Understanding Public Benefit and Risk Perceptions Through Psychological and Sociological Aspects for Sustainable Nanotechnology Development in Malaysia

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Abstract

Nanotechnology has opened a new realm to science and technology whereby it has been developed and used in various applications with potentials to facilitate sustainable development. The applications of nanotechnology are beneficial in improving public health, enhancing the functionality and endurance of consumer products, and potentially preserving the environment; however, uncertain risks associated with nanomaterials need to be understood for a good governance of nanotechnology to ensure sustainable development of nanotechnology. Hence, public perceptions of nanotechnology are instrumental for good governance of nanotechnology to determine the acceptance and rejection of the public toward nanotechnology. In this chapter, the public benefit and risk perceptions of nanotechnology are deliberated based on a case study in Klang Valley, Malaysia, through psychological and sociological aspects. Psychologically, knowledge is not a factor affecting the benefit and risk perceptions. However, the public perceives nanotechnology to be more beneficial than risky. Public attitudes are positive for nanotechnology, giving people benefit perception and reducing risk perception of nanotechnology. Trust in government, industry, and researchers increases the public benefit perception on nanotechnology as they are the driving force of nanotechnology development. The government as the regulator of nanotechnology development affects risk perception when public trust in government declines. Therefore, the government needs to play a role in getting public trust, thereby enhancing the public benefit perception on nanotechnology. Sociologically, i.e., culture, religious belief, and social aspect influence the public benefit perception but not risk perception on nanotechnology. Policy and religion emphasizing science and technology as an economic driver for the well-being bring the culture in receiving both scientific and technological developments in general and nanotechnology in particular. Correspondingly, continuous research of nanotechnology will result in the social implication by ensuring equal distribution of nanotechnology benefit, and at the same time, its risk will be effectively managed.

Keywords

Benefit • Risk • Perception • Nanotechnology • Sustainable development

1 Nanotechnology

Nanotechnology is defined as "technological research and development at atomic, molecular, or macromolecular levels, on a scale of 1–100 nm that provides a basic understanding of the material phenomenon at the scale of creating and using structures, devices, and systems that have the properties and novel functions because of its small size" (Roco 2011; Kamarulzaman et al. 2019). Small nanoscale has a wide surface to react effectively, compared to the same material but at the scale of hundreds of nano or microns. Nanomaterials can improve the previously unattainable electronic, optical, catalyst, and magnetic functions of a typical size within a range of hundreds of nanometers. The novel property of this material has function that can be processed into various forms, and physical chemistry of nanomaterials makes it widely used in manufacturing to develop more durable and high-performance products (Gleiche et al. 2006; West et al. 2016). The rapid development and widespread applications of nanotechnology make

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it one of the catalysts for the Fourth Industrial Revolution (Maynard 2015).

Nanotechnology is developed as a capable technology for a variety of powerful applications that have never been thought to exist before which is also similar to the uncertain risks associated with nanotechnology. Many of the successes acquired by the new findings today would have a social impact on the public. Nanotechnology applications have changed the lives of people with more energy, telecommunication, medical, and engineering applications (Moussaouy 2018) whereby public is the one benefited and exposed to the risks of technology developed in a country. However, some risks are acceptable to the public when the risks are properly managed to bring benefits (Starr 1969). Nanotechnology has the potential to create value to sustainable development through public, economic, and industrial development if risks associated with nanotechnology can be controlled (Renn and Roco 2006). If the public engaged in the early stage of nanotechnology development, their perceptions will be taken into account in raising public awareness of nanotechnology and thus enabling policy-makers to develop nanotechnology in harmony with the needs of the public that will also ensure their well-being and safety (Rogers-Hayden and Pidgeon 2008). In this regard, this will encourage the advancement of technology that is in line with the progress of public thinking with the cooperation of stakeholders, such as the government, researchers, and industry players, to convey knowledge to the public. Hence, this partnership will create harmonious technology with the public. The development of nanotechnology not only provides the opportunities for public participation in voicing their will for a prosperous life and concern for the associated risks, but also opportunities for stakeholders to gain people's confidence by managing the risks posed nanotechnology effectively (Michelson and Rejeski 2006). As a result of collaboration between the public and stakeholders, it will create knowledge, skills and value to nanotechnology development for a sustainable future (Moussaouy 2018).

The benefits and risks of nanotechnology can be exposed to the public through nanotechnology applications. Nanotechnology has the potential for sustainable development by enhancing product functions, strengths, and prolonging product life span. However, there are concerns about uncertain risks associated with nanotechnology. The first thing to worry is the size of nanoparticles ranging from 1 to 100 nm, and this is the size that causes the nanoparticles to have different physical, chemical, and biological properties compared to the same but larger particles (Vishwakarma et al. 2010). These tiny nanoparticles size can penetrate into the human body and damage the cells and tissues. The second is the manufacturing and disposal of nanomaterials which may produce new pollutants that can be released into the environment through water and air (Roco 2003).

There are several nanotechnology applications that involve public directly, such as cosmetics, electrical appliances, foods, sports equipment, medicine, and household products (Kishimoto 2010; West et al. 2016). Table 1 shows the benefits and risks of nanotechnology applications.

Nanotechnology applications in cosmetic products and electrical appliances have been widely available in the market (Bennet-Woods 2008; Mamadou et al. 2012).

Table 1 Benefits and risks of nanotechnology applications

Nanotechnology applications	Nanomaterials	Benefits	Risks	References
Electrical appliances	Carbon nanotubes and quantum dots	Efficient use and storage of electricity	Exposes to hazard during the production of nanomaterials	Allsopp et al. (2007)
Medicine	Carbon nanotubes and boron nitride nanotubes	Diagnosis of illness using nanomaterials and drug delivery on cells	Toxic effect of nanomaterials to the cells	Raffa et al. (2010)
Detergent	Titanium dioxide, nanosilver	Dirt is easily removed and anti-bacterial	Endangers aquatic life	Mehic (2012)
Cosmetic	Nanoliposomes	Improves the absorption of cosmetic products into the skin	Absorption of nanomaterials into skin and respiration	Raj et al. (2012)
Food	Zinc oxide, carbon nanotubes, and titanium dioxide	Smart delivery of nutrition and nanoencapsulation of nutrients to plants	Health risk to consumers	Parisi et al. (2014)
Water treatment	Zeolite and titanium dioxide	Treats water by removing organic and inorganic compounds, microorganisms, and heavy metals	Nanomaterials can be new pollutants to the environment	De Luca and Ferrer (2017)
Sports equipment	Zinc oxide, carbon nanotubes, and titanium dioxide	Increase strength, lightness, and comfortness	Risk to users' skin	Harifi and Montazer (2017)

Examples of cosmetic products containing nanomaterials are lipstick, face cream, toothpaste, and UV cream (Hristozov and Malsch 2009). Nanoliposome is used to improve the absorption of cosmetic products into the skin and thereby improve product efficiency (Raj et al. 2012). This widespread use concerns the consumers about the safety of nanomaterials contained in cosmetics that can seep into the skin and enter the respiratory tract when inhaled (Mu and Sprando 2014).

Electronically assembled hardware also contains nanomaterials, such as carbon nanotubes and quantum dots to promote efficient use and storage of electricity (Allsopp et al. 2007; Mensch and Umwelt 2014). However, consumers are at risk exposing to nanomaterials through air and skin contact, when they are working in the production of nanomaterials in a laboratory or manufacturing plant.

With the growth of world population, food and water security are the fundamental issues that need to be addressed to achieve sustainable development. Nanomaterials such as zinc oxide are applied in fertilizers to improve nutrient absorption by plants. Nanosensors are used to identify early disease on plants to prevent crop damage (Handford et al. 2014). Nanotechnology applications in food production have the capability to increase food production and avoid the shortage of food sources in the future (Parisi et al. 2014). However, the impacts of nanomaterials to consumers' health and the environment are of concerns of the public.

Nanotechnology is used to treat water including groundwater and wastewater by using carbon nanotubes, zeolites, and titanium dioxide which are capable in removing organic and inorganic compounds, microorganisms, and heavy metals (De Luca and Ferrer 2017). Magnetic nanoparticles that are widely used in treating water can be easily obtained from the nature; hence, this makes the cost of using nanomaterials in water treatment cheaper than conventional ones (Fromer and Diallo 2013; Sannino et al. 2017). Water treatment using nanotechnology is cost-effective in ensuring adequate sanitation and water supply for the world's population. However, nanomaterials could be a new pollutant to the environment through water drainage (Roco 2003).

