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RESEARCH PAPER

Psychological and sociological perspectives for good governance of sustainable nanotechnology development in Malaysia

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Abstract Nanotechnology is developed to improve public well-being, stimulate economic growth, and provide environmental solutions, which are essential for sustainable development. However, the uncertain risks of nanotechnology may destroy public confidence and impede nanotechnology development from facilitating sustainable development. Thus, public perception is a critical component to understand public acceptance of nanotechnology and for nanotechnology development to be well governed. Good governance of nanotechnology is vital to ensure the benefits are distributed equitably while protecting the public from the risks. Hence, this study was based on psychological and sociological approaches with intervention from moderators, that is, media coverage, technology and economic development, benefit and risk of nanoapplications, and benefit and risk information. A survey was conducted in Malaysia to determine the effects of moderators' influence on public perceptions. The study found, based on a psychological and sociological approach, that the moderating effects of moderators influenced public perception in a manner that increased or decreased the benefit and risk perception of nanotechnology. The results later serve as an input for recommending good governance strategies for applying nanotechnology to sustainable development.

Keywords Public perception · Risk · Benefit · Nanotechnology · Good governance · Sustainable development · Societal implications

Introduction

Nanotechnology has been extensively developed globally to become an enabling technology that can produce various medicines, cosmetics, electronics, and household cleaning products. The Malaysian National Nanotechnology Initiatives defines nanotechnology as "research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1–100 nm, to provide a fundamental understanding of phenomena and materials at the nanoscale and to create and use structures, devices and

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systems that have novel properties and functions because of their small and/or intermediate size" (Roco 2001). Nanotechnology involves a basic understanding of material phenomenon at the nanoscale that produces novel and useful properties and functions. Nanomaterials possess a larger surface area to react effectively, compared with the same material in sizes larger than 100 nm. Nanomaterials can improve the previously unattainable electronic, optical, catalyst, and magnetic functions of micron-sized materials. The novel properties of these nanomaterials allow them to be processed into various forms, such as membranes and fibers. These physicochemical properties also render the nanomaterials to be developed into more durable and high-performance products than their micron-sized counterparts (Gleiche et al. 2006; West et al. 2016).

Nanotechnology for sustainable development

Sustainable development is defined as developments that fulfill the needs of the present generation without compromising the future generation's needs (Brundtland 1987). Two main concepts are found in the definition of sustainable development: the concept of "needs," referring to the basic needs that take precedence for less fortunate individuals, and the concept of "limitations," highlighted by technology and social organizations and referring to environmental constraints to fulfilling the social needs of present and future generations and environmental protection in accordance with economic growth.

Prior to the Brundtland definition of "sustainable development," there was another definition of sustainable development in the pre-Stockholm era (before 1972); the concept of economy and "theory of limits" were based on limited environmental policies designed to fulfill the growing needs of the human population. Robert Thomas Malthus (1766–1834) argued that environmental damage was from the increasing population and not the Industrial Revolution. This concept, however, differs from the views of William Goldwin (1756–1836) and Marquis de Condorcet (1743–1794), who asserted that these adverse effects were from the Industrial Revolution and emphasized that mass production does not take care of workers' welfare and neglects the impacts of industries on the environment (Mebratu 1998). The growing population requires more basic needs, such as food and clean water; nevertheless, the environment has finite resources and unable to accommodate such expansive growth. Hence, appropriate technologies are introduced to address the environmental limitations of fulfilling the needs of a growing population. Over time, technology modifications continually progress in a manner that matches with public acceptance. Once accepted, the technology has reached its stable and sustainable stage, when it can be used by the public (Saidi 2018). The acceptance of a technology depends on the public interpretation of its benefits and risks, for example, public experience with controversial cases associated with the said technology.

Nanotechnology has been developed into an enabling technology with numerous applications never thought possible; nanotechnology applications improve quality of life through energy efficiency and advancements in applications for telecommunications, medicine, and engineering (Moussaouy 2018). Today, any breakthrough in nanotechnology eventually benefits and impacts society. The same breakthrough may also pose an uncertain risk that may eventually harm the public. However, certain risks are acceptable to the public when the risks are adequately managed and offered more benefits than harms (Starr 1969). Nanotechnology has the potential to provide added value to sustainable development through social improvement and economic and industrial advancement if the risks are controlled and well managed (Renn and Roco 2006). Public participation starting in the early development of nanotechnology increases public awareness and thus enables policymakers to develop nanotechnology that suits the public's needs, improves their well-being, and secures their safety (Rogers-Hayden and Pidgeon 2008). Additionally, the gap between the public and the stakeholders, that is, the government, industry, and researchers, can be bridged when the public has the opportunity to communicate their concerns to stakeholders regarding managing the risks posed by nanotechnology. As a result, the public and stakeholders' collaboration can generate knowledge, skills, and value added required for nanotechnology development for a sustainable future (Moussaouy 2018).

Public perception

Public perception is defined as "a social phenomenon of how the public sees risks and benefits in current situations based on facts or fictions of current knowledge, culture and/or media." The public considers "risk" to be a concept that refers to managing uncertainty and danger

in life (Sjöberg et al. 2004). Conversely, "benefits" are perceived as the belief in positive effects caused by a specific action (Leung 2007). Naturally, the perspectives of the public and experts may differ because, for example, an expert may consider "risk" to be the annual death rate while the public considers "risk" to be the hazard level caused by a single event. An individual's ability to assess the benefits and risks of nanotechnology leads to her/his acceptance or rejection. Therefore, public perception is vital to ensure the continuous development of nanotechnology to exploit its potential for sustainable development. Therefore, factors that influence public perception are gleaned to guide the government, industry, and researchers to understand the public needs in line with nanotechnology development.

Regarding public perception, a heuristic concept was introduced as a cognitive strategy to make this "benefit-risk" decision more manageable in an uncertain situation (Simon 1977). When deliberating on a decision based on benefits and risks, the decision is unavoidably influenced by an individual's personal views, socioeconomic status, political views, culture, and so forth because the decision is a part of an individual's life (Pieper 1989). Individuals' perceptions may also differ when they are exposed to the same information but a different presentation (Tversky and Kahneman 1981). According to Wildavsky (1987), an individual does not have to work hard and become a politician to opine on politics; they merely require information about politics to share their perspective (Wildavsky 1987).

The cultural theory explains the tendency of an individual to make a choice regarding whether a dangerous activity is beneficial or risky by depending on his/her practiced culture (Kahan et al. 2009). A study conducted by Kahan et al. (2009) demonstrated that individuals tend to select information relevant to their practiced cultural and political predisposition when presented with the same information. The concepts of cognitive psychology and cultural theories form the basis of this study, and two approaches, namely, psychology and sociology, are adopted from the study by Renn and Swaton (1984) to appreciate and understand the samples' public perception of nanotechnology in Malaysia.

Figure 1 presents a conceptual framework of public risk and benefit perceptions for good governance of nanotechnology; two approaches, namely, psychological and sociological, were used along with intervention by moderators, as discussed in our previous work (Kamarulzaman et al. 2018). The psychological approach focuses on the cognitive psychology involving the cognitive ability to assess risks and benefits when making informed decisions, that is, an individual's attitudes and beliefs toward stakeholders in managing nanotechnology (Renn and Swaton 1984). The sociological approach involves the decisions made by individuals influenced by social groups represented by the individuals (Renn and Swaton 1984). Additionally, intervening variables/moderators may moderate the psychological and sociological approaches, namely, media coverage, technology and economic development, benefits and risks of nanoapplications, and benefit and risk information (Petersen et al. 2007; René et al. 2010; Schütz and Wiedemann 2008; Siegrist 2010). The moderating effects of the intervening variables on the psychological and sociological approaches are the focus of this study. The public benefit and risk perceptions assessed are instrumental to the recommendation of a strategy for good governance of nanotechnology to realize sustainable development in Malaysia.

Good governance of nanotechnology for sustainable development

The growing knowledge of nanotechnology among experts and the rapid development of nanotechnology in industry have disconnected the public from the progress of technology development. The knowledge gap between the public and experts will widen because individuals with a formal education gain more knowledge over time than less-educated individuals, leaving those less-educated trailing behind (Corley and Scheufele 2010). Thus, this gap may reduce the effectiveness of nanotechnology in facilitating sustainable development. Deliberation between experts and the public is one of the few approaches taken to convey information to the public and gain public perspectives on the matters concerning nanotechnology (Kass 2001). This understanding will lead to a better governance of nanotechnology that promotes public participation in enabling the nanotechnology to be applied in enhancing the public well-being and facilitating sustainable development.

