Institut für Lebensmittel- und Ressourcenökonomik

Consumer acceptance of biotechnology: the influence of product end-use, policy context, and information framing

Dissertation

zur Erlangung des Grades

Doktor der Agrarwissenschaften (Dr. agr.)

der Landwirtschaftlichen Fakultät
der Rheinischen Friedrich-Wilhelms-Universität Bonn

von

Olivier K. Butkowski

aus

Herne

Bonn 2018

Referent: Prof. Dr. Stefanie Bröring
Korreferent: Prof. Dr. Carl Johan Lagerkvist

Tag der mündlichen Prüfung: 08.05.2018

Angefertigt mit Genehmigung der Landwirtschaftlichen Fakultät der Universität Bonn

ACKNOWLEDGMENTS

I would like to thank my supervisor Professor Stefanie Bröring for giving me the opportunity to work and grow as a researcher, for her input, and great support at all times. I would also like to thank my co-supervisor Professor Carl Johan Lagerkvist for his outstanding guidance, support, and valuable advice. The attitude of both of you made every meeting constructive and pleasant.

Many thanks to my examiners Professor Thomas Heckelei and Professor Rainer Stamminger for being part of the evaluation committee for my defense.

My highest appreciations go out to my co-authors Dr Chad M. Baum and Dr Ashkan Pakseresht. Thank you Chad, for all your comments, input, advice, and other efforts you made. All walks and talks remain in good memory. Thanks to Ashkan, for the excellent work you contributed and the joyous collaboration.

Thanks to Caro, Joana, Silvan, Laura, Laura, Sukhada, Lora, Ursula, Ellora, Chad, Natalie, Michael, Felix, Maria, Nina, Emanuele, Thomas, Agnes, and Renate for creating such a nice atmosphere.

Also my thanks go out to all who contributed to this thesis. To Sonja, Regina, Judith, and Isabella for helping me carrying out the experiments. To Jeske, Yannik, Marie, Pia, Adetoun, Etienne, and Petra for their numerous and valuable efforts. To Theo and Andreas for the IT-support. To Bonn citizens for taking part in the discussion and experiments.

Last but not least – I am deeply grateful for all your support, understanding and the sacrifices you made, Susanne. I am also grateful to my parents, brother and the rest of my family. You made this possible.

– To my dad and my son

ABSTRACT

Consumer acceptance of novel technologies is a prerequisite for market adoption of the derived products. The transition towards a more sustainable bioeconomy in Europe requires product and process innovation that promotes bio-based products such as bioenergy and makes them more cost-efficient against fossil-based products. Biotechnology in this regard is promising to enhance the efficiency of crops and biochemical conversion processes. Yet, the acceptance of green biotechnology is low in Europe compared to North America because of the associated risks. However, consumer support is heterogeneous across EU member states and there is evidence to suggest that the practical context plays a crucial role in this regard lending support to the notion that biotechnology is not generally rejected by the public. To better understand the underlying processes of biotechnology acceptance, this thesis integrates the practical context with the theoretical framework for consumer acceptance. Thus, the thesis investigated the influence of the contextual factors i) end-use (bioenergy vs. food), ii) policy regime (full commercialization vs. research and development), and iii) information framing (positive, negative, control) on key determinants of consumer acceptance, namely i) risk perception, ii) self-control, iii) risk responsibility, all in relation to individual factors. Consumer decision-making was analyzed against the backdrop of the existing socioeconomic environment. The three empirical studies of this thesis are based on data collected during two framed field experiments in Germany with a total of 436 and 322 participants, respectively. In studies I and II, a between-subjects design was employed comprising four experimental treatments, to investigate the impact and importance of the end-uses and policy regimes on risk perception as well as the underlying processes of acceptance. Study III investigated consumer acceptance of the bioenergy end-use and employed three experimental treatments with regard to information frame to explore how it affects consumer decision-making in relation to both upstream acceptance of supply-chain actors and trust in key stakeholders while controlling for respondents' emotions during the experiment. The results indicate that in contrast to the current narrative on biotechnology acceptance, the technology is not generally rejected by consumers. In specific, both the bioenergy end-use and R&D-only policy generally find more support compared to food and full market approval, respectively. While higher perceived risk usually relates to lower acceptance, one exception to this stylized fact is that consumers are more accepting of biotechnology if risks are perceived to be personally controllable. When risk messages for the bioenergy end-use had a negative tone, consumer support (rejection) declined (increased), but perceptions did not change in response to a positive frame. The support of energy companies and labeling increased consumer support, even more so in combination. In addition, trust in key actors and labeling represent distinct types of support-building mechanisms which are mutually reinforcing and replaceable. Thus, all efforts to increase both consumer perceptions of the degree of personal controllability of risks and trust offer a strategy to promote higher acceptance. For this reason, an informed dialogue with the public could be based on labeling supporting complete and transparent upstream information. Broader commitment to R&D-activities should be undertaken through legislation on both the federal state and national level, for instance, as a way to cultivate trust and lay the foundations for future commercialization efforts.