Sports activities are part of a healthy lifestyle for the well-being of the public, while advanced medicine can safeguard the public health. Nanomaterials such as carbon nanotubes, zinc oxide, and titanium dioxide are used in sports equipment to increase strength, lightness, and comfort to consumers. Among other benefits being sports clothing designed with nanotechnology have advantages, such as waterproof, anti-bacteria, anti-odor, and UV protection. However, the risk on consumers' skin and the environment is still unknown (Harifi and Montazer 2017). In advanced medicine, carbon nanotubes and boron nitride nanotubes are used in nanodiagnosis through magnetic resonance imaging and therapy using nanomaterials to improve diagnosis and treatment of diseases (Raffa et al. 2010). However, the use of nanoparticles for the delivery of drugs to certain cells has the risk of harmful substances from the nanoparticles. Nanoparticles are likely to be released into the body and cause toxic effects to cells and tissues.

Nanoscale titanium oxide and silver are known for their anti-bacterial and hydrophobic properties that can be applied in detergents, such as dishwashing soap and detergent soap (Mehic 2012). The detergent will be more effective when the dirt is easily removed, and the cleaned surface becomes waterproof. Thus, the surface will take longer time to become dirty again (Gleiche et al. 2006). Compared to larger-sized silver, nanosized silver has a higher free radical rate and when nanosized silver flows into the body of water, it can endanger the living (Mehic 2012).

The application of nanotechnology is beneficial to the public for the well-being of life and improves the public health which is one of the important elements for sustainable development. However, uncertain risks associated with nanomaterials are alarming and require a good governance of nanotechnology to ensure the safety of the public. Hence, public perceptions of nanotechnology are instrumental for good governance of nanotechnology to further understand the needs of the public toward nanotechnology. This understanding is essential for nanotechnology to be developed without leaving behind the public that can lead to rejection and thus inhibit sustainable development of nanotechnology.

2 Public Perception Toward Nanotechnology

The appropriate use of nanotechnology can address environmental limitations to meet the needs of population growth. From time to time, nanotechnology developed will undergo several modifications to meet the acceptance of the public. This modification will continue to take place so that nanotechnology can be fully accepted by the public, and the technology is said to have reached its stable and sustainable use by the public (Saidi 2018). The benefit and risk of nanotechnology will be evaluated by the public, whereas the conflict in the acceptance and rejection of nanotechnology will depend on differences in interpretation and controversial cases that are associated with nanotechnology.

Public perception is defined as a social phenomenon of how public sees risks and benefits in current situations based on facts or fictions of current knowledge, culture, and/or media. Public processes risk in their minds as a concept to deal with uncertainty and danger in life (Sjöberg et al. 2004). Conversely, benefit perception is built up when they believe it will get something positive based on a specific action (Leung 2007). The public and those who are experts on nanotechnology have a very different way of looking at the

risks. From experts' point of view, risk is seen as an annual death rate, while the public sees it as a level of danger and accidents.

The human mind builds uncertainty because the lack of complete knowledge put individuals in an unconfident position with fear or suspicious. Individuals will choose to act in a safe condition and less risky to them. However, not all risks are acceptable to the public. Some risks are acceptable if it brings benefits (Starr 1969), and this type of risk is called voluntary risk. Mathematically, risk is defined as the magnitude of the loss multiplied by the probability of occurrence. Risk is viewed from various angles including risk factors, time risks, and those that will be affected by certain risks. The subjective assessment of the probability of occurrence creates the individual's benefit and risk perceptions. The benefit and risk perceptions are indeed a debate whether the perception should be rationalized by individuals who are experts in a particular field or acceptable from the irrational opinion of the public opinion (Fischhoff et al. 1983). Individual's perceptions of nanotechnology are not only influenced by their level of knowledge, but their perceptions are also influenced by social, cultural, and ideological (Sjöberg et al. 2004).

The heuristic cognitive strategies are most commonly used by individuals to make choices and assessments quickly (Gilovich et al. 2002; Pieper 1989). Individuals will use heuristics by customizing existing information to assist them in making decisions. When a person receives information stating low risk is associated with a technology, the person will evaluate the technology as safe and vice versa (Slovic et al. 2007). Individuals will not only evaluate based on the information provided, they will also evaluate based on what they feel, whether they like or dislike a particular technology (Finucane et al. 2000). However, decisions made using heuristic methods can be biased and will contribute to errors (Stanovich and West 2000). However, today we need to make a quick decision based on what has been presented to us (Gilovich et al. 2002); hence, different levels of intelligence, worldview, and thinking will result in different decisions.

In the early stage of understanding the perceptions of nanotechnology, people with a scientific background feel that nanotechnology is beneficial, but some worry about the inequality of future benefits (Bainbridge 2002). Concerns about the risks in nanotechnology development have increased in 2003 when research on nanotechnology impacts on the public, such as new pollutants produced in nanoscale began to be published (Roco 2003). Concerns about misuse of nanotechnology produce more destructive weapons than weapons that do not use nanotechnology (Phoenix and Treder 2003). The public concerns over the same risk of nanotechnology (Cobb 2005; Cobb and Macoubrie 2004; Cormick 2009; Macoubrie 2006) whereby not only weapons are the main concerns of the public, but also devices that can affect the privacy of the public, such as mini-surveillance devices that can be placed in clothing and stuff (Cobb and Macoubrie 2004; Cormick 2009). In addition, "fear of something unknown," "acts contrary to nature's processes," and "environmental degradation" are among the public's concerns about nanotechnology (Cormick 2009).

Meanwhile, nanotechnology has been proven to give solutions to many problems, such as early detection and disease treatment, optimizing the use of non-renewable resources, effective pollution recovery, and many other benefits (Kharat et al. 2017). Researches show that people respond positively to nanotechnology compared with worry (Bainbridge 2002; Binder et al. 2012; Bostrom and Löfstedt 2010; Burri and Bellucci 2008; Cobb and Macoubrie 2004; Cormick 2009; Dijkstra and Critchley 2014; Zhang et al. 2015) though they are not knowledgeable about nanotechnology. Based on the limited knowledge, the public can still make decision based on what is provided to them by the media and use other social aspects to assess the benefits and risks of new technologies (Lee et al. 2005; Schütz and Wiedemann 2008). The individual's ability to assess nanotechnology whether is beneficial or risky will determine the acceptance or rejection of the public. The public perceptions are important to enable the continued development of nanotechnology for sustainable development; hence, the factors that influence the public perceptions will guide the government, researchers, and industry to understand the needs of the public and develop nanotechnology sustainably.

3 Psychological and Sociological Aspects for Public Benefit and Risk Perceptions

The heuristic method introduced by Simon (1977) has suggested a cognitive strategy to make a decision easily under uncertain circumstances. When a person makes a decision, the individual cannot avoid making decisions that are influenced by personal, socioeconomic, and political views, cultures, and so on that become part of a person's life (Pieper 1989). People have different perceptions when exposed to the same information but presented in different ways (Tversky and Kahneman 1981). Wildavsky (1987) argues that one does not have to work hard and become a politician to give opinions on politics, but they need to know only some of the information they have and they already can give opinions (Wildavsky 1987).

While cultural theory explains the tendency of individuals to make choices whether beneficial or risky for a dangerous thing or activity is dependent on the culture practiced (Kahan et al. 2009). Kahan et al. (2009) also shows that individuals choose information that is relevant to the cultural views as well as political inclination despite being exposed to the

same information. The concept of cognitive psychology and cultural theory is the basis that adapts two approaches, namely psychology and sociology, from Renn and Swaton (1984) to better understand public perceptions of nanotechnology. Psychological aspects focus on cognitive psychology involving one's cognitive ability to assess risks and benefits when making decisions based on knowledge, individual attitudes, and trusts to stakeholders managing nanotechnology (Renn and Swaton 1984). While sociological aspects are the decisions made by individuals who are influenced by social groups represented by them (Renn and Swaton 1984) whereby this approach encompasses culture and religious beliefs they practice. In addition, there are intervening variables (moderators) which also influence the public perceptions of nanotechnology psychologically and sociologically, such as media coverage, technology development, and economic status, different nanotechnology applications, as well as benefits and risk information (Petersen et al. 2007; René Zimmer et al. 2010; Schütz and Wiedemann 2008; Siegrist 2010).