Good governance involving the process of making and implementing decisions is required to develop nanotechnology sustainably. Good governance is defined as effective governance with specific characteristics, and its performance should be assessed by using the appropriate data (Rotberg 2014). The eight characteristics of good governance according to the United Nations

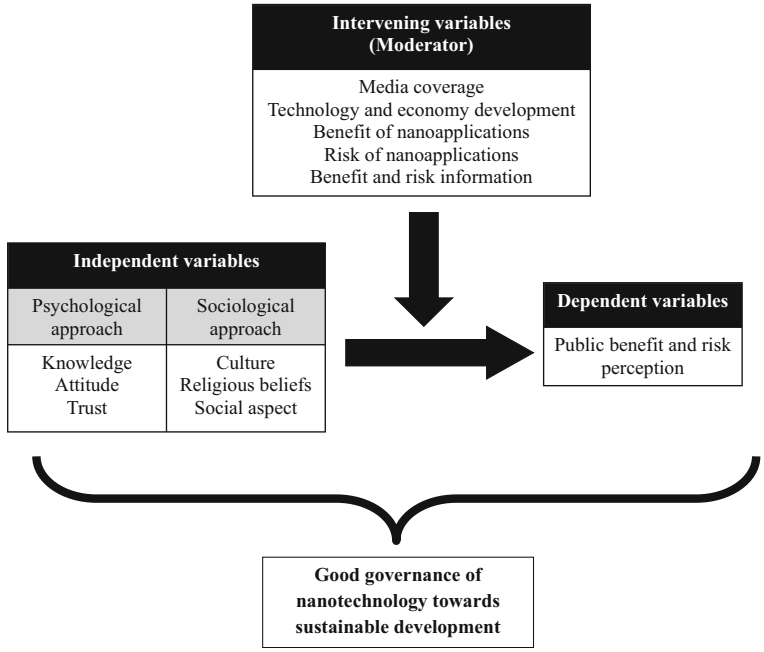

Fig. 1 Conceptual framework of intervening variables in moderating psychological and sociological approaches toward public benefit and risk perceptions for good governance of nanotechnology for sustainable development (source modified from Kamarulzaman et al. 2018)

Economic and Social Commission for Asia and the Pacific are as follows: (1) public participation, (2) rule of law with a fair legal framework, (3) transparency in decision-making and any action taken is in accordance with law, (4) responsive by providing effective feedback within a reasonable timeframe, (5) consensus-oriented regarding all parties involved, (6) equity and inclusiveness such that everyone is important and has an equal opportunity to improve their well-being, (7) effective management to produce results that satisfy the public and efficient resource management, and (8) accountable institutions for every action taken and decision made (UNESCAP 2009).

Good governance in the context of this study is collective governance in managing nanotechnology at all levels of the organizations to establish relationships among the organizations and engage public participation. Good governance of nanotechnology requires transdisciplinary knowledge and implementation between scientists and nonscientists (Hurni and Wiesmann 2014). The involvement of skillful personnel with the public can reduce the knowledge gap between the two parties (Roco et al. 2011); then, decisions are based on social orientation without prejudice (Rist et al. 2007). Decision-making procedures on risk-related matters require transparency from the stakeholders responsible for technology development and public participation (Renn and Swaton 1984).

In our context, Malaysia aspires to be the hub of nanotechnology of Southeast Asia; Klang Valley would be the center of nanotechnology development and home to government agencies, industries, and research institutions related to nanotechnology (Lee et al. 2015). Hence, the Klang Valley public receives benefits from and is exposed to the risks of nanotechnology applications. In this research, the public's perceptions of the benefits and risks of nanotechnology in Klang Valley, Malaysia, are assessed along with the effects of moderators, that is, media coverage, technology and economic development, the benefits and risks of nanoapplications, and benefit and risk information, as the preliminary step to implementing good governance of nanotechnology, whereby an equal distribution of nanotechnology benefits and proper management of the uncertain risks ensures the utmost use of nanotechnology for sustainable development.

Methods

Survey

A questionnaire was distributed to respondents in Klang Valley, Malaysia ($n = 407$), from April to June 2017

based on the estimated population of 8.18 million in this area. Klang Valley is the most populated area in Malaysia, and the dense urban landscape is home to various government agencies, nongovernmental organizations, universities, and research centers. The survey questions were structurally distributed by hand to ten (10) city councils within the Klang Valley.

Based on our result, respondents' demography was grouped into gender (female 63.9% and male 36.1%), age (18- to 20-year-olds 7.4%, 21- to 40-year-olds 85%, and 41- to 51-year-olds 7.6%), and race (Malay 68.1%, Chinese 19.7%, Indian 10.1%, Sabahan 1.5%, and Sarawakian 0.7%). The percentage of respondents' race represented the Malaysian public, which comprises three major races: 67.4% Malay, 24.6% Chinese, and 7.3% Indian (Department of Statistics Malaysia 2010). Additional information revealed information on religion (Islam 70.5%, Buddhism 18.4%, Hinduism 9.6%, Christian 1.0%, and no religion 0.5%), education level (diploma and below 45%, bachelor 37.3%, masters 15.0%, and PhD 2.7%), monthly household income (≤ MYR 1000 5.4%, ≤ MYR 3000 38.8%, ≤ MYR 5000 31.2%, ≤ MYR 7000 10.3%, ≤ MYR 9000 5.4%, and > MYR 9000 8.8%), and stakeholders (government staff 22.1%, private staff 56.3%, self-employed 9.8%, unemployed 0.5%, housewives 4.4%, and students 6.9%).

The variables' measurement of the independent variables (psychological approach), independent variable (sociological approach), intervening variables (moderators), and dependent variables is further described in the next section. Table 1 presents the descriptive analysis of all variables in the study and is also further described in the next section.

Independent variables (psychological approach)

Knowledge

Knowledge was the first question and measured with no = 0 and yes = 1.

Attitude

Attitude was measured with three questions: the respondents' opinion on the benefits of nanotechnology, would they agree on the application of nanotechnology as a consumer, and would they be willing to buy nanotechnology products. The means of the three questions were summed up to become "attitude" ($M = 4.85$, SD = 1.01, $\alpha = 0.88$).

Trust

Trust was measured in four items each in trust in the government, industry, and researchers (1 = less trustful, 7 = most trustful), that is, "Benefit and risk information regarding nanotechnology issued by the stakeholders (government, industry, or researcher) to the public," "The stakeholders (government, industry, or researcher) understand the public's needs and will develop nanotechnology in line with those needs," "The stakeholders (government, industry, or researcher) will act appropriately if the public is affected by the adverse effects of nanotechnology," and "The stakeholders (government, industry, or researcher) have a sufficient amount of technical knowledge and act according to the law to ensure the public safety." Thus, trust in government ($M = 4.43$, SD = 1.33, $\alpha = 0.94$), industry ($M = 4.64$, SD = 1.07, $\alpha = 0.9$), and researchers ($M = 5.04$, SD = 1.21, $\alpha = 0.96$) were summed up.

Independent variable (sociological approach)

Culture, religious beliefs, and social aspect

Culture, religious beliefs, and social aspect were measured in three items: "based on your lifestyle, would you accept nanotechnology" (1 = strongly disagree, 7 = strongly agree, $M = 4.86$, SD = 1.16), "based on your religion, would you accept nanotechnology" (1 = strongly disagree, 7 = strongly agree, $M = 4.90$, SD = 1.19), and "based on your lifestyle and religion, would you support the fund for nanotechnology research" (1 = strongly disagree, 7 = strongly agree, $M = 5.20$, SD = 1.20). Culture, religious beliefs, and social aspect ($M = 4.99$, SD = 1.10, $\alpha = 0.96$) were summed up.

Intervening variables (moderators)

Media

Media was measured in six items. Three items were for respondents who answered "yes" on question one, that is, "Media provides information

Table 1 Descriptive analysis of independent, dependent, and intervening variables

	M	SD	Cronbach's alpha
Independent variable (psychological approach)			
Knowledge of nanotechnology	47.2% (know nothing about nanotechnology)	–	
Attitude toward nanotechnology	4.85	1.01	0.88
Trust in government on nanotechnology development	4.47	1.33	0.94
Trust in industry on nanotechnology development	4.63	1.07	0.94
Trust in researchers on nanotechnology development	5.04	1.21	0.96
Independent variables (sociological approach)			
Culturally accept nanotechnology	4.86	1.16	0.96
Religious beliefs on accepting nanotechnology	4.90	1.19	
Socially accept research funding of nanotechnology	4.88	1.13	
Dependent variables			
Benefit perception of nanotechnology	4.82	0.82	
Risk perception of nanotechnology	4.51	0.92	
Intervening variables			
Media coverage on technology and nanotechnology	4.51	1.32	
Technology and economy development	5.54	1.10	0.94
Benefit of nanoapplications	4.92	1.03	0.86
Risk of nanoapplications	4.15	1.17	0.90
Benefit and risk information gathered	5.41	1.17	0.88

on the benefits of nanotechnology," "Media provides information on the risks of nanotechnology," and "Media provides reliable nanotechnology information" (1 = strongly disagree, 7 = strongly agree, $M = 4.10$, SD = 1.00, $\alpha = 0.84$). The other three items were for respondents who answered "no" on question one, that is, "Media provides information on the benefits of technology," "Media provides information on the risks of technology," and "Media provides reliable technology information" (1 = strongly disagree, 7 = strongly agree, $M = 4.97$, SD = 1.47, $\alpha = 1.00$). Therefore, media ($M = 4.51$, SD = 1.32) was summed up.

