize that ICA and HID will be positively correlated with SNTP diffusion. Models 2–1, 2–2 and 2–3 introduce these two independent variables; patent grants by a country (representing ICA) and Internet use (representing HID). Patent grants are significant across all three models; hence, we find support for H4. Internet use is significant for the models with the combined HEV and PEV data and the HEV only data (2–1 and 2–2), and insignificant yet has a positive coefficient for PEV only data. Similar results are observed when all variables are incorporated in Models 3–1, 3–2 and 3–3. These results support H5 since we find historical adoption attitudes matter for the diffusion of SNTP. As mentioned earlier, it may be noted that models for PEVs (1–3, 2–3, and 3–3) only utilize data for three years. The insignificance of the PEV model's effect for Internet use in 3–3 could genuinely be a null effect, or it could be due to a paucity of data since only three years' worth of data were available. As can be observed, the standard error for the coefficient has almost doubled when

Table 2.
Correlation table

	Log Sales	LTO	IVR	UAI	ICA (Log Patent Grants)	HID (Internet Use)	Log Population	Log GDP Per Capita	Techn. Dummy	Econ. Freedom
Log Sales	1									
LTO	0.208***	1								
IVR	0.262***	−0.380***	1							
UAI	−0.157***	0.080**	−0.213***	1						
ICA (Log Patent Grants)	0.448***	0.197***	0.149***	−0.201***	1					
HID (Internet Use)	0.516***	0.214***	0.355***	−0.159***	0.035	1				
Log Population	0.181***	0.0244	−0.114***	−0.079**	0.733***	−0.490***	1			
Log GDP Per Capita	0.0219	0.0738**	0.106***	−0.040	0.077**	0.250***	−0.158***	1		
Technology Dummy	−0.116***	0.019	0.038	−0.032	0.03	0.0477	−0.016	0.030	1	
Economic Freedom	0.294***	0.015	0.497***	−0.302***	0.005	0.668***	−0.436***	0.248***	0.052	1

Note(s): $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$

Table 3. Regression analyses – Log (Sales)

	All: 1–1 Coef/Std Err	HEV: 1–2 Coef/Std Err	PEV: 1–3 Coef/Std Err	All: 2–1 Coef/Std Err	HEV: 2–2 Coef/Std Err	PEV: 2–3 Coef/Std Err	All: 3–1 Coef/Std Err	HEV: 3–2 Coef/Std Err	PEV: 3–3 Coef/Std Err
LTO (Long-term Orientation)							0.020^{**} (0.00)	0.025^{**} (0.01)	0.014^{+} (0.01)
UAI (Uncertainty Avoidance)							0.001 (0.00)	–0.001 (0.01)	0.001 (0.01)
IVR (Indulgence)							0.025^{**} (0.00)	0.033^{**} (0.01)	0.013 (0.01)
ICA (Log Patent Grants)				0.364^{**} (0.06)	0.495^{**} (0.08)	0.261^{*} (0.12)	0.268^{**} (0.07)	0.393^{**} (0.10)	0.291^{*} (0.14)
HID (Internet Use)				0.076^{**} (0.01)	0.075^{**} (0.01)	0.008 (0.01)	0.083^{**} (0.01)	0.068^{**} (0.01)	0.025 (0.02)
Economic Freedom	0.182^{**} (0.01)	0.211^{**} (0.01)	0.051^{**} (0.02)	0.042^{**} (0.01)	0.061^{**} (0.02)	0.016 (0.02)	0.022^{+} (0.01)	0.042^{*} (0.02)	0.006 (0.02)
Log Population	0.924^{**} (0.05)	1.085^{**} (0.07)	1.263^{**} (0.08)	0.621^{**} (0.09)	0.643^{**} (0.13)	0.889^{**} (0.20)	0.733^{**} (0.11)	0.680^{**} (0.16)	0.881^{**} (0.23)
Log GDP Per Capita	0.151^{*} (0.08)	0.297^{*} (0.11)	0.231^{+} (0.12)	-0.173^{*} (0.07)	–0.055 (0.11)	0.209^{+} (0.12)	-0.193^{*} (0.08)	–0.015 (0.12)	0.043 (0.14)
Technology Dummy	-0.819^{**} (0.15)			-0.914^{**} (0.13)			-1.144^{**} (0.14)		
Log Chrgr Density			0.823^{**} (0.04)			0.763^{**} (0.05)			0.680^{**} (0.06)
Year Controls?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Intercept	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# of Obs	1,600	820	234	1,500	760	222	1,240	630	183
Avg. VIF	1.60	1.65	1.30	2.37	2.49	2.91	2.51	2.66	3.18
R-Sq	0.4081	0.4088	0.7290	0.5599	0.5694	0.7306	0.5915	0.5777	0.7544

Note(s): $^{+}p < 0.1$; $^{*}p < 0.05$; $^{**}p < 0.01$

one goes from models 3–1 or 3–2 to 3–3. This observation bolsters the idea that a paucity of data may cause the coefficient's insignificance in model 3–3.