ZUSAMMENFASSUNG

Die Verbraucherakzeptanz neuartiger Technologien ist eine Voraussetzung für die Marktakzeptanz der Folgeprodukte. Der Übergang zu einer nachhaltigeren Bioökonomie in Europa erfordert Produkt- und Prozessinnovationen, die biobasierte Produkte wie Bioenergie fördern und sie gegenüber Produkten auf fossiler Basis kostengünstiger machen. Die Biotechnologie verspricht in diesem Zusammenhang eine Effizienzsteigerung von Nutzpflanzen und biochemischen Umwandlungsprozessen. Noch ist die Akzeptanz der Biotechnologie in Europa im Vergleich zu Nordamerika aufgrund der damit verbundenen Risiken gering. Allerdings ist die Unterstützung der Verbraucher in den EU-Mitgliedstaaten heterogen und es gibt Hinweise darauf, dass der praktische Kontext in diesem Zusammenhang eine entscheidende Rolle spielt und dass Biotechnologie nicht generell von der Öffentlichkeit abgelehnt wird. Um die zugrundeliegenden Prozesse der Akzeptanz von Biotechnologie besser zu verstehen, integriert die vorliegende Dissertation den praktischen Kontext mit dem theoretischen Rahmen der Verbraucherakzeptanz. So untersucht diese Arbeit den Einfluss der Kontextfaktoren i) Endprodukt (Bioenergie vs. Lebensmittel), ii) Politik (freie Vermarktung vs. Forschung & Entwicklung) und iii) Informationsrahmen (positiv, negativ, neutral) auf die wichtigsten Determinanten der Verbraucherakzeptanz, und zwar i) Risikowahrnehmung, ii) Selbstkontrolle, iii) Risikoverantwortung unter Berücksichtigung der individuellen Eigenschaften der Verbraucher. Die Entscheidungsfindung der Verbraucher wird anschließend vor dem Hintergrund des bestehenden sozioökonomischen Umfelds untersucht. Die drei empirischen Studien dieser Arbeit basieren auf Daten, die während zweier Feldexperimente in Deutschland mit insgesamt 436 bzw. 322 Teilnehmern gesammelt wurden. In den Studien I und II wurde ein between-subjects-Design verwendet, das vier Versuchsgruppen umfasst, um den Einfluss und die Bedeutung der Endprodukte und politischen Regelungen auf die Risikowahrnehmung sowie die zugrundeliegenden Akzeptanzprozesse zu untersuchen. Die Studie III analysiert die Verbraucherakzeptanz des Endprodukts Bioenergie. Hierfür wurden drei Versuchsgruppen basierend auf den Informationsrahmen eingesetzt, um zu untersuchen, wie dieser die Entscheidungsfindung der Verbraucher beeinflusst, und zwar sowohl in Bezug auf die vorgelagerte Akzeptanz der Akteure in der Wertschöpfungskette als auch auf das Vertrauen in die wichtigsten Stakeholder. Während dieses Experiments wurden auch die Gefühle der Probanden erfasst. Die Ergebnisse deuten darauf hin, dass die Technologie im Gegensatz zur aktuellen Darstellung der Akzeptanz der Biotechnologie von den Verbrauchern nicht generell abgelehnt wird. Insbesondere werden das Endprodukt Bioenergie und die F&E-Politik gegenüber dem Endprodukt Lebensmittel bzw. der freien Vermarktung bevorzugt. Während höhere Risikoeinschätzungen in der Regel eine geringere Akzeptanz hervorrufen, ist eine Ausnahme zu dieser Gegebenheit, dass Verbraucher Biotechnologie eher akzeptieren, wenn die Risiken als persönlich kontrollierbar wahrgenommen werden. Bei negativen Informationen zum Endprodukt Bioenergie ging die Unterstützung der Verbraucher zurück und die Ablehnung nahm zu. Bei einem positiven Rahmen änderte sich die Wahrnehmung hingegen nicht. Sowohl die Unterstützung der Energieversorger als auch die Produktkennzeichnung haben, insbesondere in Kombination, die Unterstützung der Verbraucher erhöht. Darüber hinaus sind das Vertrauen in Schlüsselakteure und die Kennzeichnung eigenständige Faktoren, die zur Unterstützung der Technologie beitragen. Jedoch kann sich dieser Effekt durch die Kombination beider Faktoren auch verstärken und gegenseitig kompensieren. So bieten alle Bemühungen, um sowohl die Wahrnehmung der Verbraucher über den Grad der persönlichen Kontrollierbarkeit von Risiken als auch das Vertrauen zu erhöhen, eine Strategie zur Förderung einer höheren Akzeptanz. Daher sollte der Dialog mit der Öffentlichkeit auf einer transparenteren und vollständigen Kennzeichnungspflicht gründen. Größere Unterstützung und Anreize für F&E-Aktivitäten sollten durch Gesetze auf Landes- und Bundesebene erfolgen, um beispielsweise ein Grundvertrauen bei Verbrauchern zu schaffen, das die Grundlage für eine eventuelle künftige Vermarktung gewährleistet.

ABBREVIATIONS

ANOVA, Analysis of variance

BVL, German Federal Office of Consumer Protection and Food Safety

BMBF, German Federal Ministry of Education and Research

BMEL, German Federal Ministry of Food and Agriculture

CRISPR, Clustered Regularly Interspaced Short Palindromic Repeats

DNA, Deoxyribonucleic acid

EC, European Commission

EU, European Union

ESM, Experience sampling method

FAO, Food and Agricultural Organization

FC, Full commercialization

GE, Genetic engineering

GM, Genetically modified

GMO, Genetically modified organism

NGO, Non-governmental organization

PII, Personal Involvement Inventory

R&D, Research and development

RED, Renewable Energy Directive

s.d., Standard deviation

SDG, Sustainable development goal

SMM, Serial multiple-mediator

UN, United Nations

USDA, United States Department of Agriculture

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1. INTRODUCTION

Technological innovation is taking on an increasingly crucial role against the backdrop of a more sustainable economy and the greater attention to tradeoffs between social, environmental, and economic aims (SCAR, 2015). One major societal challenge is thus to ensure food security while providing sustainable energy for all (UN, 2015). According to IRENA (2014), the share of modern renewables will more than triple by 2030, with biomass holding the highest share. This thesis takes the case of green biotechnology as one example of innovation in the agricultural sector and how public concerns over applications to food have led to a legislative response in Germany that restricts its use and R&D efforts which, in turn, puts pressure on the global competitiveness of the EU's agricultural sector (Parisi et al., 2016). Amidst this difficult political climate, acceptance is thus crucial to encourage policy makers to create a political environment that embraces technological innovation and to shape legislation that incentivizes and fosters novel technologies such as green biotechnology. However, widespread adoption of innovation is predicated on consumer acceptance and little is known about the perceptions of green biotechnology with regard to more sustainable products such as bioenergy, and in relation to the broader practical context.