Technology and economic development

Technology and economic development were measured in five items. The degree of agreement indicated by the respondents (1 = strongly disagree, 7 = strongly agree) for "science and technology grow rapidly in Malaysia," "science and technology improve quality of life," "science and technology improve economic status," "science and technology facilitate daily affairs," and "science and technology are essential for the country's progress" was observed. Technology and economic status ($M = 5.54$, SD = 1.10 $\alpha = 0.94$) were summed up.

Nanotechnology applications

Six nanotechnology applications are cosmetic, electrical appliances, medicine, food, sports equipment, and detergent. These applications were measured regarding the benefit (1 = less beneficial, 7 = most beneficial, $M = 4.92$, SD = 1.03, $\alpha = 0.86$) and risk (1 = less risky, 7 = most risky, $M = 4.15$, SD = 1.17, $\alpha = 0.90$).

Benefit and risk information

Four items were measured for risk and benefit information (1 = strongly disagree, 7 = strongly agree): "I read the benefits and risk information on the product before making a purchase," "I understand the benefits and risks information of the product before making a purchase," "I do not buy a product that does not have the benefit and risk information,"

and "I am confident that the benefit and risk information on the product is accurate." The means of four items were summed to become the benefit and risk information ($M = 5.41$, SD = 1.17, $\alpha = 0.88$).

Dependent variables

Benefit and risk perceptions of nanotechnology

The benefit and risk perceptions of nanotechnology were measured in twelve items. Benefit perception was a summative index of six items regarding the benefit of applying nanotechnology in cosmetics, electrical appliances, medicine, food, sports equipment, detergent, nanotherapy, nanopesticides, and nanofertilizers (1 = less beneficial, 7 = most beneficial, $M = 4.82$, SD = 0.82, $\alpha = 0.84$). Risk perception was a summative index of six items regarding the risk of applying nanotechnology in cosmetics, electrical appliances, medicine, food, sports equipment, detergent, nanotherapy, nanopesticides, and nanofertilizers (1 = less risky, 7 = most risky, $M = 4.51$, SD = 0.92, $\alpha = 0.88$). Table 1 shows the measure of independent, dependent, and intervening variables from the questionnaire items.

Analysis

PROCESS macro was conducted using SPSS 21, and the procedures were conducted as described by Hayes (2013). PROCESS macro was used to determine moderators' effects of the intervening variables on the independent variables, that is, psychological and sociological approaches, which later affected the outcome of dependent variables, that is, the public's benefit and risk perceptions (Hayes 2013). The results are shown in Table 2 for the psychological approach, Table 3 for the sociological approach, and Figs. 2, 3, 4, 5, 6, 7, 8, and 9 to explain the moderating effect of the intervening variable on the public's benefit and risk perception of nanotechnology.

Results

Based on the psychological approach, Table 2 shows that media has a moderating effect on attitude and trust in researchers in influencing the benefit perception, and media has a moderating effect regarding knowledge influencing the risk perception of nanotechnology. Figure 2 a shows that media exposure increases public attitude, which later increases the benefit perception regarding nanotechnology ($\beta = 0.05$, $p < 0.05$). Figure 2 b shows that media exposure increases trust in researchers, increasing the public's benefit perception ($\beta = 0.05$, $p < 0.05$). Figure 2 c shows that low exposure to media moderates public knowledge by increasing the risk perception among the public ($\beta = 0.53$, $p < 0.05$). In the case of the sociological approach, media shows no moderating effect in influencing the public's perception of the risks and benefits of nanotechnology.

In Table 2, technology and economic development moderate the influence of knowledge and attitude on benefit perception, risk perception is moderated by technology, and economic development is moderated by attitude, trust in the government, and trust in researchers. Figure 3 a shows high technology and economic development moderate knowledge by increasing benefit perception ($\beta = 0.28$, $p < 0.05$), and low technology and economic development moderate knowledge by decreasing the benefit perception toward nanotechnology ($\beta = 0.10$, $p < 0.001$). Figure 3 b shows technology and economic development; whether the development is low or high, it moderates attitude by increasing the benefit perception. In the case of risk perception, Fig. 3 c shows low technology and economic development moderate attitude by increasing risk perception; however, high development of technology and economy decrease risk perception ($\beta = -0.08$, $p < 0.05$). Figure 3 d shows trust in government is moderated by low technology and economic development, which increase risk perception, but high technology and economic development have a minimal increasing effect on risk perception of nanotechnology ($\beta = -0.01$, $p < 0.001$). Figure 3 e shows trust in researchers is moderated by low technology and economic development, which increase risk perception, and high development of technology and economy moderate trust in researchers, which decrease risk perception of nanotechnology ($\beta = -0.09$, $p < 0.05$).

Based on the sociological approach, Table 3 shows culture ($\beta = -0.12$, $p < 0.05$) and social aspect ($\beta = -0.10$, $p < 0.05$) are moderated by technology and economic development regarding influencing risk perception of nanotechnology. Figure 4 a shows low development of technology and economy moderate development of culture from increasing risk perception, and high technology and economic development decrease risk perception. Figure 4 b shows social aspect is

Table 2 Regression coefficients from PROCESS macro by Hayes for the moderating effects of intervening variables on the psychological approach that influence the public perception of nanotechnology

Psychological approach		Media	Technology and economy development	Benefit of nanoapplications	Risk of nanoapplications	Benefit and risk information
Benefit perception	Knowledge	− 0.11	0.28*	− 0.01	0.25	0.01
	Attitude	0.05*	0.10**	0.03	− 0.03	0.01
	Trust in government	0.03	− 0.04	0.09**	− 0.04	− 0.02
	Trust in industry	− 0.01	0.03	0.05*	− 0.03	− 0.02
	Trust in researchers	0.05*	0.02	0.02	− 0.08*	− 0.05*
Risk perception	Knowledge	0.53**	0.17	0.13	− 0.01	0.30*
	Attitude	− 0.07	− 0.08*	− 0.25**	0.03	− 0.02
	Trust in government	− 0.04	− 0.01**	0.17**	0.07**	− 0.07*
	Trust in industry	− 0.02	− 0.06	− 0.18**	0.07**	0.11*
	Trust in researchers	0.03	− 0.09*	− 0.18**	0.05*	0.14**

**$p < 0.001$, *$p < 0.05$

moderated by low technology and economic development, which increases the risk perception, and high development of technology and economy moderate social aspect by decreasing the risk perception of nanotechnology.

In Table 2, the benefit perception of nanoapplications based on the psychological approach shows a moderating effect on trust in government ($\beta = 0.09$, $p < 0.001$) and trust in industry ($\beta = 0.05$, $p < 0.05$) regarding influencing benefit perception and shows a moderating effect on attitude ($\beta = -0.05$, $p < 0.001$), trust in government ($\beta = 0.17$, $p < 0.001$), trust in industry ($\beta = -0.18$, $p < 0.001$), and trust in researchers ($\beta = -0.18$, $p < 0.001$) regarding influencing risk perception. Figure 5 a shows that a low perceived benefit of nanoapplications moderates trust in government by slightly decreasing benefit perception, and a high perception of nanoapplications benefits increases the perceived benefit of nanotechnology. Trust in industry, see Fig. 5b, is moderated by the perceived benefits of nanoapplications, which increase benefit perception. Risk perception of nanotechnology decreases, see Fig. 5c, due to the moderating effect of the high benefit perceived regarding nanoapplications on attitude; if the benefit of nanoapplications is perceived to be low, it moderates attitudes and increases risk perception.

Table 3 Regression coefficients from PROCESS macro by Hayes for the moderating effects of intervening variables on the sociological approach that influence the public perception of nanotechnology

Sociological approach		Media	Technology and economy development	Benefit of nanoapplications	Risk of nanoapplications	Benefit and risk information
Benefit perception	Culture	0.04	0.02	0.04	− 0.01	0.01
	Religious beliefs	0.03	0.04	− 0.02	− 0.08**	0.01
	Social aspect	0.03	0.03	0.01	− 0.05*	0.00
Risk perception	Culture	− 0.02	− 0.12*	− 0.24**	0.03	− 0.04
	Religious beliefs	0.02	− 0.07	− 0.23**	0.03	− 0.02
	Social aspect	− 0.01	− 0.10*	− 0.26**	0.03	− 0.03