3.1 Psychological Aspects

Psychological aspects refer to cognitive psychology involving the receipt of information, retention of information, and retrieval of necessary information. However, information may be interpreted differently depending on respective individual whereby individual with complete information and knowledge will make more objective decision than an underprivileged individual. This situation differs from individual who does not have enough information to make decisions that are biased based on their preference (Finucane et al. 2000). However, the biased decisions are still accepted as one of the ways in thinking whereby a person's failure to express feelings because impairment of the brain causing the individual not able to make decision and socialize (Damasio et al. 1990).

Experts like scientists and researchers who are knowledgeable about nanotechnology show different perceptions about nanotechnology compared to the civil society (Cormick 2009; Siegrist et al. 2007a, b). Both of these groups of experts agree that the benefits of nanotechnology exceed the risks even though people tend to see nanotechnology has more risks than experts do. Those with complete knowledge of nanotechnology will find the benefits exceeding the risks and are willing to accept the technology (Binder et al. 2012; Brossard et al. 2009; Retzbach et al. 2011; Scheufele and Lewenstein 2005). Based on experts' knowledge, they are less concerned about the risks of nanotechnology as the risks of nanotechnology have no direct impact on the civil society (Siegrist et al. 2007a, b). Complete knowledge will put individuals in a confident position without fear. The difference in the perceptions of benefits and risks between experts and the public is also due to experts' experience which is not available to the public. Their experience, knowledge, and expertise in handling nanotechnology enable them to see the development of nanotechnology in a controlled manner resulting in their risk perception lower than the public (Renn and Swaton 1984). However, experts are concerned with "new pollution" and "new disease" that may arise due to nanotechnology in the future (Cormick 2009).

Limited knowledge of the public about nanotechnology does not refrain them from being positive with the development of technology when they have confidence in those managing nanotechnology. The trust given by the public to the government, researchers, and industry makes it easier for them to make decisions based on information received about nanotechnology (Chen et al. 2013). Public policy can also be easily formed with the trust given by the public (Pidgeon et al. 2009). According to Siegrist et al. (2007a, b), experts have more faith in the government in handling nanotechnology and protecting the public from risks. While the public depends on how the government, researchers, and industry manage the risks inherent in nanotechnology, people also tend to be hesitant and afraid of the goals of nanotechnology and the effects of nanotechnology they will receive. Citizens who trust government agencies like the Food and Drug Administration (FDA) will continue to believe the government will prioritize the public's interest by providing information on nanotechnology in labeling and possibly establishing a mandatory labeling in the future (Brown and Kuzma 2013). The public trusts are important for policy-makers to enable them to manage the public's doubts and concerns and move on to develop nanotechnology in the direction of convincing the public.

The attitude functions as a heuristic signal to individuals when one recalls their behavior in the past and influences their judgments and decisions in the present situation (Bem and McConnell 1970; Pratkanis 1988; Ross et al. 1981). The information received is defined differently according to the individual's background. A person will decide whether to like the information they receive based on their memory of the information. Heuristic attitudes are defined as "evaluative relationships in which one uses an object as a strategy to solve the problem by determining whether the object is in a preferred category (such as a strategy of liking, approaching and protecting) or being in an unwanted category (such as a strategy of hate, avoid and harm)" (Pratkanis 1988). The positive or negative attitudes of the public toward nanotechnology differ depending on the benefits and risks seen by individuals (Besley 2010; Chen et al. 2013). People who have a positive attitude toward science and technology and have never encountered a bad controversial experience involving science and technology in their country will see

nanotechnology as beneficial, thereby having a positive attitude toward nanotechnology (Zhang et al. 2015). In contrast, people who faced controversial issues with science and technology will see nanotechnology as risky and likely to reject nanotechnology (Bennet-Woods 2008).

3.2 Sociological Aspects

Apart from the knowledge gap between experts and the public, the beliefs held by the public toward those managing nanotechnology, heuristic attitudes that produce risk and benefit perceptions, and personal values also operate as a perception filter for people to understand the emergence of new technologies. Individuals from diverse backgrounds will interpret the same information differently depending on the value and tendency they hold. Sociological aspects refer to the perceptions of the public that are created and influenced by social groups represented by a particular individual and also based on the cultures and the religions practiced.

An individual's way of life is a combination of cultural values (shared values and beliefs) and social relationships (human relationships) (Douglas 1978). Culture is defined as a lifestyle that contains values and beliefs taught by older generations and then inherited by the younger generation (Oltedal et al. 2004). In addition, one's views are also shaped by social groups, such as organizations and peers who are part of the individual (Tansey and O'Riordan 1999). The public learns and understands their culture in deciding whether something is beneficial or risky and choose something according to their cultural values (Mamadouh 1999). Solid support for nanotechnology can be observed in China whereby Zhang et al. (2015) shows that Chinese have high expectations on nanotechnology to improve their standard of living and enable them to compete globally. It has become a culture for the Chinese society to support technology since the establishment of the Open-Door Policy in 1978 which involved science and technology as the prime mover for economic and industrial development.

In the social context for social interactions and social relationships in social groups (a group of individuals with similar aims and collective unity), public perceptions of nanotechnology not only focus on nanotechnology toxicological risks but extend to the benefits and risks of nanotechnology in manufacturing and production, distribution, use and disposal of products that will only be experienced by certain social groups and not other groups (Conti et al. 2011). This leads to public perceptions of nanotechnology that involve the distribution of nanotechnology equally to all different societies and gender groups across various social groups. The inequality of the distribution of the benefits and risks of nanotechnology to social groups in society may lead to a handful of social groups tend to be exposed to risks rather than benefits of nanotechnology. Meanwhile, affordable social groups have access to nanotechnology benefits without being exposed to risks.

Different social groups will have different perceptions depending on how the technology benefits them and how risks are handled. Furthermore, social groups with knowledge of nanotechnology also have different interpretation of benefits and risks based on their technical skills in handling the technology (Saidi 2018). In this situation, social beliefs are best suited for the public when there is a lack of capacity, knowledge, interests, and resources. Social beliefs are the willingness to rely on those responsible for decision making and taking action relating to technology, environmental, medical or health management, and public safety management (Siegrist et al. 2000). Therefore, public acceptance of new technologies depends on information provided and social trust guides to the government, researchers, and industries (Cobb and Macoubrie 2004; Currall 2009; Siegrist et al. 2000).

Religion is part of a value system that affects individuals to understand new facts that are received including science and technology. Public acceptance of technology varies based on faithfulness of religion. People with a strong religious faith are morally disproportionate with nanotechnology as compared to those who have less faith in religion. The benefit perception toward nanotechnology is found among the less religious public and living in a secular society. Technology is a moral issue that gets the attention of the public holding religious beliefs because for them technology interferes the natural processes of nature. This situation is considered to be risky and morally unacceptable (Scheufele et al. 2009) because the public that hold strong faith also do not support funding for research and development of nanotechnology (Brossard et al. 2009) as they believe the technology interferes natural processes and associate with the term of "play God."

3.3 Other Factors

With limited knowledge of nanotechnology, heuristic is the common method used by people to make decisions. Television, radio, Internet, and newspapers are easily accessible to the public and are the main sources of information for the public (René Zimmer et al. 2010). Exposure to media coverage about nanotechnology will increase the public's understanding of the technology. Typically, mass media often reports something new with negative tone (Metag and Marcinkowski 2014) whereby this negative information that is over-showing about a technology will cause the public to become phobia toward the technology and causes the rejection of the technology.

Public perception depends on how the media display information about nanotechnology (Cacciatore et al. 2011;

Lee et al. 2005). Based on the information presented, the public will assess and decide whether nanotechnology is beneficial or risky. Media coverage can be in a different tone whether reporting on the benefits of nanotechnology exceeds risks by choosing only certain risks to highlight or report on nanotechnology risks exceeds its benefits (Gorss 2008). In addition to news tones that may affect public perceptions, scientific information should also be covered so that the public can develop benefit or risk perceptions objectively (René Zimmer et al. 2010).

The media that deals with the benefits of nanotechnology which covers its impact on social, economic, ethical, and related risks will provide complete input to the public. Subsequently, their perceptions will be formed based on a better understanding of the current development of nanotechnology (Tyshenko 2014). However, the public have the freedom to choose information they want to know and have their own interpretation (Lemanczyk 2014). Media coverage gives the public an idea of the development of new technologies that can influence the perceptions of the public at an early stage; however, as the technological development goes on, public perceptions may change accordingly (Nisbet and Huge 2007).