In contrast to the case of biotech food, second-generation bioenergy still remains a core task of the political agenda in Germany which aims to foster the "production of second-generation fuels, efficiency improvement in biogas-production and the breeding and farming of energy crops, in order to diversify the range of energy crops (among other reasons)" (BMEL, 2014), p. 61. Nevertheless, those bioenergy technologies that are currently available are neither cost-competitive with fossil fuels nor indeed are all uses of biomass use sustainable, especially given the resulting competition between food and energy for limited resources. Applications of biotechnology, however, can increase crop yields, abiotic and biotic stress resistance or optimize (chemical and physical) crop characteristics for biofuel production (Davison et al., 2015), rendering it a possible and promising contributor for future societal challenges. The transition towards a more sustainable bioeconomy must therefore take into account the broad range of potential end-uses for the novel technologies which aim to improve production efficiency as well as the use of related by-products.

And yet the determinants of acceptance are little understood for the purpose of bioenergy production (Verbeke, 2007) and little is known about how acceptance is ultimately related to the policy context. As such, the legislative response to public concerns follows the precautionary
principle which requires the safety of products and processes to be established. On the one hand, such preventative measures can stimulate innovation as producers are required to

demonstrate how their activities are safe, but on the other, restrictions that are too broadly established might hamper progress (Garnett and Parsons, 2017). While Europe remains a key player on the global agricultural market, it has however fallen behind some of its competitors in North America, Asia, and Africa with respect to biotechnology innovation (Parisi et al., 2016). A recent amendment of the EU Directive on the deliberate release of GMOs allows member states to opt out of approving GMOs. While Germany has decided to take the opt-out measure for GM maize, Spain kept its approval and still allows for such products to be commercialized. In Germany, political party agreements at the Federal State level resulted in the abandonment of green biotechnology, even explicitly excluding it from subsidies for R&D efforts (Landesregierung Baden-Württemberg, 2011-2016; Landesregierung Baden-Württemberg, 2016-2021). This poses a question for the future of biotechnology (and other promising inventions) in Germany. Moreover, we do not yet, however, understand whether the public sees this response as appropriate since there is a lack of research in this regard. As demonstrated by the recent controversies over the use of biotechnology crops for food production this motivated to investigate how the practical context, namely product end-use and policy regime, affects consumer acceptance.

In this regard, the current focus of consumer research on the food sector might be misleading as biotechnology in food production is the Achilles' heel of acceptance (Gaskell et al., 2010). Consumer acceptance has been shown to vary by area of application of genetic engineering (GE) (e.g. Siegrist, 2008) which calls into question the current approach of regulating GMOs irrespective of end-use (Sprink et al., 2016). Eurobarometer studies have shown that the general, EU-wide optimism about biotechnology fell from 50 percent in 1991 to 41 percent in 1999, before it rose back to 50 percent in 2002 (Gaskell et al., 2003) and 53 percent in 2010 (Gaskell et al., 2010). This begs the question about what drives such changes in the public perception of this technology. Moreover, consumer acceptance is quite heterogeneous across EU member states, with citizens of GM crop producers such as Spain or Portugal typically more supportive of GM food than, for instance, the French or German public (Gaskell et al., 2010). While De Steur et al. (2014) observe that consumer acceptance of GM food is largely determined by the associated risks, Leikas et al. (2009) emphasize the importance of perceived risk controllability and personal risk responsibility in this regard. However, little is known about the key determinants of acceptance of biotechnology for bioenergy production, since most consumer-acceptance studies have tended to focus on food or non-food applications, rather than bioenergy. In fact, Gaskell et al. (2010) report that 78 percent of Europeans support first-generation biofuels, even if not sustainable, and 89 percent support sustainable biofuels. This lends support to the notion that biotechnology could find higher acceptance if used for bioenergy production compared to the food end-use.

Moreover, it is not necessarily clear whether the communication of risks and benefits is likely to be an effective strategy. Indeed, the public debate seems to actually fuel uncertainty rather than offering firmer orientation (e.g. McFadden and Lusk, 2015). As such, not only the framing of information has a considerable influence on consumer preferences (Lusk et al., 2004), but also the source of information (Frewer et al., 2016). Thus, in their role as major source of information, trust in supply-chain actors is likely to remain a main concerns of consumers for the foreseeable future (Frewer et al., 2013; De Steur et al., 2014) and therefore consumer acceptance must be assessed against the backdrop of existing socioeconomic environments shaping consumer decision-making (Palacios-Huerta and Santos, 2004). Given that bioenergy represents an important area of application, and in fact one of many, for a future sustainable bioeconomy, this research investigates how information on biotechnology is perceived by consumers for the purpose of bioenergy production. In this manner, the current literature on risk communication is extended with regard to another application category of biotechnology that is increasingly perceived as a crucial feature of a more sustainable economy.