**$p < 0.001$, *$p < 0.05$

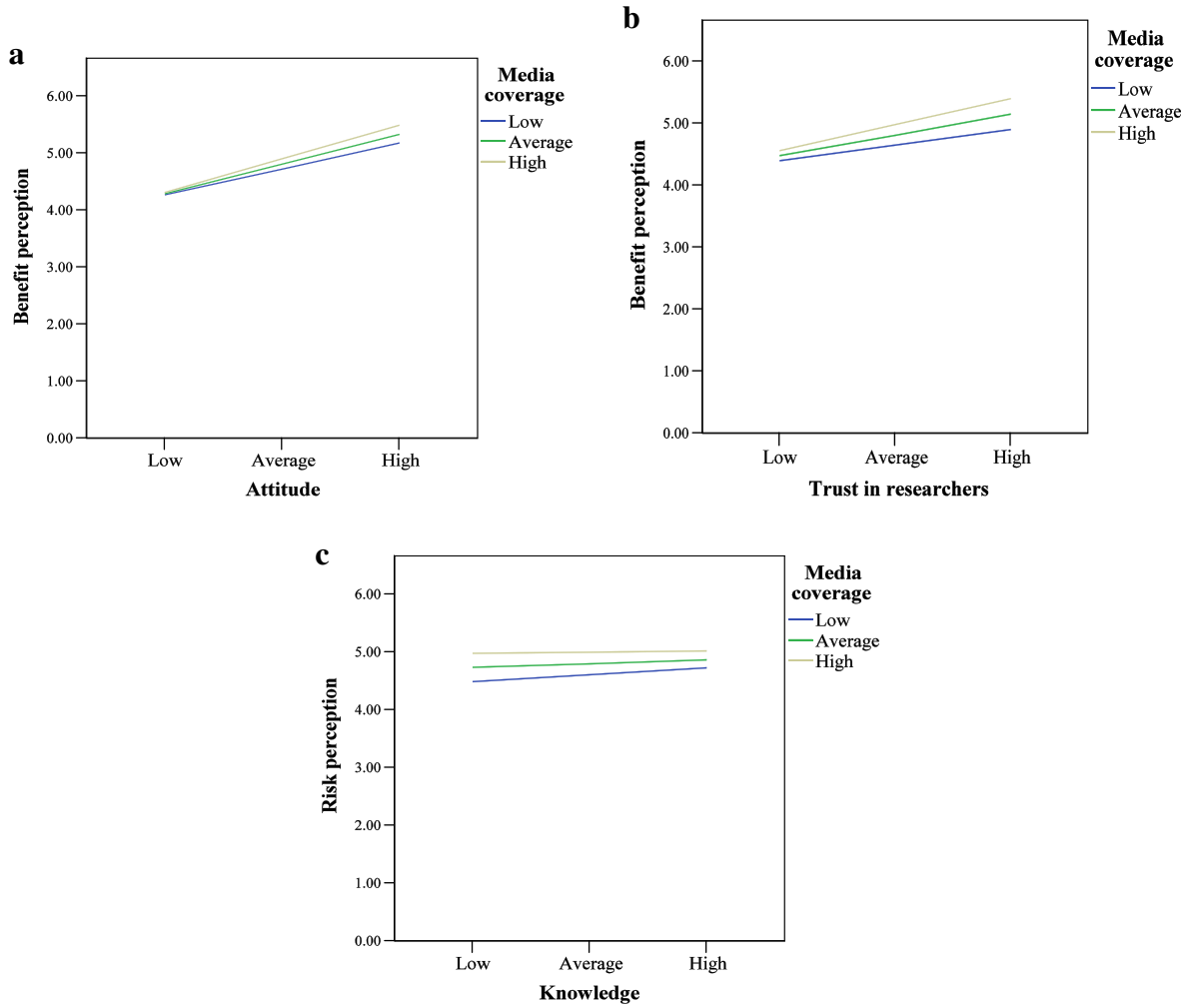

Fig. 2 Media: psychological approach. **a** Media coverage moderates attitude in influencing benefit perception. **b** Media coverage moderates trust in researchers in influencing benefit perception. **c** Media coverage moderates knowledge in influencing risk perception

Figure 5 d–f show that the high perceived benefit of nanoapplications moderates trust in government, trust in industry, and trust in researchers by decreasing risk perception. Additionally, a low perceived benefit of nanoapplications moderates trust in government, trust in industry, and trust in researchers by increasing risk perception. Table 3 shows the sociological approach in which culture, religious beliefs, and social aspect are moderated by the perceived benefit of nanoapplications by influencing the risk perception of nanotechnology (culture, $\beta = -0.24$, $p < 0.001$; religious beliefs, $\beta = -0.23$, $p < 0.001$; social, $\beta = -0.26$, $p < 0.001$). Figure 6 a–c show a high perceived benefit of nanoapplications in the moderation of culture, religious beliefs, and social aspect by decreasing the risk perception and a low perceived benefit of nanoapplications in the moderation of culture, religious beliefs, and social aspect by increasing the risk perception of nanotechnology.

Additionally, the perceived risk of nanoapplications was observed to have a moderating effect on trust in researchers regarding influencing the perception of the benefits of nanotechnology ($\beta = -0.08$, $p < 0.05$; Table 2) based on the psychological approach. Additionally, the perceived risk of nanoapplications shows a moderating effect on trust in government ($\beta = 0.07$, $p < 0.001$), trust in industry ($\beta = 0.07$, $p < 0.001$), and trust in researchers ($\beta = 0.05$, $p < 0.05$) by influencing the risk perception of nanotechnology. Figure 7 a shows

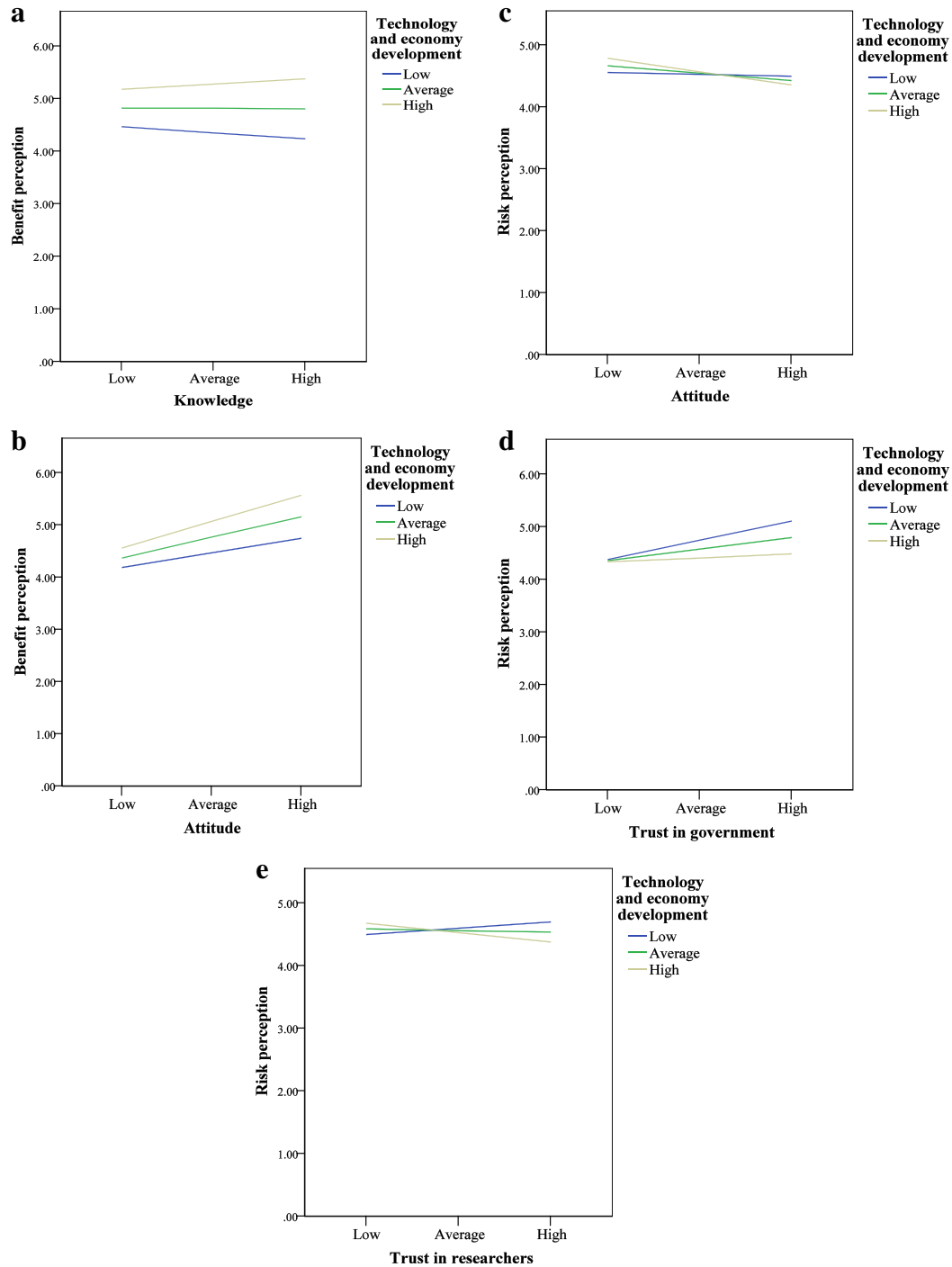

Fig. 3 Technology and economy development: psychological approach. **a** Technology and economy development moderate knowledge in influencing benefit perception. **b** Technology and economy development moderate attitude in influencing benefit perception. **c** Technology and economy development moderate attitude in influencing risk perception. **d** Technology and economy development moderate trust in government in influencing risk perception. **e** Technology and economy development moderate trust in researchers in influencing risk perception