Public perceptions evolve as technology progresses. When technology is developing, more information about technology will reach the public and give them more understanding of the technology (Kahan et al. 2009). People have different perceptions and reactions to technologies they already know and understand. Low risk perceptions are found among societies in developed countries that adopt technology. Along with the development of technology, environmental destruction is something that worries a society that is not familiar with certain technologies as they view technology is threatening the environment and causing destruction. Compared to people in a country that is familiar with technology, environmental destruction is not a major cause of technological development (Lima et al. 2005). Fear of technology will decrease when people become more familiar with the technology and find benefits exceeding risks. In countries which economies are driven by technology, the public have benefit perception over their risk perception (Liu et al. 2009; Zhang et al. 2015). Public support for nanotechnology depends on their expectations of nanotechnology contributions to socioeconomic well-being (Könninger et al. 2010).

Although nanotechnology is generally accepted by the public, the public sees the benefits and risks of nanotechnology differently, and these differences depend on specific applications (Siegrist et al. 2008). The public accepts nanotechnology applications when they are useful, beneficial, and essential to them (Gupta et al. 2012). While nanomaterials in food can further enhance nutrient absorption into the body, nano-containing foods are of the most worried nanotechnology applications and most not accepted by the public (Kishimoto 2010; Siegrist et al. 2007a, b; Siegrist et al. 2008). The public believes nanomaterials in food are hazardous and can be harmful to health in the long run (Giles et al. 2015; Siegrist et al. 2007a, b). Electrical appliances containing nanomaterials and nanotechnology applications in medicine, such as channeling drugs to specific target cells, are accepted nanotechnology applications as they are beneficial to the environment and universal health (Gupta et al. 2012). Comparing to food packaging containing nanomaterials, the public finds that food packaging containing nanomaterials is more beneficial than food containing nanomaterials (Siegrist et al. 2007a, b).

The benefits and risks' information about nanotechnology products through labels are used to inform the public about the content of nanotechnology products and increase their awareness of products containing nanomaterials. Providing nanotechnology risks' information to the public increases the public awareness as the negative information has more impact compared to benefits information (Cobb 2005). The provided labels act as information tools to the public that help them to make decisions and select products in guided way (Chuah et al. 2018). The information provided will give the public an overview of the benefits and risks inherent in nanoproducts. Product labeling with "contains synthetic nanoparticles" label provides product risk information, hence increases consumer risk perception rather than non-labeled nanoproducts (Cobb 2005; Siegrist and Keller 2011). Labels help the public to make objective decisions without bias even though the information on labels is limited. Rational decisions made based on limited information are better than just relying on intuition alone without any fact of support (Renn and Swaton 1984). However, without any knowledge of nanotechnology and if users do not read labels on the product, nanotechnology product labeling can be ineffective as a medium to convey information to the public (Brown and Kuzma 2013).

3.4 Concept

The development of nanotechnology has shifted from research in laboratories to commercialization of products in the market. In 2020, nanotechnology is expected to increase up to USD 75.8 billion from nanoapplications in the fields of electronics, energy, cosmetics, medicine, defense, food, and agriculture (Sheila 2017). Nanotechnology is also referred as an industrial revolution that is potentially for sustainable development (Gaskell et al. 2005; Leinonen and Kivisaari 2010; Wiek et al. 2012). Public perception of nanotechnology on health, safety, and environment is an important factor to be addressed to ensure the responsible development of nanotechnology and meet the needs of today's generation without compromising the needs of future generations.

Technology transfer between industries and researchers not only produces products that use competitive nanotechnology in the market but also examines their impact on human health and the environment throughout the lifecycle of nanotechnology products (Musazzi et al. 2017). The increasingly advanced nanotechnology knowledge among experts and the rapid development of nanotechnology in the industry, however, have led the public to lag behind current technological developments. Previous studies show that educated individuals about technology will continue to increase their knowledge of nanotechnology, while less educated individuals will continue to lag behind (Corley and Scheufele 2010).

This gap of understanding and knowledge makes the use of new technologies, such as nanotechnology to be applied in the life of the public effectively becomes vague. Discussions between experts in the field of nanotechnology with civil society are the approaches taken to convey information to the public, while at the same time gaining the perspectives and views of the public on nanotechnology (Kass 2001). This will lead to good governance of nanotechnology that promotes public involvement to enable nanotechnology to be applied to the well-being of the public, thus leading to sustainable development. Good governance involves the process of making and implementing the decisions needed to develop nanotechnology properly. Good governance is defined as effective governance with specific characteristics, and governance performance needs to be assessed with accurate data (Rotberg 2014). There are eight characteristics of good governance, being (1) public involvement, (2) the rule of law with a fair and equitable legal system, (3) transparency in decision making and any action taken is in accordance with the law, (4) provide feedback which is effective at the right time, (5) consensus oriented of the parties involved, (6) the equality and inclusion of all parties involved, (7) effective and efficient in managing and using resources sustainably, and (8) accountability for each effect of the decision taken (UNESCAP 2009).

Good governance in this context is collective in managing nanotechnology at all levels of the organization to establish relationships not only among organizations but also with the public. Good governance of nanotechnology requires transdisciplinary knowledge and implementation between scientists and non-scientists (Hurni and Wiesmann 2014). The involvement of those with the skills of the public can reduce the knowledge gap between them (Roco et al. 2011), and decisions are made with social-oriented interests without prejudice (Rist et al. 2007). Procedures for decision making on risk-related issues require transparency in the administration and public involvement (Renn and Swaton 1984). Hence, the public benefit and risk perceptions toward nanotechnology give a preliminary view of the acceptance or rejection of the public which is the basis of good governance of nanotechnology so that the benefits of nanotechnology are distributed equally at all levels of society while the risks are well managed to ensure the safety of society.

The conceptual framework as shown in Fig. 1 provides an understanding of the two approaches, namely psychological and sociological approaches, that influence the public perception toward nanotechnology. The concept of

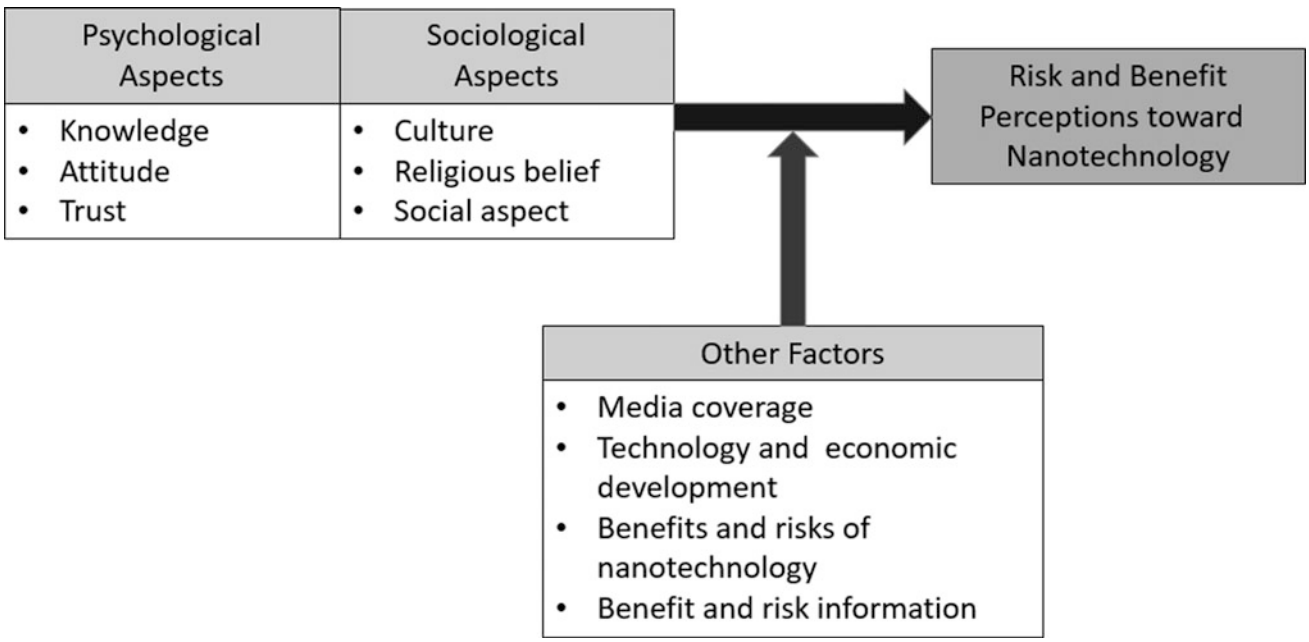

Fig. 1 Conceptual framework for understanding psychological and sociological aspects that influence the risk and benefit perceptions toward nanotechnology (Kamarulzaman et al. 2018)

psychological and sociological approaches is adapted from Renn and Swaton (1984) that used these approaches to understand the perception of risk among society. Psychological aspects consist of knowledge, attitude, and trust aspects, while sociological aspects consist of culture, religious belief, and social aspects. Apart from these two approaches, there are also other factors affecting public perceptions known as moderators consisting media coverage, technological development and economic status, benefits and risks of nanotechnology applications as well as benefit and risk information. Understanding all these factors in influencing the public benefit and risk perceptions will be instrumental for sustainable nanotechnology development in Malaysia.