Amidst the debate about the adoption of GMOs and differences in acceptance by end-use, this thesis sets itself the question of whether, and to what extent, green GE is likely to be accepted by the public for the purpose of bioenergy production. Thereby it seeks to provide insight into the consumer understanding of the regulatory context. Such insights will prove useful for identifying potential strategies enable policymakers to both foster the public debate about whether and how biotechnology is wanted or needed and create a political environment where the benefits of technology innovation can be enabled. To better understand consumer acceptance and the influence of the practical context, this thesis uses risk perception as a proxy for acceptance, as is common in the literature, before investigating the specific influence of the contextual factors of product end-use, policy context. To investigate the influence of information framing on acceptance, consumer decision-making is then analyzed in relation to stances of the supply-chain stakeholders and how these actors are trusted by the consumers. As a result, the thesis as a whole attempts to contribute, in a more general sense, to the transformation towards a bio-based economy, as postulated by the European Commission (2012).

Objectives

The EU faces several societal challenges such as the increasing global demand for food as a result of population growth and increases in per-capita levels of income. In specific, changing dietary patterns in countries such as Brazil and China increase the desire for meat, which puts pressure to maintain production of staple foods and thereby aggravates land-use problems. Subsidies for biorenewables can even endanger the global competitiveness of the European food sector owing to the competition between these two sectors for agricultural raw materials (Lenk et al., 2007). According to the Eurobarometer on public perception of biotechnology in 2010, not only can this have immediate consequences such as job losses and inflation, but it is generally the case that consumer rejection tends to be lower in countries with higher political support (Gaskell et al., 2010). As further evidence from this study for a link between public perception and policy regime, rejection is higher in countries such as Germany where green biotechnology tends to be avoided due to consumer concerns about safety aspects and transparency of the production processes. And yet, advances in biotechnology have the potential to tackle societal challenges by enhancing agronomic traits such as increasing drought resistance, thereby reducing the probability for supply disruptions. Thus, rejection of biotechnology might hamper the success of the European bioeconomy strategy. In order to leverage the potential of these technologies, however, it is then necessary to establish broader consumer acceptance. For this reason, it is crucial that we better understand the relevant determinants of acceptance, as well as why and how this varies across consumers and the practical context.

Generally speaking, lack of consumer acceptance is likely to stem from the perceived uncertainty regarding the consequences of GMOs (i.e. for human health, the environment, society, and ethical considerations) (Hess et al., 2016). As such, some key determinants of consumer acceptance of GM food include the risk and benefit perceptions of consumers, trust in institutions, and emotion (Roeser, 2012). However, contextual factors such as the end-use (Frewer and Shepherd, 1995; Frewer et al., 1997b; Frewer et al., 1997a; Knight, 2006; Christoph et al., 2008), policy regime (Ronteltap et al., 2007; De Steur et al., 2014; Lusk et al., 2014), and information communication (e.g. Ronteltap et al., 2007) have also been observed to influence consumer acceptance of biotechnology also in relation to societal structures such as the social and economic environments (Palacios-Huerta and Santos, 2004) and in specific also the behavior of other supply-chain actors (Sapp and Korsching, 2004; Pakseresht et al., 2017). To this point, the deeper exploration of these factors is however limited. Notably, differences in public perception due to the specific of the regulatory approach to GM crops have not yet been investigated. We do not know, as a result, whether or not consumers perceive risks to be lower for R&D-only approaches compared to the unrestricted commercial use of the technology, making it unclear what constitutes the appropriate legislative response to public concerns. For instance, drawing on the case of Germany, is the public likely to respond favorably to the decision to opt-out from cultivation and restrict funding for R&D? Not knowing this, in turn, makes risk communication from science to the public more difficult. Not to mention, it could turn out that the current regulatory approach, which in practice tends not to differentiate by end-use of biotechnology, is wholly inappropriate. To address this gap, the thesis therefore employed two distinct policy scenarios as experimental treatments. In this fashion, the thesis is able to better explore the current market-readiness for bioenergy from GM crops, and thereby understand which policy strategy best offers the opportunity to exploit the advantages of green biotechnology.

Since consumers can neither exert control over nor directly observe the production process and technology used, it is necessary to trust in the information that is provided by policymakers, scientists, NGOs, and/or industry supply-chain actors. As such, public perception is influenced by the decisions of the industry because consumers have to rely on the information they receive or find presented on, for instance, labels. In other words, owing to these limitations, consumers can be expected to use information from supply-chain actors to inform and orient their decisions. The stances of supply-chain actors, from producers to processors to retail, are fundamentally engaged in information communication, thus making it crucial to take these into account when investigating consumer acceptance of biotechnology in bioenergy production. Meanwhile, with respect to the use of biotechnology in food production, Pakseresht et al. (2017) find that consumer decision-making is influenced by the opinions of other stakeholders, thereby demonstrating the usefulness of examining consumer perceptions in their existing environments and policies. However, given that, apart from this one study, research in this domain is more or less nonexistent, another aim of this thesis is to investigate the role of the stances of supply-chain actors with regard to the acceptance of biotechnology in bioenergy production.