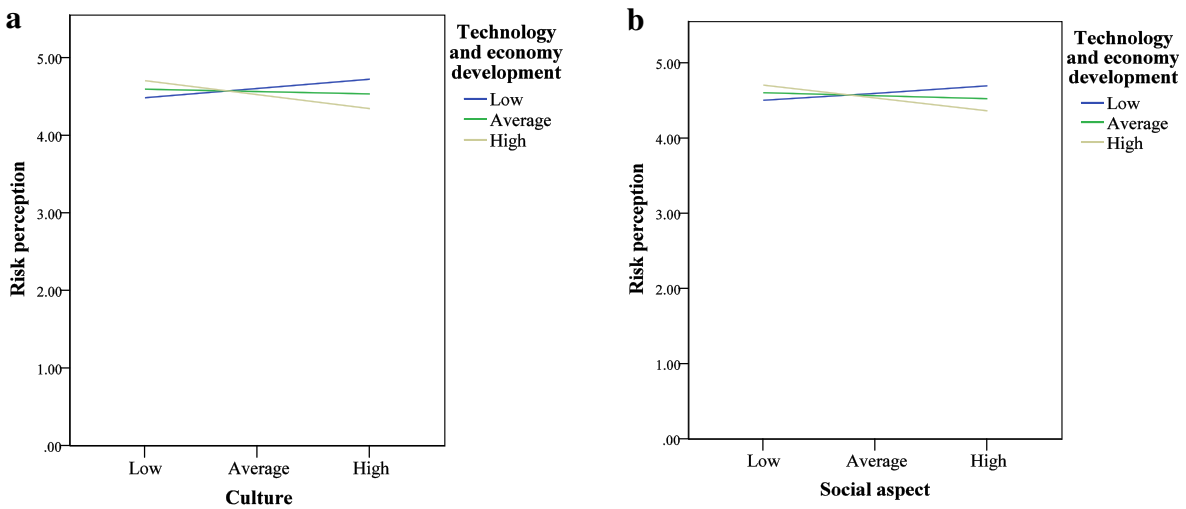

Fig. 4 Technology and economy development: sociological approach. **a** Technology and economy development moderate culture in influencing risk perception. **b** Technology and economy development moderate social aspect in influencing risk perception

that a low perceived risk of nanoapplications moderates trust in researchers by increasing benefit perception, compared with a high risk perception, which has a less moderating effect on trust in researchers regarding increasing the perception of the benefits of nanotechnology. Figure 7 b–d show trust in government, trust in industry, and trust in researchers are moderated by the high perceived risk of nanoapplications by increasing the risk perception of nanotechnology; low perceived risk of nanoapplications moderates trust in government, trust in industry, and trust in researchers by decreasing the risk perception of nanotechnology.

Based on the sociological approach, Table 3 indicates religious beliefs and social aspect are moderated by the perception of the risk of nanoapplications by influencing the perception of the benefits of nanotechnology. Figure 8 a and b show a low risk perception regarding nanoapplications used to moderate the religious beliefs and social aspect by increasing the benefit perception, compared with the high risk perceived regarding nanoapplications that have a less moderating effect on religious beliefs and social aspect regarding increasing perception of the benefits of nanotechnology. In Table 2, the benefit and risk information shows a moderating effect on trust in researchers by influencing benefit perception ($\beta = -0.05, p < 0.05$). Benefit and risk information also moderates knowledge ($\beta = 0.03, p < 0.05$), trust in government ($\beta = -0.07, p < 0.05$), trust in industry ($\beta = 0.11, p < 0.05$), and trust in researchers ($\beta = 0.14, p < 0.05$) in influencing risk perception. Moderating effects of benefit and risk information are further shown in Fig. 9a–e. Benefit and risk information moderates trust in researchers by increasing the benefit perception of nanotechnology in Fig. 9a. Knowledge is moderated by low benefit and risk information by decreasing risk perception, and high benefit and risk information moderates knowledge by increasing risk perception, as shown in Fig. 9b. Figure 9 c–e show that when high benefit and risk information is gathered by the public, it moderates their trust in government, trust in industry, and trust in researchers by decreasing risk perception, and when low benefit and risk information is gathered by the public, it moderates trust in government, trust in industry, and trust in researchers by increasing the risk perception of nanotechnology. However, there is no significant moderating effect of benefit and risk information based on the sociological approach, as shown in Table 3.

Discussion

Nanotechnology has developed rapidly since the past decade and has been used in many applications in the consumer market (Roco 2001). Studies on public perception have also evolved from understanding how the public perceives nanotechnology to what influences their perception. This study focuses on the intervening variables or moderators of the influence on public perception and how these moderating effects can be used

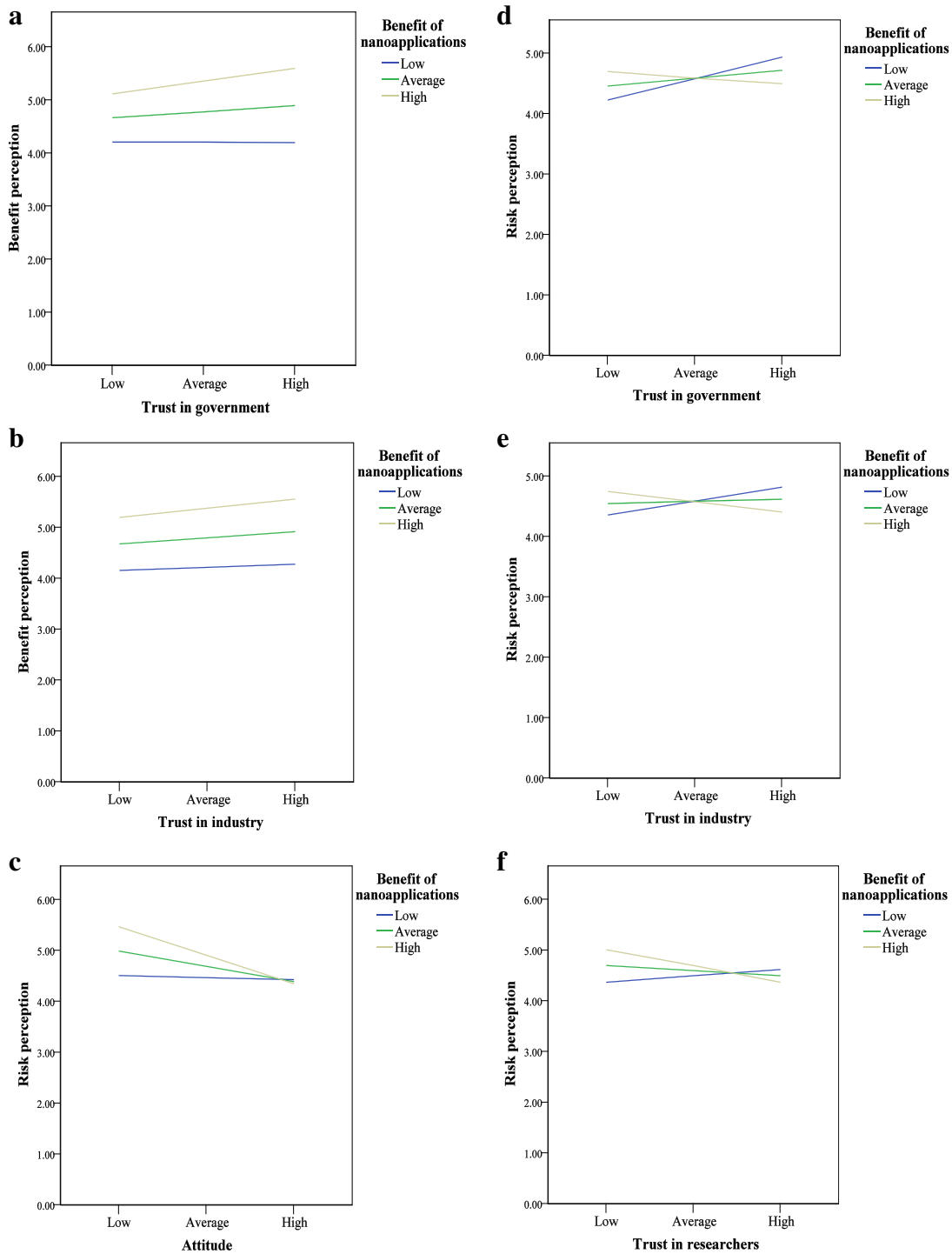

Fig. 5 Benefit of nanoapplications: psychological approach. **a** Benefit of nanoapplications moderates trust in government in influencing benefit perception. **b** Benefit of nanoapplications moderates trust in industry in influencing benefit perception. **c** Benefit of nanoapplications moderates attitude in influencing risk perception. **d** Benefit of nanoapplications moderates trust in government in influencing risk perception. **e** Benefit of nanoapplications moderates trust in industry in influencing risk perception. **f** Benefit of nanoapplications moderates trust in researchers in influencing risk perception