Following is the definition for perception and factors contributing to benefit and risk perceptions.

Public perception:

(i) Benefit perception—Benefit perception illustrates the mental process of representing and assimilating the possibility of beneficial events relating to certain objects or activities that may occur in the future (Renn and Swaton 1984).
(ii) Risk perception—Risk perception describes mental processes representing and assimilating the likelihood of adverse events associated with certain objects or activities that may occur in the future (Renn and Swaton 1984).

Psychological aspects:

(i) Knowledge—Knowing the definition, usefulness, and application of nanotechnology (Kishimoto 2010).
(ii) Attitude—The views and opinions of the public on nanotechnology are either beneficial or not including the application of nanotechnology into consumer products as well as the desire to purchase products that contain nanomaterials (Kishimoto 2010). Attitude is also a heuristic signal when one remembers the past behavior that will affect the decisions made today (Bem and McConnell 1970; Pratkanis 1988; Ross et al. 1981).
(iii) Trust—Trust refers to the government, industry, and researchers in developing nanotechnology toward meeting the needs and wants of the public (Kishimoto 2010).

Sociological aspects:

(i) Culture—Culture is defined as a lifestyle with shared values and beliefs inherited by older generations to young people who influence one's views and perceptions on something (Oltedal et al. 2004).
(ii) Religious belief—Religious belief is part of a value system that affects individuals in understanding new facts received including science and technology (Kim 2017).
(iii) Social aspect—Social groups, such as organizations and peers that influence one's views and perceptions on a subject including religious groups they represent (Tansey and O'Riordan 1999).

Other factors:

(i) Media coverage—Media coverage includes print and electronic media covering the benefits and risks of technology in general and nanotechnology in particular that affect the public's response to new technologies (Schenk et al. 2008).
(ii) Technological development and economic status—The development of a growing technology is capable of improving quality and economics that can facilitate the day-to-day affairs of the nation's development (Zhang et al. 2015)
(iii) Benefits and risks of nanotechnology—The benefits and risks of nanotechnology in applications that are used by the public (Kishimoto 2010).
(iv) Benefit and risk information—Benefit and risk information available on consumer products (Siegrist and Keller 2011).

4 Case Study: Klang Valley, Malaysia

The Ministry of Science, Technology and Innovation (MOSTI) had previously identified nanotechnology as one of the areas of research priorities and had spent more than 33.5 million USD on nanotechnology-related projects (Hashim et al. 2009). These investments were made to maintain Malaysia's market competitiveness in advanced materials, electronics, nutrition, cosmetics, medical designs, and various applications (Piccinno et al. 2012). In the early stages, nanotechnology was used to produce nanosized gold, silver, zinc, titanium, and black carbon, and now innovation has grown in nanotechnology covering nanotubes, graphene, and so forth (Lee et al. 2013).

The National Nanotechnology Initiative (NNI) Malaysia was launched in 2006 with a vision focusing on nanotechnology for the development of national science, technology, industry, and economy. NNI Malaysia was established to enhance Malaysia's economy, accelerate improvements, and

enhance contributions to the public and the environment through the development of nanotechnology by gathering resources and knowledge among researchers, industry, and government. In 2007, a study funded by the Economic Planning Unit (EPU) released a report entitled "Identification of business and R&D opportunities in the applications of nanotechnology in Malaysia" suggesting nanoelectronics as one of the nanotechnology pioneering applications to be developed in Malaysia (Masrom 2012).

The National Nanotechnology Center (NNC) was set up in 2009 to foster nanotechnology activities under the auspices of NNI Malaysia. NNC's initiatives cover National Nanotechnology Statement, National Nanotechnology Center of Excellence, NanoMalaysia Limited, and NanoMalaysia Center in Iskandar, Malaysia. The National Nanotechnology Policy Statement states that "it is expected that nanotechnology will be a strategic growth engine for Malaysia, which will be achieved through a symbiotic national nanotechnology ecosystem that will ensure sustainable development." Subsequently, the Malaysian government launched the National Nanotechnology Statement in July 2010 to use nanotechnology as an engine that enables new economic growth and sustainable development that ensures the well-being of the public (Masrom 2012).

NanoMalaysia Limited was incorporated in 2011 as a limited company with a guarantee to act as a business entity in running nanotechnology commercialization activities such as managing NanoMalaysia Center and other NNC-approved infrastructure, commercialization of nanotechnology products, planning and coordination, research and development and international investment for nanotechnology, international networks and marketing of nanotechnology industry Malaysia, and products in global supply and value chains.

The efforts to enhance the development of nanotechnology in Malaysia have led to the establishment of the National Nanotechnology Center of Excellence in 2011 to support research and provide facilities and training. Several nanotechnology research centers were established at universities in Malaysia, such as Ibnu Sina Institute for Fundamental Science Studies (IIS) at Universiti Teknologi Malaysia, Institute of Microengineering and Nanotechnology (IMEN) at Universiti Kebangsaan Malaysia, Center of Innovative Nanostructures and Nanodevices (COINN) at Universiti Teknologi PETRONAS, Institute of Nano Electronics Engineering (INEE) at Universiti Malaysia Perlis, NEMS/MEMS Research Laboratory at MIMOS, Nano-Opto-Electronics Research Lab (NOR LAB) at Universiti Sains Malaysia, Institute of Advanced Materials (ITMA) at Universiti Putra Malaysia, and Nanotechnology and Catalysis Research Center (NANOCAT) at Universiti Malaya. Laboratory facilities set up at these research centers provide Malaysia an environment to develop toward a transdisciplinary technology country to achieve sustainable development as stated in the National Nanotechnology Statement (Masrom 2012).

Since nanotechnology has been identified as one of the new country's growth engines, the applications of nanotechnology in various fields help to improve the country's economy and thus drive sustainable development making it one of the technologies available for the Fourth Industrial Revolution (Schwab 2015). The Fourth Industrial Revolution will continue to grow rapidly, and Malaysia should follow such developments as it is envisaged in the Eleventh Malaysia Plan (Zainal Abidin 2018). Now, nanotechnology continues to advance from research to industry and is then commercialized in the form of products to consumers. The market value of nanotechnology commercial revenue is expected to increase by up to 10% in the years to come (Roco et al. 2011). This increase will certainly impact the country's economy and the daily lives of the people. However, local public still does not know about nanotechnology capabilities and is uncertain about the risks associated with nanotechnology (Chen et al. 2013; Cobb and Macoubrie 2004; Kishimoto 2010).

With the increased use of nanotechnology in manufacturing of products in Malaysia, the benefit and risk perceptions of society need to be understood to determine the acceptance of the society on nanotechnology. The increased understanding of science and technology that is being developed in Malaysia will encourage the public to participate in decision making. Positive attitude and public acceptance of new technologies such as nanotechnology are important in ensuring nanotechnology capabilities to continue to grow (Siegrist 2010). Public reactions to nanotechnology also involve policies and regulations designed to prioritize public interest in terms of safety, health, and environmental pollution prevention (Burri and Bellucci 2008; Cormick 2009; Siegrist 2010). Since Malaysia aspires to become a nanotechnology development hub and the Klang Valley is central to the development of nanotechnology, lack of knowledge and awareness on nanotechnology will lead to the deterioration of public involvement and trust to the government and inhibit the development of nanotechnology in Malaysia. Therefore, Klang Valley is taken as a case study to understand the perception of the society on nanotechnology which will be an important instrument for policy-makers, industry, and researchers to develop nanotechnology with good governance toward sustainable development that is compatible with the will of the public and thereby ensure the interests and well-being of society in Malaysia.