Consequently, a better understanding of how the content and framing of information influences consumer acceptance of biotechnology is required. Thus, in addition to the contextual factors end-use and policy regime, it is also investigated to what extent the informational context functions as a determinant of acceptance. In particular, the communication of scientific information to the public is frequently emphasized as a strategy to cultivate acceptance (Brauerhoch et al., 2007; Pierce, 2013; Weitze et al., 2013). Risk and benefit communication about food, both in general and in the specific area of consumer research, has therefore focused on application related to GM food, possibly due to the controversial and broadly negative nature of discussions here (Frewer et al., 2016). For this reason, Hess et al. (2016) concluded that negative perceptions of biotechnology in the EU come along with the greater focus on risk-related issues in consumer research. Given what this suggests about the importance of how the problem is framed, further research has examined, for instance, how negative media coverage can exert a subtle influence on consumer perceptions – that is, in addition to the content of the information (Scheufele and Lewenstein, 2005; Ho et al., 2010). Nonetheless, messages can only be useful for the target audience if they are ultimately understood (Verbeke, 2005). Thus, another objective of the thesis is to understand how exactly consumers process the information that is communicated to them, as well as the types of factors that are most significant in this regard. In contrast to the end-use of food, and as is the case for so many other factors, this question about the influence of information on consumer acceptance has not yet been researched in the context of bioenergy.

Against the backdrop of the transition towards a more sustainable bioeconomy, and the consequent need for product- and process-oriented solutions as well as advances in biotechnology such as genome editing, the thesis aims to investigate the following principal research question:

To what extent does the practical context determine the level of public acceptance of green biotechnology?

The aim of the thesis is thus to provide answers with regard to whether and how the broader practical context (i. product end-use, ii. policy regime, and iii. information framing) influences the key determinants of consumer acceptance of biotechnology in its existing socioeconomic environment (i. supply-chain) against the background of individual-level determinants (i. trust, ii. involvement, and iii. socio-demographic characteristics). By integrating key determinants of consumer acceptance along with relevant contextual and individual factors, the following research questions were derived for the corresponding empirical analyses:

(1) How does risk perception differ with regard to the practical context, and what are the most important determinants of acceptance in this regard?

(2) What is the interrelationship between the key determinants of acceptance, and how are these related to both the practical context and individual factors such as trust and socio-demographic characteristics?

(3) How is decision-making affected by information framing, the upstream decisions of supply-chain actors and emotion?

While the practical context in the empirical studies (1) and (2) entailed i. product end-use and ii. policy regime, study (3) investigated the effect of iii) information framing. Accordingly, these research questions are discussed in Chapters 2, 3, and 4, respectively.

The outline for the rest of the Introduction is as follows. Section 1.1 provides an overview about how the practical context is relevant for the debate surrounding biotechnology, along with a brief introduction into the legislation of GMOs. Section 1.2 describes the theoretical background by presenting the key determinants of consumer acceptance and some of the relevant contextual factors. Section 1.3 then presents the outline of the thesis as well as a visualization of the overall thesis setup.

1.1. THE PRACTICAL BACKGROUND

1.1.1. THE GM DEBATE

The debate about GM crops has been far-reaching and with many supply-chain actors involved, such as farmers, the processing and producing industries, and consumers. Consumer evaluations of biotechnology in food and non-food applications have been the subject of studies from a variety of research disciplines, and across many countries. According to opinion polls such as the Eurobarometer studies public perception about biotechnology has been varying both over time and with respect to region. Extant cross-country comparisons show that the acceptance of Europeans is lower than, e.g., in the U.S. (Zilberman et al., 2013). Typically, Europeans are more concerned about the associated risks than non-EU citizens (Hess et al., 2016). However, more generally, the existing controversy about genetically modified (GM) food in Europe suggests that applications of this technology find low public and governmental support. The Eurobarometer survey on biotechnology from 2010 showed that public support of GM food in the EU-27 was at 27 percent in 2005 and remained at a comparable level in 2010 (23 percent) (Gaskell et al., 2010). Moreover, while 47 percent of German respondents were supportive of GM food in 1996, only 22 percent still supported it in 2010. In comparison, support from Spanish respondents declined from 66 percent in 1996 to 35 percent in 2010 with Spain being among the countries with the highest support. Nevertheless, the authors found that a majority of Europeans are still optimistic about biotechnology in general, which might be also due to increasing concerns about energy and sustainability. In this regard, Germany is among the countries being the most pessimistic about this technology. Dunwell (2014) posited that the heterogeneity in perceptions across EU countries can be attributed to diverging opinions about the merits and demerits of GMOs. The author concluded, on p. 120, that Germany and other major grain producers of the EU, such as France and Poland, are “conflicted” countries which show broad opposition to GM crops from the consumer and governmental sectors, whereas industry, farmers, and science are supportive. These three countries accounted for 47 percent of the EU-28 total cereal production in 2014 (Eurostat), suggesting a high potential for biotechnology which will remain untapped unless consumers have reasons to believe that this technology might be beneficial for attaining wider societal goals. Moreover, opinions of German consumers and the government are influenced by NGOs and campaigns on GMOs that emphasize risks and thus enforce negative perceptions (Katzek, 2014).

According to consumer research, acceptance of biotechnology for food is lower than for non-food applications (Knight, 2006; Christoph et al., 2008) and perceived risks are consequently higher for food (Frewer and Shepherd, 1995). For instance, biotechnology in medical applications finds not only higher support (Heijs and Midden, 1995) but is also perceived to be less risky overall (Frewer et al., 1995). The end-use thus represents a crucial indicator of consumer acceptance. Consequently, acceptance of biotechnology in biorenewables could be indeed higher than for food since negative perceptions of this technology have the potential to be out-weighed by positive perceptions about this more sustainable source of energy (Verbeke, 2007). Against the backdrop of relatively low cultivation efforts and R&D spending in Europe a focal question is, therefore, whether GMOs are rejected due to the technology itself (a process-oriented definition) or because public perception of biotechnology varies by applications to the end-use (a product-oriented definition).