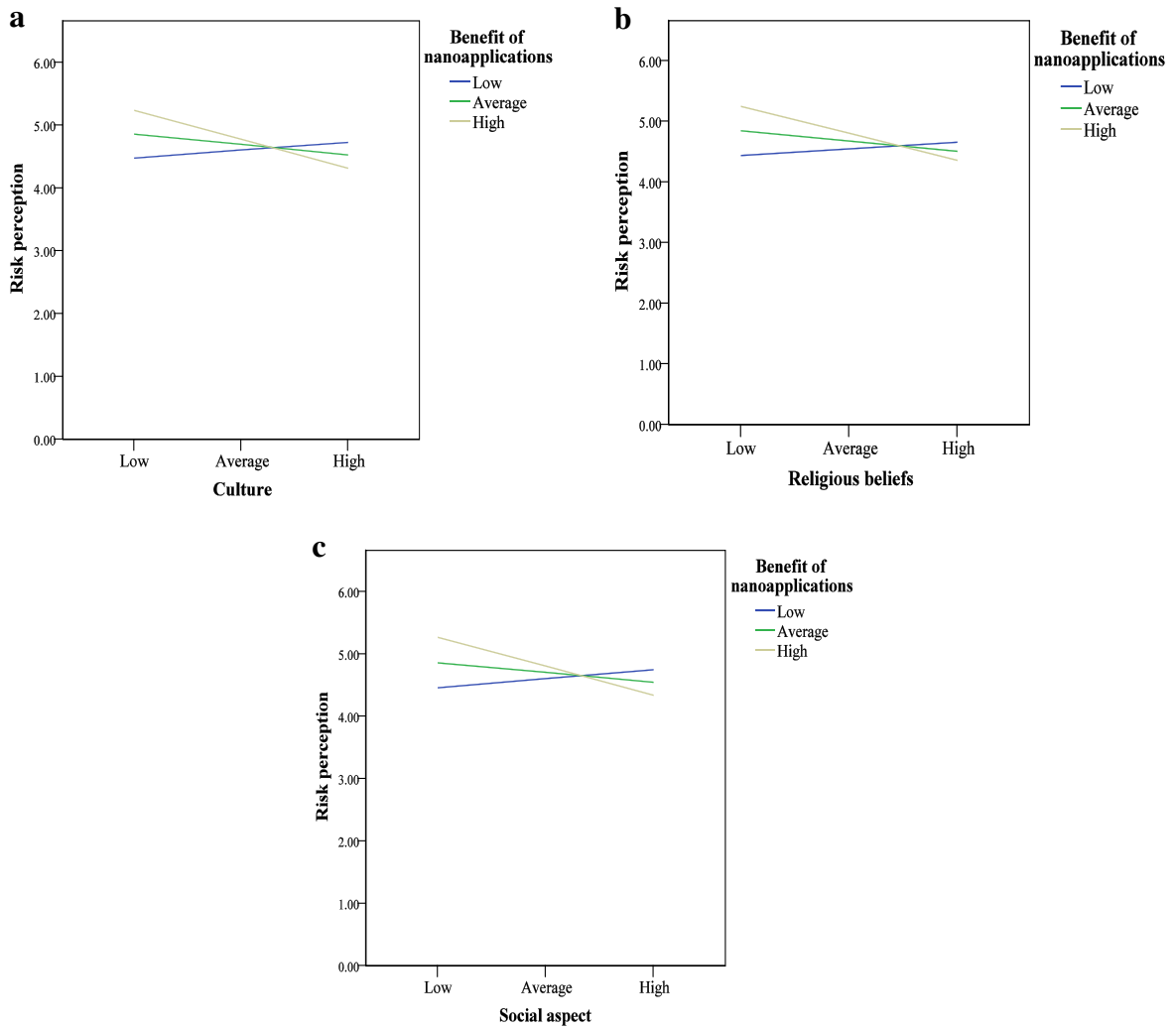

Fig. 6 Benefit of nanoapplications: sociological approach. **a** Benefit of nanoapplications moderates culture in influencing risk perception. **b** Benefit of nanoapplications moderates religious beliefs in influencing risk perception. **c** Benefit of nanoapplications moderates social aspect in influencing risk perception

for good governance of nanotechnology that aims to achieve sustainable development.

The Malaysian public shows a positive attitude toward nanotechnology and has a high level of trust in researchers. Notably, media coverage that contains useful information about nanotechnology in ensuring the safety of nanotechnology can further increase the benefit perception of nanotechnology because the media provides the public with critical, up-to-date information. Thus, this study suggests media framing on nanotechnology is required for researchers' engagement. The information presented by researchers will further increase public trust, increasing their benefit perception. However, an increase in risk perception can be observed when the public is exposed to a high amount of media coverage. Because the public has limited knowledge of nanotechnology, with 47.2% of the respondents admitting to having zero knowledge about nanotechnology, the risk information is more influential compared with the benefit information (Cobb 2005). Therefore, when individuals with limited knowledge are exposed to too much media on risk information, they perceive nanotechnology as posing a risk than being beneficial. The finding is supported by a study on the importance of media coverage in providing information about the benefits and risks of nanotechnology in shaping public

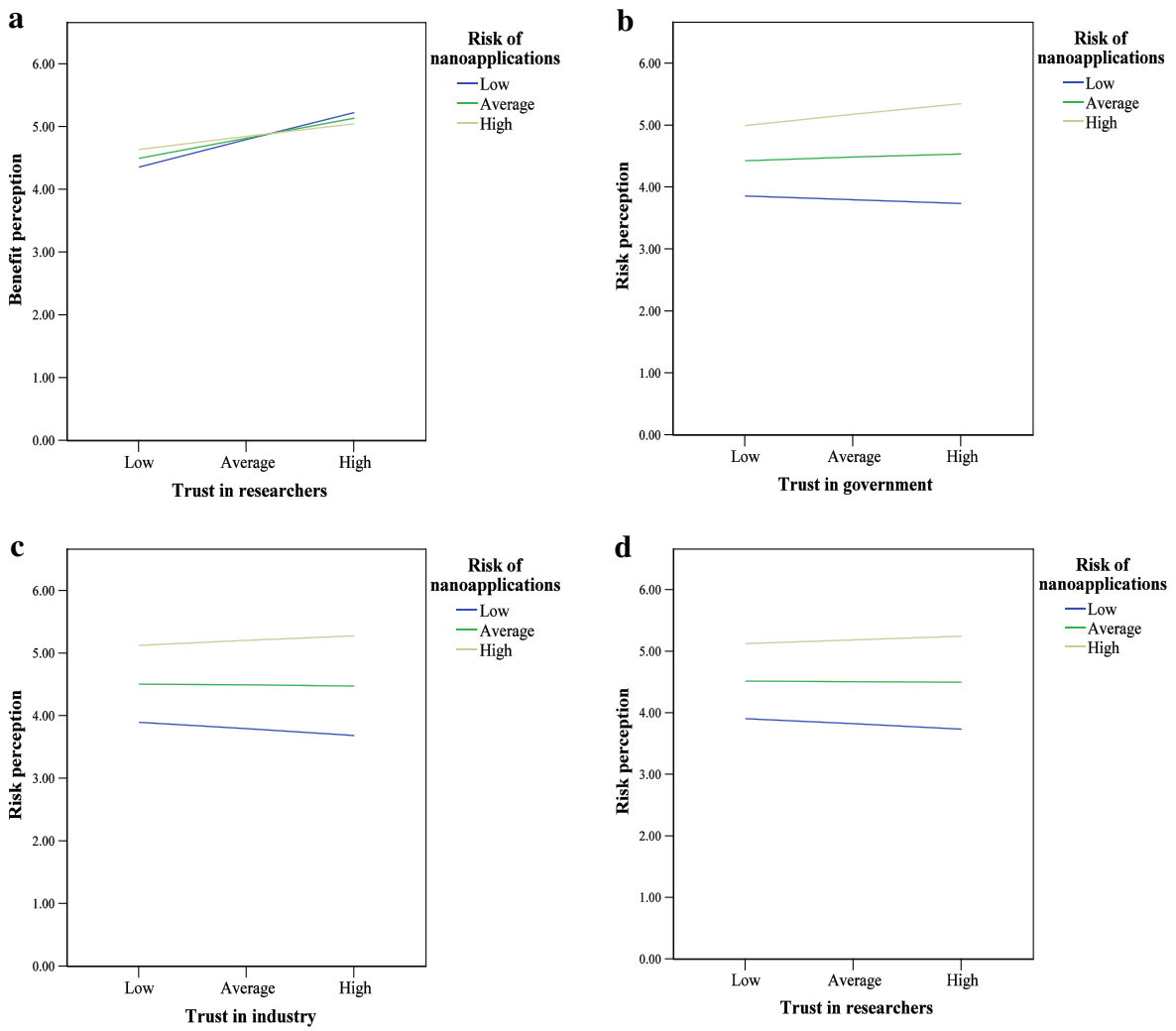

Fig. 7 Risk of nanoapplications: psychological approach. **a** Risk of nanoapplications moderates trust in researchers in influencing benefit perception. **b** Risk of nanoapplications moderates trust in government in influencing risk perception. **c** Risk of nanoapplications moderates trust in industry in influencing risk perception. **d** Risk of nanoapplications moderates trust in researchers in influencing risk perception

perceptions of nanotechnology (Ho et al. 2011). Media coverage and the internet provide the public with easy access to information. However, the choice of information depends on individuals' interests and curiosity. Public interpretation of the information received also differed from one segment to another (Lemanczyk 2014); the information presented must be factual and nonfictional. Scientific information, for example, current scientific developments, attracts interested individuals but not individuals with different interests. Therefore, media coverage of various aspects including benefits, risks, economics, social aspect, and ethics would provide extensive coverage that could educate the public (Tyshenko 2014).