5 Public Perception Toward Nanotechnology Development

5.1 Perception Based on Demography

To understand psychological and sociological aspects in influencing public risk and benefit perceptions on nanotechnology, a stratified sampling survey was conducted on the public respondents in Klang Valley. This study tested on ten (10) different demographic categories, i.e., gender, age, marital status, race, residency area, religion, education, stakeholders, household income, and occupation. Table 2 shows only the significant demography that has effect on public benefit and risk perceptions. Race and level of education are shown to have significant influence on both public benefit and risk perceptions. This study on the other hand is focusing on the race, but ethnicity is not included. There are significant differences between the majority race (Malay) with other minorities (Chinese and Indian) in terms of benefit and risk perceptions as the Malay feels a lot more secured with nanotechnology. Highly educated individuals have more confidence in the government and researchers to protect them from the risks of nanotechnology, thus perceiving more benefit than risk in nanotechnology. This can be comparable in another study conducted by Cobb and Macoubrie (2004) where whites and educated individuals perceive nanotechnology more beneficial than risky.

Next, age and household income only influence public risk perception but not benefit perception. Younger respondents in this study have lower risk perception because youngsters are more optimistic about nanotechnology (Gaskell et al. 2005). George et al. (2014) discover that public over the age of 48 and under the age of 36 showing less concern about nanotechnology. Pilisuk and Acredolo (1988) show that less educated individuals which are poor, minorities, and among women having higher risk perception toward technology. Additionally, poor people have higher tendency to reject new technology as they perceive high risk in the technology (Boholm 1998). Wealthy people which have the access to education and financially secured have better understanding on science and technology, thus perceive science and technology as beneficial and have the ability to protect them from hazards (Pilisuk and Acredolo 1988). Minorities may be trapped in poverty and have no access to education (Brundtland 1987) and therefore have higher concern about technology (Boholm 1998; Gallup Organization 1979; Vaughan and Nordenstam 1991). Besides that, women show higher risk perception than men since they are more vulnerable, therefore more alert when it comes to risk (Flynn et al. 1994). However, this study did

Table 2 Significant differences of benefit and risk perceptions among Klang Valley demography

Significant difference in benefit perception by demography	
Race	
Malay	Chinese
Education	
SRP/PMR/LCE	SPM/MCE
	Diploma Bachelor degree Master degree
Significant difference in risk perception by demography	
Age	
18–20	21–40
	41–51
Race	
Malay	Indian
Education	
Ph.D	STPM/Matriculation
	Diploma
	Bachelor degree
Household income	
MYR 1001–RM3000	MYR 5001–RM7000
MYR 9001 above	MYR 3001–RM5000
	MYR 5001–RM7000

not find any significant on different gender in influencing public perception as in previous studies. This inconsistent finding on the demography may in turn suggest that the individual difference in nanotechnology perceptions could not be explained by demographic factors alone. Po et al. (2003) suggest other factors to be considered to further understand public perception. Thus, psychological, sociological, and moderating factors are further discussed in the next section.

5.2 Psychological Aspects

Descriptive analyses on the psychological aspects are shown in Table 3 whereby 47.2% of the Klang Valley public has no idea what nanotechnology is. However, they have positive attitude toward nanotechnology. Government, industry, and researchers are the three main stakeholders responsible in developing nanotechnology whereby the public trust shows that researchers are the most trusted stakeholders followed by industry and government.

To further test these psychological aspects in influencing benefit and risk perceptions of nanotechnology, simple regression test is employed and shown in Table 4. The findings are discussed in Sects. 5.2.1, 5.2.2, and 5.2.3.

5.2.1 Knowledge

As discussed in the introduction, knowledge influences benefit and risk perceptions. However, the result from this study shows that knowledge has no significant effect on benefit and risk perceptions among the Klang Valley public. The respondents have difficulty in expressing their answer as almost half of them stating that they do not have any knowledge on nanotechnology. However, upon brief explanation given to the respondents, they can answer the survey and express their views and concerns about the risks associated with nanotechnology (Grinbaum 2006). Their perceptions of nanotechnology are carried out heuristically through their knowledge of science and technology, as well as the benefits and risks they derive from different media, including media coverage and product labels (Capon et al. 2015a; Siegrist and Keller 2011).

5.2.2 Attitude

Positive public attitude leads to benefit perception of nanotechnology, thereby reduces risk perception of nanotechnology. Attitude functions as a heuristic signal when one remembers the past behavior that will affect their present decision (Bem and McConnell 1970; Pratkanis 1988; Ross et al. 1981). Attitude influences benefit and risk perceptions depending on the public benefit or risk perceived in the

Table 3 Descriptive analyses on psychological aspects

Psychological aspects	%	Mean	SD
Knowledge about nanotechnology	47.2% (know nothing about nanotechnology)	–	–
Attitude toward nanotechnology	–	4.85	1.01
Trust in government on nanotechnology development	–	4.47	1.33
Trust in industry on nanotechnology development	–	4.63	1.07
Trust in researchers on nanotechnology development	–	5.04	1.21

Note Likert scale measurement, 1 = strongly disagree, 7 = strongly agree

Table 4 Standardized regression coefficient psychological aspects in influencing benefit and risk perceptions of nanotechnology

Independent variables		Dependent variables			
		R^2	Benefit perception (β)	R^2	Risk perception (β)
Psychological aspects	Knowledge (independent t-test)	–	-1.140	–	1.100
	Attitude	0.403	0.635**	0.012	−0.107*
	Trust in government	0.133	0.364**	0.029	0.170*
	Trust in industry	0.168	0.410**	0.004	0.064
	Trust in researchers	0.157	0.397**	0.001	−0.023

Significant level at $^{**}p < 0.001$; $^{*}p < 0.05$

nanotechnology applications (Besley 2010; Chen et al. 2013). It is found that public benefit perception on nanotechnology applications outweighs risk perception. The potential of nanotechnology applications in the medical field to improve disease diagnosis and treatment has elevated public benefit perception (Gardner et al. 2010). Meanwhile, concerns on eating nano-related foods which may associate with uncertain health risks raise the public risk perception. The public will have better judgment on nanotechnology when they are familiar with the products (van Giesen et al. 2018). The public familiarity of nanotechnology applications affects their attitude toward the technology and consequently influences their benefit and risk perceptions of nanotechnology (Frewer et al. 2014; Gupta et al. 2015).

5.2.3 Trust

Trust is a key factor for public acceptance of particular technology. The public that has the confidence in stakeholders helps the public to accept new technology. The trust that the public has for the government, industry, and researchers increases the public benefit perception of nanotechnology as these stakeholders are the driving forces for the development of nanotechnology. Among the three stakeholders, researchers gain a higher trust from the public in providing information on nanotechnology-related benefits and risks, developing nanotechnology in accordance with the public needs, ensuring the public safety from adverse effects of nanotechnology and having enough technical knowledge in managing nanotechnology development. Lin et al. (2013) agrees that the public has more trust in researchers compared to the government and industry. In addition, this study reveals that the lack of public trust in government compared to the other two stakeholders increases the risk perception among the public, although government is the main regulator that has the authority to manage nanotechnology. The explanation for this circumstance is that the public may have lost the political trust in government due to inefficiency to achieve former policy (Stoker et al. 2017). However, the public does not know that different government agencies are working together to manage nanotechnology risks, where the public relies solely on their belief that the ruling government does not prioritize public needs (Macoubrie 2005). Opposed to the industry and researchers, they are not directly involved in the national policy making, thus gaining greater public trust. The public also has higher confidence for researchers to safeguard public safety from nanotechnology risks attributable to their profound knowledge and skills (Kishimoto 2010).

5.3 Sociological Aspects

Descriptive analyses on the sociological aspects are shown in Table 5 whereby the public culture, religious belief, and social aspect are well accepting the nanotechnology.

To further test these sociological aspects in influencing benefit and risk perceptions of nanotechnology, simple regression test is employed and shown in Table 6. The findings are discussed in Sects. 5.3.1, 5.3.2, and5.3.3.

5.3.1 Culture

The Malaysian public has been familiar with science and technology on the basis of sociological aspects since the introduction of National Science, Technology and Innovation Policy (2013–2020) highlighting science and technology as the economic driver of the public well-being (Prime Minister's Office 1986). The introduction of this policy has made the development of science and technology in general and nanotechnology in particular to be culturally acceptable to the Klang Valley public; this introduction increases the benefit

Table 5 Descriptive analyses on sociological aspects

Sociological aspects	–	Mean	SD
Culturally accept nanotechnology	–	4.86	1.16
Religious beliefs on accepting nanotechnology	–	4.90	1.19
Socially accept research funding of nanotechnology	–	4.88	1.13

Note Likert scale measurement, 1 = strongly disagree, 7 = strongly agree

Table 6 Standardized regression coefficient sociological aspects in influencing benefit and risk perceptions of nanotechnology

Independent variables		Dependent variables			
		R^2	Benefit perception (β)	R^2	Risk perception (β)
Sociological aspects	Culture	0.285	0.534**	0.001	−0.033
	Religious beliefs	0.364	0.604**	0.002	−0.045
	Social aspect	0.354	0.595**	0.002	−0.041

Significant level at $^{**}p < 0.001$; $^{*}p < 0.05$

perception of nanotechnology but not risk perception. Identical to China, the introduction of Open-Door Policy in 1978 which utilized science and technology for improving the standard of living of the public and also enhancing China global competitiveness has made the public to have high acceptance of nanotechnology (Zhang et al. 2015). The introduction of such policy in a country has made the development of science and technology in general and nanotechnology in particular to be culturally acceptable to the public.