1.1.2. Regulatory framework

Similar to the varying perceptions, the cultivation of GM crops is heterogeneous between countries of the EU which is a result of how it has been regulated. The EU Directives 2001/18/EC on the deliberate release of genetically modified organisms (GMOs) and 2009/41/EC on contained use of GMOs regulate the cultivation of GM crops within EU borders. In article two of Directive 2001/18/EC, GMOs are therein defined as "an organism, with the exception of human beings, in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination". According to the Directive, genetic modification refers to at least one of the following techniques to alter the genetic material of a crop: transgenic recombination of nucleic acids in the host organism (e.g. maize) via a vector system (e.g. bacillus thuringiensis (bt)), direct injection of genetic material prepared outside the host organism, or cell fusions that result in new combinations of heritable genetic material. The first technique is usually referred to with genetic engineering. Regulation 2003/1829/EC on GM food and feed determines the procedures for placing GMOs on the market for the purpose of food or animal feed. Non-GMOs are therefore required to contain not more than 0.9 percent (for authorized GMOs) or 0.5 percent (for unauthorized GMOs) of GM content that is due to contamination during cultivation, transport, and production. Furthermore, GMOs that are approved under this regulation must comply with Regulation 2003/1830/EC on labeling and traceability. This amendment to Directive 2001/18/EC is in accordance with Regulation 2003/1829/EC which, in article 26, requires that "traceability and labelling of genetically modified organisms and traceability of food and feed products produced from genetically modified organisms […] ensures that relevant information concerning any genetic modification is available at each stage of the placing on the market of GMOs and food and feed produced therefrom and should thereby facilitate accurate labelling." Therefore, for products which consist of, or contain GMOs it should appear on the product that “This product contains genetically modified organisms” or “This product contains genetically modified [name of organism(s)]”. Micro-organisms are regulated by the Directive 90/219/EC. However, there are examples of products on the market which challenge at least one of the broad requirements for balanced labeling, namely to be complete (Wegwarth et al., 2014). For instance, enzymes that have been produced from GM micro-organisms are not required to be declared such that consumers can hardly be aware – without proactively seeking information - that cheese production in Germany heavily relies on genetically engineered Chymosin (BMBF, 2015). On the one hand, the regulatory framework on GMOs should feature a simple implementation of the requirements. On the other hand, it should guarantee transparency and freedom of choice at all time. In summary, this leaves the question about consumer perception of labeling requirements and the effect on trust in the implementing bodies, i.e. governments and the industry.

1.1.3. The ability to opt-out

In general, applications for GMOs in food and feed (but also other non-food applications) can be approved by the member states after a risk assessment is conducted by the European Food Safety Authority (EFSA) and risk management performed by the European Commission (EC). A recent amendment (2015/412/EC) of the deliberate release Directive, which has been initiated due to negative public perceptions, made it possible to opt-out at the national level from authorized GMO release and use. Accordingly, in September 2015, the German government has decided to take the opt-out measure for MON810, meaning that the release and use of this GM maize variety would no longer be permitted. The reasons for this decision generally refer to incompatibility of growing GM crops together with conventional and organic varieties. Further justification in this vein states that an increased risk to national ecosystems and biodiversity should be prevented, as well as costs that would originate from maintaining the co-existence of different systems (BMEL, 2015). R&D efforts, in contrast, have been explicitly exempted in order to ensure freedom of the arts and sciences (article 13 of the EU Charter of Fundamental Rights of the European Union). However, despite the potential of green biotechnology for German agricultural production, R&D spending for this technology is not of major concern anymore which is mirrored by political party agreements at the Federal State level which puts pressure on the agricultural sector’s global competitiveness. It is thus crucial to understand whether this legislative response is appropriate with regard to consumer perception of the associated risk that come along with the release and contained use of GMOs which also motivates the objective to investigate whether consumers differentiate between these frameworks or if perceptions of biotechnology base on a more general rejection of the technology itself.

1.1.4. CURRENT EXTENT OF R&D AND CULTIVATION OF GM CROPS

Despite the controversies around biotechnology and its application to agricultural production, global GM crop cultivation has been on the rise since the late 1990s. As such, agricultural biotechnology can be divided into the main areas of seeds and plants (green), animals, and microorganisms (white). Genetic engineering, or modification, is a tool or method in biotechnology to introduce new traits or characteristics to an organism which results in GMOs. These terms are often used synonymously. According to James (2014), the area for global production of GM crops in 2014 accounted for 181.5 million hectares (which for example is about 20 percent of the total land area of the U.S. or China). Of this area, the share of the U.S. was 40 percent, followed by Brazil (23 percent) and Argentina (13 percent). The EU accounted in the same year for 143 thousand hectares, from which Spain produced 92 percent. At the global level, GM soy is the primary crop followed by maize and cotton. In the EU several maize varieties are permitted for cultivation (e.g. MON810). Finally, the cultivation of GM crops for commercial purposes in Germany accounted, in 2008, to 3171 hectares from the maize variety MON810 and, in 2011, two hectares for the potato variety Amflora. No GM crops have been cultivated in Germany thereafter. The last field release in Germany for R&D purposes was in 2013 on 1800 square meters in the Federal State Mecklenburg-Western Pomerania (BVL, 2005).