Because technology and economy continue to develop, the public will eventually have a better understanding and familiarity with new technology; thus, based on the results from this study, a proposal is that such familiarity may increase the Malaysian public's knowledge and positive attitude toward nanotechnology. An economy driven by scientific and technological advancements will allow countries' competitiveness to be a part of the Fourth Industrial Revolution (Tangau 2017). Hence, in tandem with technology and economic

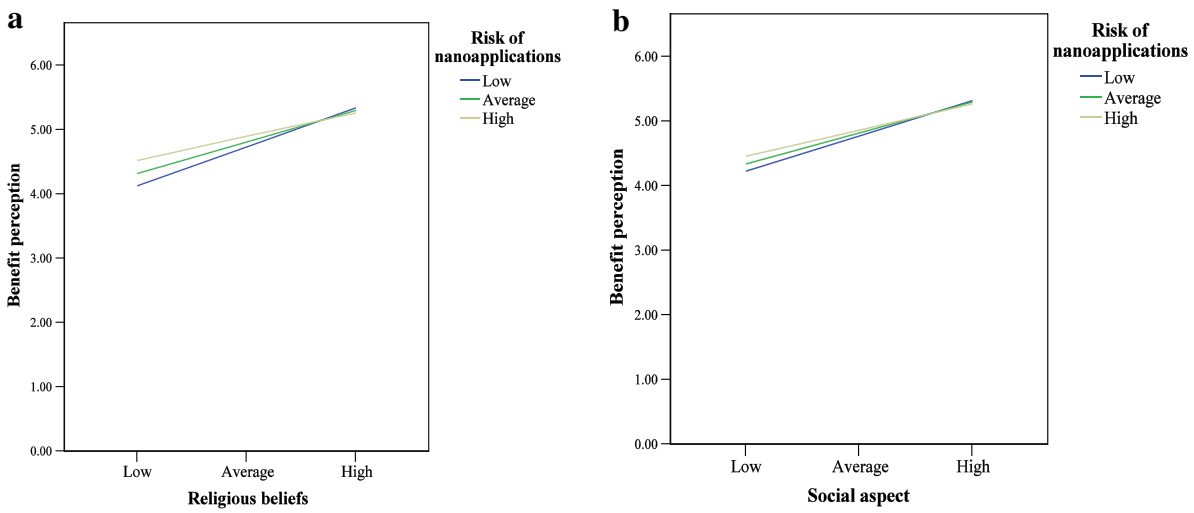

Fig. 8 Risk of nanoapplications: sociological approach. **a** Risk of nanoapplications moderates religious beliefs in influencing benefit perception. **b** Risk of nanoapplications moderates social aspect in influencing benefit perception

development, public culture and social aspect agree that science and technology should spur the economy and enhance public well-being, decreasing the public's risk perception of nanotechnology. Countries that have never had dreadful experience related to scientific and technological development, such as a technological disaster, would not have a public culture affected by social phobia of adopting new technologies, such as nanotechnology (Macnaghten et al. 2016; Roco and Bainbridge 2001). A public protected from any controversial development in technology would accept new technologies by relying on their trust in their government and researchers with a decrease in risk perception among them. Under the stable development of technology and the economy, trust is noteworthy because it influences public perception significantly regarding whether nanotechnology will be accepted or rejected.

This study also found that the perceived benefits of the nanoapplications result in public trust in government and industry, which increases the public's benefit perception of nanotechnology because government and industry play essential roles in managing and delivering useful products to the public. This finding is supported by a study on the increase in public trust in government and industry when nanotechnology applications are beneficial to the public (Maynard 2006). In addition, the result of this study demonstrated that the perceived benefits of nanoapplications affect attitude, trust in government, trust in industry, and trust in researchers by decreasing public risk perception of nanotechnology. Malaysians find that nanotechnology applications are beneficial (Table 1), and the public's attitude toward nanotechnology is also positive. Consequently, the public has a low risk perception of nanotechnology. Public trust in government, industry, and researchers is vital and may boost public confidence regarding the perceived benefits of nanoapplications, leading their risk perception to diminish (Capon et al. 2015). Moreover, the findings show that Malaysian culture, religious beliefs, and social aspect are positive toward nanotechnology. As a result, the public tends to perceive the benefits of nanoapplications, reducing their perceived risk of nanotechnology (Mamadouh 1999).

One notable finding of this research is that high public trust in researchers results in increased benefit perception, although risks are associated with nanotechnology applications. The public believes that researchers will protect them from the risks of nanotechnology, and this, consequently, increases their benefit perception (Kishimoto 2010). However, if too many risks are associated with nanotechnology applications, this negativity will affect public trust in researchers which decreases the public's benefit perception. High perceived risk from nanoapplications, by contrast, increases risk perception and may cause the deprivation of public trust in the government, industry, and researchers (Oh 2009). Thus, the government, industry, and researchers must manage nanotechnology risks to avoid trust deprivation among the public, which may inhibit nanotechnology development. Public religious beliefs and social aspect have been

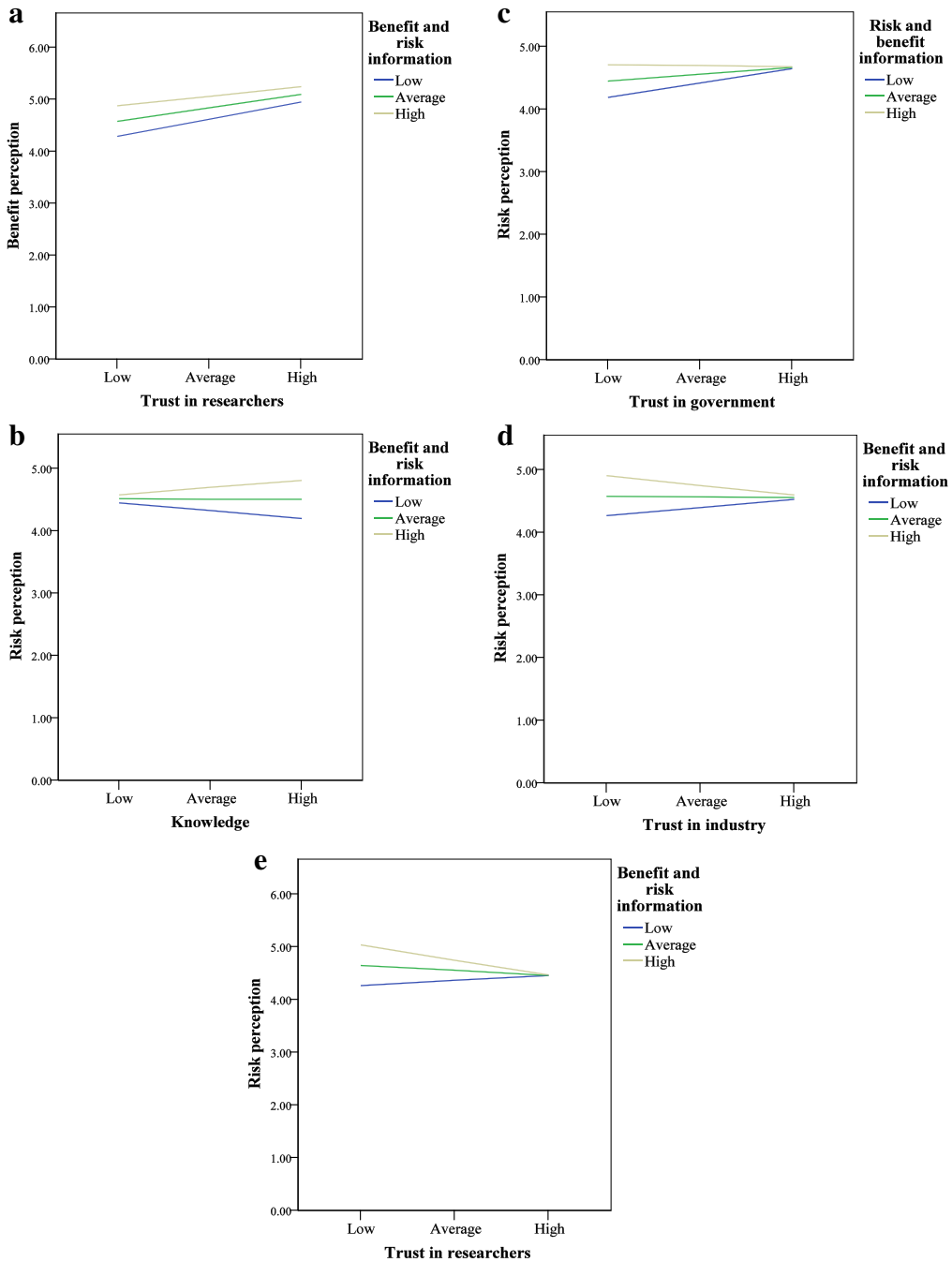

Fig. 9 Benefit and risk information: psychological approach. **a** Benefit and risk information moderates trust in researchers in influencing benefit perception. **b** Benefit and risk information moderates knowledge in influencing risk perception. **c** Benefit and risk information moderates trust in government in influencing risk perception. **d** Benefit and risk information moderates trust in industry in influencing risk perception. **e** Benefit and risk information moderates trust in researchers in influencing risk perception

shown to have a positive perception of nanotechnology, although there are risks associated with nanoapplications. People who adhere to religious dogma consider it critical to make so-called ethical choices, including the safety of applying nanotechnology in consumer products (Conroy and Emerson 2004; Magill 1992).