5.3.2 Religious Beliefs

Religious beliefs influence benefit perception but not risk perception. Religiosity plays a role in influencing ethical choices (Conroy and Emerson 2004; Magill 1992). The development of science and technology emphasizing on religious ethics (Chapman 1999) creates the foundation for accepting nanotechnology for the religious public. Consequently, no technological development conflicting with the ethics practiced in Malaysia, which in turn results in a higher benefit perception of nanotechnology for people with religious beliefs. This result is, however, in contrast with the finding by Brossard et al. (2009) whereby they point out that religious public perceives nanotechnology to be more risky than beneficial.

5.3.3 Social Aspect

According to the social implication of nanotechnology on the public, supporting research funding is crucial to ensure fair distribution of nanotechnology benefit while managing the uncertain risk. Thus, social aspect influences benefit perception but not risk perception. Social aspect impacts on society in terms of the development of nanotechnology, enabling the public to engage in nanotechnology development in order to develop nanotechnology that is in line with public interests (Forloni 2012). Public concerns arise from nanotechnology's unbalanced benefits and risks that are not shared equally with all social groups (Conti et al. 2011) whereby social groups with a high standard of living can enjoy the benefits of nanotechnology, while those with a low standard of living will be left behind. Continuous nanotechnology research will therefore enable all social groups in the public to enjoy the benefits and to be protected against the risks of nanotechnology (Kelechukwu 2016).

5.4 Other Factors (Moderators)

Other factors are shown to have significant moderating effects on psychological and sociological aspects in influencing public benefit and risk perceptions of nanotechnology. Table 7 shows media coverage, technology and economy development, benefit of nanoapplications, risk of nanoapplications, and benefit and risk information moderate psychological aspects in influencing public perception of nanotechnology, whereas Table 8 shows media coverage, technology and economy development, benefit of nanoapplications, risk of nanoapplications, and benefit and risk information moderate sociological aspects in influencing public perception of nanotechnology. The findings are discussed in Sects. 5.4.1, 5.4.2, 5.4.3, 5.4.4, and 5.4.5.

5.4.1 Media

As shown in Table 7, media coverage has a moderating effect on attitude and trust in researchers in influencing benefit perception, while media coverage has a moderating effect on knowledge in influencing risk perception of nanotechnology. Malaysian public shows a positive attitude toward nanotechnology and has high trust in researchers. Media coverage containing useful nanotechnology information on the safety of nanotechnology can further increase the benefit perception of nanotechnology as media is an important medium for keeping the public up to date with the latest information required through researchers' engagement. The information given by the researchers will therefore increase public confidence and further boost public benefit perception. However, when the public is exposed to high media coverage, an increase in risk perception can be observed. This is due to the limited knowledge of nanotechnology among the public. Since 47.2% of the respondents admitting to have zero knowledge about nanotechnology, the risk information become more influential compared to benefit information (Cobb 2005). Consequently, when people with limited knowledge are exposed to too many risk information on the media, they will perceive nanotechnology as risky rather than being beneficial. Media coverage is important for providing information on the benefits and risks of nanotechnology as it has the impact to shape public perceptions toward nanotechnology (Ho et al. 2011). Media coverage gives the public an easy access to information whereby the predominant use of Internet today makes it easy for the public to obtain information. The choice of information, however, depends on the interests and curiosity of individuals. The public interpretation of the received information is also different from one to another (Lemanczyk 2014); the presented information must be factual and non-fictional. Scientific information, however, will only attract certain groups of public who are interested on current scientific developments and leave others with different interest uninformed with the current issue of nanotechnology. Therefore, media covering various aspects including benefits, risks, economics, social, and ethics will provide an extensive coverage to educate and improve the public knowledge (Tyshenko 2014).

5.4.2 Technology and Economy Development

As shown in Table 7, technology and economy development moderates knowledge and attitude in influencing benefit perception, while risk perception is moderated by technology and economic development on attitude, trust in government and trust in researchers. As shown in Table 8, technology and economy development moderates culture and social aspect in influencing risk perception but shows no moderating effect in influencing benefit perception. As technology and economy continue to develop, the public will gain better understanding and familiarity with the new technology that will increase public knowledge and positive attitude toward nanotechnology. An economy driven by the advancement of science and technology will allow the competitiveness among countries to be part of the Fourth Industrial Revolution (Tangau 2017). Therefore, in conjunction with technology and economic development, public culture and social aspect agree on science and technology to fuel the growth of economy and enhance the public well-being, resulting in a reduction of public risk perception of nanotechnology. Countries that have never had terrible experience of scientific and technological development, such as technological disasters, would not lead to culture and social phobia in adopting new technologies, such as nanotechnology (Macnaghten et al. 2016; Roco and Bainbridge, 2001). Public that is protected from any controversial development of technology will accept new technologies by trusting the government and researchers which result in the decrease in risk perception among them. Trust is noteworthy in a stable technological and economic development, as it significantly influences public perception to illustrate whether nanotechnology will be accepted or rejected.

5.4.3 Benefit of Nanoapplications

As shown in Table 7, benefit perceived in nanoapplications shows a moderating effect on trust in government and industry in influencing benefit perception, while moderating attitude, trust in government, trust in industry, and trust in researchers in influencing risk perception. Table 8 shows the sociological aspects in which culture, religious beliefs, and social aspect are moderated by perceived benefit of nanoapplications in influencing risk perception of nanotechnology. It is found that the perceived benefit of nanoapplications helps to contribute to public confidence in government and industry which increases benefit perception of nanotechnology, as both government and industry play a critical role in the management and distribution of useful nanotechnology products to the public. This finding is further supported by Maynard (2006) that public has higher trust in government and industry when nanotechnology applications are beneficial. In addition, perceived benefit in nanoapplications is found to be affecting attitude, trust in government, trust in industry, and trust in researchers, resulting in the decrease of public risk perception. The public finds that nanotechnology is beneficial; thus, their attitude toward nanotechnology is also positive. Consequently, the public has a low risk perception of nanotechnology. Public trust in government, trust in industry, and

Table 7 Regression coefficients from PROCESS macro by Hayes for the moderating effects of psychological aspects in influencing the public perception of nanotechnology

Psychological aspects		Media coverage	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**

Significant level at $^{**}p < 0.001$; $^{*}p < 0.05$

Table 8 Regression coefficients from PROCESS macro by Hayes for the moderating effects of sociological aspects in influencing the public perception of nanotechnology

Sociological aspects		Media coverage	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

Significant level at $^{**}p < 0.001$; $^{*}p < 0.05$

trust in researchers are vital which may boost public confidence to perceive benefit in nanoapplications, where in this manner, leading their risk perception to be diminished (Capon et al. 2015b). Furthermore, public culture, religious beliefs, and social aspect which are positive toward nanotechnology, resulting in public tendency to perceive benefit in nanoapplications, thereby reduce their risk perception of nanotechnology (Mamadouh 1999).

5.4.4 Risk of Nanoapplications

As shown in Table 7, risk of nanoapplications is found to have moderating effect on psychological aspects whereby it moderates trust in researchers in influencing benefit perception of nanotechnology. At the same time, risk of nanoapplications moderates trust in government, trust in industry, and trust in researchers in influencing risk perception of nanotechnology. For sociological aspects, Table 8 indicates religious beliefs and social aspect are moderated by risk perceived in nanoapplications in influencing benefit perception of nanotechnology. It is an interesting finding where high public trust in researchers leads to the increase of benefit perception, although there are risks associated with nanotechnology applications. The public is confident that researchers will protect them from nanotechnology risks and thus increase their benefit perception toward nanotechnology (Kishimoto 2010). Nevertheless, if too many risks are associated with nanotechnology applications, this negativity will affect the public confidence in researchers, thereby reducing their benefit perception. Very high risk perceived from nanoapplications, on the other hand, increases risk perception and in a long run may deprive public trust in government, industry, and researchers (Oh 2009). It is therefore imperative for government, industry, and researchers to manage nanotechnology risks in order to avoid public trust deprivation that may inhibit the development of nanotechnology. It is also shown that public religious belief and social aspect are positive about nanotechnology, thus perceiving nanotechnology as beneficial although there are risks associated with nanoapplications. People who adhere to religion believe that it is important to make ethical choices including the safety application of nanotechnology in consumer products, given that religious beliefs act as guidance for them to choose ethically (Conroy and Emerson 2004; Magill 1992).