H1, H2 and H3 hypothesize that LTO and IVR will be positively correlated and UAI and negatively correlated with SNTP diffusion. Models 3–1, 3–2 and 3–3 introduce these Hofstede dimensions. LTO is significant; however, it may be noted that for the PEV only model, the significance is at the 10% level (p-value of 6.9%). We argue that LTO should mainly have a neutral or positive effect on diffusion. It is hard to argue that a country that is adaptive and focuses on changing with the times (has a high LTO score) should not be amenable to innovations. Hence, this is a one-tailed test for significance, and as such, has a p-value of 0.0345. Thus, H1 is supported. It was surprising to find that UAI does not impact technology diffusion. In all three models, the point estimates of UAI were close to 0 and were insignificant. Thus, H2 was not supported. Finally, IVR was significant in two out of three models; hence, H3 was partially supported. Note, as with H5 above regarding Internet use, the coefficient of IVR is not significant in model 3–3. However, unlike H5, where we claimed support, we claim H3 is only partially supported since the standard error does not change significantly when comparing models 3–1 or 3–2 with 3–3. Hence, we cannot claim data paucity as the primary reason for the coefficient's insignificance since a null effect cannot be ruled out.

Tables 4 and 5 show the Necessary Condition Analyses. As per Dul (2016, p. 59), the size effect indicates to what extent condition X constrains outcome Y. Further, Dul (2016, p. 61) suggests that size effects of between 0.1 and 0.3 are considered medium, those above 0.5 be considered very large and effects below 0.1 are small. Table 4 shows that IVR, Patent Grants and Internet Use effects are worth investigating. IVR's effect is strong with a size effect of 0.351 (it may be noted that, as discussed in the Methods section, the size effect is akin to a point estimate of a coefficient), and the p-value is 0.017. Similarly, Internet use has a sizeable effect and is highly significant ($p = 0.000$). Finally, patent grants have a small yet significant effect ($p = 0.047$). As discussed earlier, the dependent variable is sales per capita.

Interestingly, we find that IVR is necessary for the diffusion of technology. When the regression result is combined with the NCA result, it leads to the conjecture that the insignificance of IVR in the model 3–3 is most probably a data paucity situation rather than a null effect situation, since generally a variable that is necessary for an outcome, may have an average effect on the outcome as well. Of course, this is a conjecture and needs to be validated with further research.

A bottleneck table (see Table 5) shows the level of an independent variable necessary for a specific level of the dependent variable. For example, to reach 20% of the maximum value of sales per capita, 50.6% of the country's population should be using the Internet. The maximum value of Internet use (per Table 1) is 1, 0.506*1 = 0.506 is needed to reach a level of 20% of the maximum sales per capita. It can be observed from Table 5 that to reach 50% of the maximum per capita sales, the Internet usage of the country should be at a very high level of 93%. The IVR and patent grant effects are much smaller.

Table 4.
Necessary condition analysis – size effects and p-value

	CR-FDH	
	Size effect	p-value
LTO	0.233	0.217
UAI	0.294	0.557
IVR	0.351	0.017
ICA (Patent grants)	0.067	0.047
HID (Internet use)	0.787	0.000

Note(s): CR-FDH, ceiling regression with free disposal hull. Used for continuous variables; Sales per capita is the dependent variable

Sales %	IVR	ICA (Patent grants)	HID (Internet use)
0	8.3	0	22.2
10	13.6	0	36.4
20	19.0	0.6	50.6
30	24.4	2.5	64.8
40	29.7	4.5	79.0
50	35.1	6.4	93.3
60	40.4	8.3	100
70	45.8	10.3	100
80	51.2	12.2	100
90	56.5	14.1	100
100	61.9	16.1	100

Table 5. Necessary condition analysis – bottleneck analysis

H6a hypothesized that one or more of the Hofstede's measures – LTO, IVR and UAI – might be sufficient but not necessary for SNTP diffusion. Based on Tables 4 and 5, only IVR is necessary; thus, H6a is supported.

H6b hypothesized that one or both of ICA and HID would be necessary for SNTP diffusion. Based on Tables 4 and 5, both ICA (Patent Grants) and HID (Internet use) are necessary; thus, H6b is supported. The results have been summarized in Table 6.