The benefit and risk information in the form of a label on nanoproducts serves as a communication tool that assists the public with making decisions (Chuah et al. 2018). The public relies on their trust in researchers to increase their benefit perception when the provided information is insufficient. Public trust in researchers is vital in shaping the public's perception of benefits whereby the public is willing to accept vulnerability when they have a high positive expectation of researchers (Roosen et al. 2015). Knowledge, by contrast, increases risk perception when there is a high availability of benefit and risk information. This situation is caused by limited knowledge about nanotechnology among the public. As risk information is more influential, the public, with its various backgrounds, is going to interpret the same information differently (Douglas 1978). The balance of benefit and risk information revealed to the public is crucial to avoid misinterpreting information because the public may not have the expertise and are likely to find the risk more alarming than the benefit (Siegrist and Keller 2011). The lack of information provided to the public can increase risk perception and may deteriorate public trust in government, industry, and researchers. The public expresses the need for information from the experts to lower risk perception amidst the uncertainties of nanotechnology. Mandatory labeling is required to gain public trust and reduce public concern regarding nanotechnology risks (Forloni 2012). In addition, sufficient information will allow public to make decision objectively without overly relying on trust in government, industry, and researchers whereby it may be biased and leads to the wrong decision (Gilovich et al. 2002).

Strategy for good governance of nanotechnology toward sustainable development

Table 4 summarizes the strategy for good governance of nanotechnology by using the intervening variables, namely, media, technology and economic development, benefit and risk of nanoapplications, and benefit and risk information, and can be adequately implemented by the policymakers. In the context of this study, the strategy provides a guideline for further research to consider psychological, sociological, and moderating factors in understanding public perception of nanotechnology. Presently, a recommendation is to develop nanotechnology in line with the public interest and gain their confidence in the ability of nanotechnology to facilitate sustainable development. However, the recommended strategy must be tested in further research to determine the intended effect.

Media coverage is an essential tool to connect the public with nanotechnology development. Equal and inclusive media coverage supported by facts disseminated to all levels of the public will create an informed public capable of assessing nanotechnology. The public will be able to make an objective decision based on facts rather than fiction (Hope and Petersen 2007). Through mutual consent-oriented decision-making, stakeholders are jointly involved with experts to develop nanotechnology without abandoning the needs of the public, especially minority groups. The public trust in researchers should also be leveraged as much as possible by involving more researchers in various fields to share knowledge through media coverage. Researchers participating in delivering information about nanotechnology to the public can enhance the understanding and knowledge of the public. Information is interpreted differently (Lemanczyk 2014); hence, information from various fields such as engineering, ethics, economics, psychology, and sociology would be included to provide a comprehensive perspective of the impact of nanotechnology to the public from all angles and to not merely focus on individuals who are proficient in science and technology per se. Media coverage is a medium to disseminate information effectively, and enhancing the public's perception of benefits may enable nanotechnology to be developed that could achieve sustainable development.

Technology and economic development increase public familiarity with emerging technology, whereby along with the technology and economic development, nanotechnology affects the public by creating jobs (Isaacs et al. 2015). Furthermore, technology and economic development have psychological and sociological impacts that influence public perception, as reported in this research. Therefore, this study suggests the public should be engaged with the development of nanotechnology through exposure to the latest studies on nanotechnology. The development of nanotechnology studies should be used as a guide that informs the public regarding the extent of the rapid development in nanotechnology. The knowledge gap between the researchers and the public will remain if no input is provided to the public from the research conducted. As a result, the public would continue to have a perception

Table 4 Recommendation for good governance of sustainable nanotechnology development

Intervening variable (moderators)	Approaches	Good governance characteristics
Media	Psychology: Benefit perception: • Attitude • Trust in researchers Risk perception: • Knowledge Sociology: Benefit perception: – Risk perception: –	• Consensus-oriented • Equity and inclusiveness
Technology and economy development	Psychology: Benefit perception: • Knowledge • Attitude Risk perception: • Attitude • Trust in government • Trust in researchers Sociology: Benefit perception: – Risk perception: • Culture • Social aspect	• Participation • Transparency
Benefit of nanoapplications	Psychology: Benefit perception: • Trust in government • Trust in industry Risk perception: • Attitude • Trust in government • Trust in industry • Trust in researchers Sociology: Benefit perception: – Risk perception: • Culture • Religious beliefs • Social aspect	• Responsiveness
Risk of nanoapplications	Psychology: Benefit perception: • Trust in researchers Risk perception: • Trust in government • Trust in industry • Trust in researchers Sociology: Benefit perception: • Religious beliefs • Social aspect Risk perception: –	• Responsiveness
Benefit and risk information	Psychology: Benefit perception: • Trust in researchers Risk perception: • Knowledge • Trust in government	• Rule of law • Effectiveness and efficiency • Accountability

Table 4 (continued)

Intervening variable (moderators)	Approaches	Good governance characteristics
	• Trust in industry • Trust in researchers Sociology: Benefit perception: – Risk perception: –	

solely based on their feelings (Binder et al. 2016), and not supported by the information from nanotechnology studies. Good governance of nanotechnology should promote public involvement and consider public concerns. Therefore, without reliable information tailored to multiple levels of intellect, the public may have difficulty in effectively communicating their needs, desires, and concerns regarding the development of nanotechnology because they would not be capable of making scientific decisions (Lin et al. 2013). Sustainable development driven by nanotechnology can perhaps be achieved by overcoming the barriers of communication between the public and policymakers.

Benefits and risks of nanoapplications depend on the size of the materials used. Similar materials of different sizes have different properties. Nanosized materials possess properties that can be used to produce high-quality products. Additionally, the risks of products containing nanomaterials remain unknown. An abundance of products on the market claim to contain nanomaterials; however, the validity of this claim is dubious. No regulations have been established for nanoproduct manufacturers, and no mandatory tests are required of manufacturers to verify the presence of nanomaterials in their products. Therefore, it is desirable for the public to know whether their purchased products contain nanomaterials. Hence, this study suggests that a responsible institution responsive to public concerns and inquiries by providing feedback from research findings on products on the market that claim to contain nanomaterials is necessary. The public also needs information from the continuous research on nanoproducts on the market to have confidence in the capabilities of nanotechnology (Macoubrie 2005). Feedback should be provided to the public within a reasonable timeframe after research activities have been conducted so that the public is satisfied with the benefits they receive from nanoproducts and protected from unwanted risks. Feedback will increase public confidence in stakeholders to be responsible for developing nanotechnology that has the ability to improve the quality of life and well-being.

For benefit and risk information, this study suggests good governance by ensuring the safety of the public through legal regulations through law enforcement. The legislation will provide an effective regulatory environment for nanotechnology development activities (Roco and Bainbridge 2005). Regulations for mandatory labeling are required to provide information to the public on the benefits and risks of nanoproducts. The public supports mandatory labeling containing information on the benefits and risks along with research evidence so they can use nanotechnology with confidence; additionally, sufficient information increases the public trust in stakeholders (Brown and Kuzma 2013; Chuah et al. 2018; Macoubrie 2005). These actions should be taken immediately to further prevent the public from having a negative attitude toward the government because the government may take a long time to act while nanoproducts have already entered the consumer market (Gehrke 2018). Consequently, taking immediate action requires standard labeling on nanoproducts to be further reinforced through law enforcement; then, public confidence in the government will increase and the subsequent use of nanotechnology would spur sustainable development of the country.

Conclusion

This study was conducted using psychological and sociological approaches to determine the intervening factors affecting the public perception of nanotechnology.

Public perception serves as a guide for good governance of nanotechnology, that is, not only for the public to be well informed to accept nanotechnology development but also to ensure the public is capable of making a fact-based decision. Furthermore, the public will be able to communicate their needs, wants, and concerns regarding nanotechnology effectively to policymakers. Therefore, emerging nanotechnology can be beneficial for sustainable development by driving economic growth, solving environmental problems, and improving the well-being of the public.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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