5.4.5 Benefit and Risk Information

As shown in Table 7, benefit and risk information shows a moderating effect on trust in researchers in influencing benefit perception. Benefit and risk information also moderates knowledge, trust in government, trust in industry, and trust researchers in influencing risk perception. However, there is no significant moderating effect by benefit and risk information on sociological aspects as shown in Table 8. The benefit and risk information in the form of nanoproduct label serves as a communication tool for public decision making (Chuah et al. 2018). Public relies on their trust in researchers which result in increasing benefit perception when there is a lack of nanotechnology information available. Public trust in researchers is crucial in influencing benefit perception, whereby the public is willing to accept vulnerability when they have a high positive expectation for researchers (Roosen et al. 2015). Knowledge, on the other hand, shows to increase risk perception although benefit and risk information is readily available to the public. This situation is caused by limited knowledge about nanotechnology among the public. As risk information is more influential, public with a different background is going to interpret the same information differently (Douglas 1978). The balance of benefit and risk information disclosed to the public is critical in order to avoid misinterpretation of information, as the public may not have the expertise and may be attracted to risk information more than benefit

information (Siegrist and Keller 2011). In conjunction with information availability, lack of information provided to the public can increase the risk perception of nanotechnology and may deteriorate public trust in government, industry, and researchers. Public conveys the need for information from the expert to reduce risk perception in the midst of nanotechnology uncertainties. Therefore, mandatory labeling is required to gain public trust and reduce public concern regarding nanotechnology risks (Forloni 2012). In addition, adequate information will enable the public to make decisions objectively without relying excessively on their trust in government, industry, and researchers which may be biased and could lead to the wrong decision (Gilovich et al. 2002).

6 Conclusions

Nanotechnology is one of the most advanced technologies used in facing Fourth Industrial Revolution. The development of nanotechnology from researches in laboratories has moved to the commercialization of the nanotechnology products in the market. The public are consumers of nanotechnology products that will receive impacts from products containing nanomaterials. Good quality, durable, anti-bacterial, and anti-fungal products will increase consumers' interest in using nano-containing products. The advancement of nanotechnology use in medicine has improved the diagnosis and treatment of diseases that would benefit the public in improving public health. However, nanotechnology also has uncertain risks that can bring health problems to the public and pollute the environment. Nanotechnology is still at its early stage of development in Malaysia, so the public perceptions of nanotechnology will be instrumental for policy-makers to develop nanotechnology so that its benefits can be enjoyed equally by all levels of society and the risks can be well managed.

In general, public perceptions of nanotechnology in Malaysia are positive as Malaysia receives both scientific and technological developments as drivers for the country's economic growth. Public perceptions based on psychological aspects show that knowledge is not a factor affecting the benefit and risk perceptions. However, the public perceives nanotechnology to be more beneficial than risky. Public attitudes are also positive for nanotechnology in which this positive attitude gives people benefit perception and reduces risk perception of nanotechnology. Trust in government, industry, and researchers increase the public benefit perception on nanotechnology as these stakeholders are the driving force of the development of nanotechnology in Malaysia. The government as the regulator of nanotechnology development affects risk perception when public trust in government declines. Therefore, the government needs to play a transparent role in getting public trust, thereby enhancing the public benefit perception on nanotechnology.

Based on sociological aspects, culture, religious belief, and social aspect in Malaysia influence the public benefit perception but not risk perception on nanotechnology. The National Science and Technology Policy has emphasized science and technology as an economic driver for the well-being of Malaysian. Hence, it has become a culture in Malaysia receiving both scientific and technological developments in general and nanotechnology in particular. Religions in Malaysia accept nanotechnology whereby technology development in Malaysia must be parallel with Islam, the official religion of the nation, which clearly rejects any form of technology that violates ethics. Hence, no ethical conflicting technology can be practiced in Malaysia. Correspondingly, continuous research of nanotechnology will result in the social implication by ensuring equal distribution of nanotechnology benefit and at the same time its risk will be effectively managed. Thus, social aspect does effect on the benefit perception and does not affect the risk perception of nanotechnology.

There are other factors (moderators), which are media coverage, technology and economy development, benefit of nanotechnology applications, risk of nanotechnology applications and benefit and risk information, moderating psychological and sociological aspects in influencing public perception of nanotechnology. Based on psychological aspects, media coverage moderates attitudes and trust in researchers in influencing benefit perception of nanotechnology, whereas risk perception of nanotechnology is influenced by the moderating effect of media coverage on knowledge. However, the media coverage does not affect the sociological aspects. Media being an important medium for communicating information to the public requires the involvement of researchers so that nanotechnology can be communicated to the public effectively. Hence, avoiding risk information dominating the media coverage without supporting fact will increase public risk perception, especially to those with limited knowledge about nanotechnology. A comprehensive media coverage covering various areas about nanotechnology will help stakeholders to create awareness to all levels of society which comprises various interests, propositions, and backgrounds.

Based on psychological aspects, rapid technology and economic developments have the moderating effect on public knowledge and attitudes which increase the benefit perception of nanotechnology. On the other hand, attitudes' trust in government and researchers reduce risk perception of nanotechnology as technology and economy continuously developed. Based on sociological aspects, nanotechnology which is accepted by public culture and social status reduces risk perception as a result of advanced technology and

economic developments. Numerous studies on nanotechnology have illustrated its growing development and gradually impacting the economy. Therefore, this study suggests that public must also be informed of recent studies so that the public can obtain factual information from researchers. It also reduces the gap between researchers and the public by encouraging the public to make scientific decisions so that their responses to express the needs and wants from nanotechnology development are factual. The effectiveness of public communication will facilitate policy-makers to develop nanotechnology that is in line with the public needs well guided rather than just mere emotion.

Based on psychological aspects, the benefit of nanotechnology applications is affecting trust in government and industry that influence public benefit perception. Both stakeholders play a role in managing and delivering useful products to the public. By perceiving benefit of nanotechnology applications, public positive attitude, their trust in government, industry, and researchers will reduce the risk perception of nanotechnology. As for sociological aspects, public culture, religious beliefs, and social aspect which well accept nanotechnology have prompted them to find nanotechnology as beneficial, causing risk perception of nanotechnology to be diminished.

For the risk of nanotechnology applications based on psychological aspects, public has high trust in researchers which enables them to perceive benefit despite the risk of nanotechnology applications. However, when they perceive risk of nanotechnology applications is too high, the public trust in government, industry, and researchers will increase their risk perception. Based on sociological aspects, public religious beliefs and social aspect accept nanotechnology well resulting in benefit perception despite the risk associated with nanotechnology applications. However, high risk will still reduce their benefit perception of nanotechnology. If the risk of nanotechnology applications is poorly managed, it will cause the deterioration of public trust of the stakeholders to develop nanotechnology in Malaysia. Consequently, it is proposed that the benefit and risk of nanotechnology applications shall be informed to the public through continuous research on products containing nanomaterials. As a result, public trust in stakeholders will increase whereby public is more confident on the benefit of nanotechnology that they receive and protect them from the unwanted risk.

The benefit and risk information on the product acts as a guide for the public to make choices. Based on psychological aspects, benefit and risk information has the effect on public trust in researchers which further increase public benefit perception of nanotechnology, whereas for risk perception, adequate information availability has the effect on public trust in government, industry, and researchers which has potential in reducing risk perception. However, different circumstances are found in knowledge. Comprehensive benefit and risk information, however, increases the risk perception among the public; whereby with the public limited knowledge about nanotechnology, risk information is more likely to influence public perception than benefit information. However, there is no significant moderating effect by the benefit and risk information on sociological aspects in influencing public perception of nanotechnology. Benefit and risk information of nanotechnology on the product is an important tool for the public to make decision. Labeling a product containing nanomaterials with both risk and benefit information supported by reliable research evidences is urgently needed as nanotechnology products have already entered the consumer market. Finally, mandatory law enforcement on labeling is required to promptly increase public trust in stakeholders and subsequently develop nanotechnology to drive sustainable development in ensuring the safety and well-being of the public.

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