5. Discussion and conclusion

The study enhances our understanding of SNTP diffusion across countries. Electric vehicles were used as the context since the technology is relatively new, sustainable and is starting to spread across the globe, thus, providing an opportunity to study the research question. The analyses focused on national-level constructs related to the culture and attitudes of society. Specifically, three Hofstede's measures of cultural dimensions were analyzed: LTO, UAI and IVR. The ICA and predilection towards acceptance of generic technologies (HID) were also assessed. The study of the correlation of these variables with sustainable new technology diffusion advances the conversation on diffusion research. Furthermore, the use of NCA adds new insight to assessing the impact of independent variables on outcomes. NCA allows for assessing whether a variable is necessary for an outcome; in contrast, regression analysis techniques provide the average effect of a variable on the outcome.

The study found that LTO, ICA and HID are significantly correlated with the diffusion of SNTP. The study also found partial support for IVR being correlated with diffusion. While we were surprised, UAI was not correlated with diffusion, recent research by Minkov (2018) found that Hofstede's UAI measure lacks internal reliability, perhaps the source of the

Hypothesis #	Synopsis of hypotheses	Finding
H1	LTO	Supported
H2	UAI	Not supported – surprising
H3	IVR	Partially supported
H4	Innovative output (ICA)	Supported
H5	Innovation adoption attitude (HID)	Supported
H6	Necessary conditions – exploratory analyses	
	H6a: LTO, UAI	Not necessary
	H6a: IVR	Necessary
	H6b: ICA and HID	Necessary

Table 6. Summary of results

problem. Finally, IVR and HID were found to be necessary for technology diffusion with large size effects, whereas ICA was found to be necessary but with a small size effect.

While higher levels of LTO in a country were found to be correlated with the diffusion of new sustainable technologies, the variable was found not to be necessary for diffusion. This result is interesting as it suggests that perhaps high levels of LTO speed up diffusion (if it exists); however, its absence (or low levels) will not act as a bottleneck in the diffusion process. Thus, governments of countries with high levels of LTO should be optimistic about the chances of diffusion of sustainable technologies. On the other hand, the governments of countries with low levels of LTO may not despair. Other variables could compensate for the lack of LTO and lead to high levels of diffusion. IVR, which was found to be necessary and partially significant, indicates that the absence of high levels of IVR in a country would slow down the process of diffusion of sustainable technologies. This result implies that governments and firms focusing on the diffusion of new sustainable technologies in low IVR countries would have to be patient and take a long-term view. UAI was surprisingly found to not correlate with the diffusion of new sustainable technologies. This result is contrary to what has been found for the diffusion of generic products. Tellefsen and Takada (1999) and Tellis *et al.* (2003) reported a negative relationship between UAI and diffusion. It is worth noting that the above-mentioned studies are with respect to new products and generic new technologies. Thus, it seems that UAI has a differential impact on sustainable and generic new technology diffusion.

ICA has a high average effect on diffusion. However, from a necessity perspective, the size effect is small. This result has similar implications as LTO. If a country is high in innovativeness, it should lead to higher levels of diffusion of SNTP. At the same time, it is not a prerequisite for high rates of diffusion. Finally, HID is both necessary and has a high average effect on diffusion. Governments and firms in countries with high levels of HID could hope for quick diffusion of SNTP in the country. From a policy perspective, this makes the job of a government easier. On the other hand, countries with low levels of HID need to be patient when developing policies encouraging the population to adopt SNTP. Environmental regulation has a significant effect on technology choice and the extent of industry adoption; it would stand to reason that regulation and incentives could affect the diffusion of SNTP across the general population. Governments may want to run campaigns and use incentives to encourage the adoption of SNTP by the general population. This suggestion becomes especially important given the fact that HID is a necessary condition. It behooves governments to incentivize and otherwise encourage the diffusion of SNTP for the dual benefit of a better environment and overall well-being for its people.

5.1 Limitations and future research

This study, like any other, has limitations. The study focuses on one sustainable technology and its diffusion across multiple countries. Future studies could expand the scope to other sustainable technologies to increase generalizability. Another area of proposed future research could be developing a larger dataset of PEV sales, which could help us better understand the effect of variables such as IVR, which was found to be necessary and partially significant. Perhaps a future study could combine culture and governance to draw out the independent versus the combined effects. Finally, with the current coronavirus pandemic, there might be some systemic changes that occur in diffusion. Thus, studying the coronavirus pandemic's impact on the cross-country diffusion of technologies might be worthwhile.

In conclusion, this paper reported on multiple variables found to be correlated with the diffusion of SNTP. The literature on factors impacting innovation is extensive; however, the literature on diffusion of sustainable products based on new technologies across countries is sparse. Furthermore, the study of SNTP diffusion across countries is in a nascent stage. This paper furthers the discussion in the latter; hopefully, it spurs further research.

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