1.1.5. RISK DIMENSIONS AND TRUST

The EU regulatory framework on GMOs incorporates the potential risk for human health (e.g. allergies) and the environment (e.g. biodiversity); however, it is important to note that socioeconomic and ethical aspects were identified as other potential sources for adverse effects (Stirling and Mayer, 1999; Peterson et al., 2000; WHO, 2014). These include, for instance, risks that the crops of non-GM farmers are subject to horizontal gene transfer from GMOs, which could affect their harvest and thus destroy their reputation (socioeconomic). Moreover, large biotechnology companies could take advantage of their monopoly in order to exploit farmers and reduce their ability to make a living (ethical). The possible environmental issues include, among others, the threat of genetic drift and persistence, loss of biodiversity, and the increased use of chemicals. Opponents of biotechnology moreover criticize the absence of long-term studies and argue that risks to both human health and environment have not yet been adequately assessed (Bawa and Anilakumar, 2013). The cultivation of GM crops might therefore lead to a loss in biodiversity (Conway, 2000; Pimentel, 2000) and its intake may result in allergenic responses in humans (Stirling and Mayer, 1999). Supporters, in contrast, refer to the potential benefits for environmental quality through, e.g., reduced pesticide use in agricultural production (Klümper and Qaim, 2014) and the improvements in health quality (Lutter and Tucker, 2003). Nonetheless, though the risks and benefits tend to focus on different types of outcomes, what these perspectives have in common is the overall difficulty of consumers to exercise control over the supply chain. Instead, consumers must trust in the responsible actors, ranging from regulatory actors and policymakers to agri-input suppliers, farmers, and the processing and producing sectors. Trust in this direction is critical to establish the sense that benefits are realized and that these actors are willing and able to protect individuals from risks and prevent damage to societal concerns such as the environment. However, trust in the industry is usually low, especially for bigger companies, owing in part to the sense that these have limited accountability (Frewer et al., 1996). As such, a possible explanation might be that the lack of accountability arouses suspicion of dishonesty given the greater emphasis to maximizing profits (e.g. Schütz and Wiedemann, 2008).

1.2. The theoretical background

1.2.1. Acceptance of GMOs

Innovation activity is a vital driver for the emerging bioeconomy given the need for new techniques that enable the circular use of raw materials to create more sustainable products (Golembiewski et al., 2015). Inventions, however, require consumer acceptance in order for their potential to be realized. According to Rogers (1983), p. 138, an "invention is the process by which a new idea is discovered or created. In contrast, innovation [..] occurs when a new idea is adopted or used". Although agri-food markets in Europe are demand-driven (Verdouw et al., 2011) and consumers have a high power to co-determine the commercialization of products, acceptance is required at all levels of the value chain for a functioning bioeconomy. Therefore, it is necessary to explore what it is that would drive consumers and supply-chain actors to adopt the kinds of behaviors that could make transformation towards a bio-based economy possible. According to Rogers' diffusion theory, acceptance is a crucial prerequisite to the adoption of novel technologies or products and an ultimate determinant of the degree of diffusion (Rogers, 1983). In other words, the degree of diffusion at the macro level corresponds to the extent of behavioral adoption at the micro level. If a given product or technology is bought or adopted more frequently, then its diffusion can be expected to be high as well.

Once we begin to consider decision-making more directly, it is also important to be aware that discussions of adoption and acceptance behavior need not be reflected in any actual action taking place. Rather, *behavior* in this context could perhaps be better described as a promise or desire to engage in a behavior under certain circumstances. As a result, depending on the discipline in which such research is taking place (i.e. psychology or economics), we may alternatively describe the degree to which an individual wishes to engage in acceptance and adoption behavior in the terms of attitudes, preferences, and intentions. In this respect, intentions provide a helpful proxy for actual behavior by describing “a person’s motivation in the sense of her or his conscious plan or decision to exert effort to enact the behavior” (Conner and Armitage, 1998 p. 1430). For this reason, intentions are often used in consumer research as a link between attitudes and stated preferences on the one hand and individual behavior on the other (e.g. Ronteltap et al., 2007).

Broadly stated, both the concept of preferences in economics and that of attitudes in psychology describe the value that individuals attach to a particular event or object (Kahneman et al., 1999). Substantial similarities thus exist between the two. In the case of preferences, however, such value judgments are generally expressed through a choice between two (or more) potential alternatives, rather than favor or disfavor in the case of attitudes. When the alternatives correspond to actual products, as might be the case in a real-world shopping environment, individual preferences are said to be *revealed*, given that we might directly observe either the purchasing process itself or its outcome. Thus, revealed preferences relate to observed buying behavior in a market situation. In contrast, if we instead only ask which product an individual might prefer in a particular situation, then this involves a *stated preference*. This thesis relies on data from stated preferences. The difference between revealed and stated preferences, not to mention their potential implications for understanding behavior, is also reflected by the intention-behavior gap (e.g. Rogers, 1983). The way that consumer research tends to measure stated preferences is mostly via intentions and hypothetical decisions. There is a plethora of stated-preference valuations of the acceptance of GM food, some of which focus on intentions to use or buy, the willingness to accept or pay, the level of support (or rejection) that is given, how much one consider it to be risky, beneficial, safe, etc., approve or disapprove, and so on (Hess et al., 2016). For the purposes of clarification, *acceptance* in consumer research thus can alternatively relate, on the one hand, to active decision-making based on volition, i.e. the willingness to participate, whereas *acceptance* also entails a second and more passive component which relates to tolerance of specific outcomes. Both components of *acceptance* are employed in this thesis. While Chapter 2 and 3 focus on the passive component of acceptance by assessing respondents’ risk perception, Chapter 4 investigates participants’ decision-making by means of *support* or *rejection*. Notably, with regard to biotechnology perceived risks are the major antecedent of acceptance (e.g. De Steur et al., 2014) and therefore risk perception has been used as a proxy for consumer acceptance.

1.2.2. Risk perception of GMOs

1.2.2.1. Risks and benefits

Stated preferences are the result of a variety of factors. In specific, consumer research has identified the following determinants of consumer acceptance of biotechnology: consumers' risk and benefit perceptions, trust in institutions (Ronteltap et al., 2007; Costa-Font et al., 2008; Rollin et al., 2011; Frewer et al., 2013; De Steur et al., 2014), attitudes (Bredahl et al., 1998; Frewer et al., 2013), sensory attributes (Lusk et al., 2014), sociodemographic characteristics (Lusk et al., 2005; Ronteltap et al., 2007; De Steur et al., 2014), labeling (Frewer et al., 1998; Teisl et al., 2008; Dannenberg, 2009; Rollin et al., 2011; Bawa and Anilakumar, 2013), the level of knowledge, and information communication (Bredahl et al., 1998; Ronteltap et al., 2007; Costa-Font and Gil, 2008; Rollin et al., 2011; De Steur et al., 2014; Lusk et al., 2014; Frewer et al., 2016). There is a strong consensus that outlines how consumer acceptance of biotechnology is guided by individual perceptions of risks and benefits (e.g. Frewer et al., 2013). Benefits play an important role whenever they have a direct and tangible effect for consumers (Engel et al., 2002; Hossain et al., 2003), for instance in terms of health and environmental protection (Ueland et al., 2012; Yue et al., 2015) which are the two main categories of benefits that were identified to be important for acceptance of novel products. For example, Hess et al. (2016) show that, even though evaluations of GM foods did not generally differ, perceptions of these products were less positive when livestock genes were modified directly and more positive when providing a medical benefit. Apart from that, Lusk et al. (2015) posited that, for U.S. consumers, the acceptability of GM food is likely to be higher if the benefits for national competitiveness are better understood. Risks, however, tend to reduce consumer support and therefore are negatively related to acceptance. The inverse relationship between individual perceptions of risks and benefits, respectively, is generally well-established (Alhakami and Slovic, 1994), as well as for the specific case of GM food (Costa-Font and Mossialos, 2007; Ueland et al., 2012). With respect to GM food, for instance, it is demonstrated that perceived risks seem to outweigh perceived benefits in most cases (De Steur et al., 2014; Hess et al., 2016). A possible explanation is that risks and benefits are perceived differently across individuals. In fact, benefit perceptions tend to rely more on heuristics and personal experience (e.g. taste), whereas risk perceptions are more (although not exclusively) connected to the cognitive processing of long-term consequences (e.g. dread, likelihood, and controllability of risk) (Fischer and Frewer, 2009; Ueland et al., 2012). For these reasons, this thesis seeks to explain consumer acceptance by focusing on the level of stated support and perceived risks of biotechnology on the part of consumers.

1.2.2.2. Definition of risk

One approach for quantifying and measuring the subjective risk perceptions of individuals builds upon the psychometric paradigm, initially discussed by Starr (1969). Accordingly, risk can be defined as a combination of subjective knowledge about both the likelihood and severity of the risk, as well as the degree of control one has (Slovic, 1987). Rayner and Cantor (1987) thus define risk in terms of both probability and magnitude over time. Notably, the conceptualization of perceptions is often problematic given that quantitative representations of judgements about probabilities and magnitude of risk are subject to a number of heuristics and biases (Tversky and Kahneman, 1974). To clarify, the research in this thesis is thus not based on expected utility theory but rather on stated preferences in a more general sense. Moreover, use of stated preferences is therefore susceptible to biases such as underweighting or inflation of objective outcome probabilities (Kahneman and Tversky, 1979). The authors argue that the discrepancy between decision-making and expected utility resulting from such biases can however be explained by their prospect theory. That is, individuals have a tendency to be risk-seeking for uncertain losses, even if they have lower expected utility. In contrast, they are risk-averse for uncertain gains and are therefore likely to choose a certain gain even if expected utility is lower. This finding implies, however, that consumers may not be willing to bear a risk if it does not come along with certain, i.e. tangible and observable, benefits, just as previously illustrated for the case of biotechnology in agricultural production. This is also reflected by the legislative response to public concerns about GMOs. In the general, regulatory approaches assign a higher burden of proof for demonstrating that the derived product is safe than is the case for, for instance, food flavorings (Garnett and Parsons, 2017). Another aim of the thesis is thus to better understand the risk perceptions of consumers and how these vary across particular end-uses and dimensions.

1.2.2.3. Risk dimensions

However, existing research tends to handle the complex array of associated risks by focusing on only a few specific aspects, that is, instead of investigating all four risk dimensions of biotechnology simultaneously. Some of the risks that are of major public concern with regard to GM food and crops involve human health, environmental safety, economic considerations, and ethical aspects (Bawa and Anilakumar, 2013). Reflecting the broad importance of environmental risks, Siegrist (1999) thus shows that Swiss students' acceptance of biotechnology is partly predicted by environmental attitudes. What is more, in line with the principal emphasis on food applications, Moon and Balasubramanian (2003) find that consumers in the U.S. and U.K. are more likely to pay a premium for non-GM food if they perceive there to be a substantial risk of GM food to human health or the environment. Comparing risks perceptions of Italian and U.S. consumers, Harrison et al. (2005) determine that the potential for health and environmental risk raises greater concern for Italians, suggesting the possibility of cross-cultural differences. Meanwhile, Martinez-Poveda et al. (2009) estimate a structural equation model that investigates the effects of health concerns, institutional information and disinformation, respectively, on the risk perceptions of Spanish consumers. They find the most influential factor to be threats to health status, i.e. the greater the concern of health-related consequences, the higher is the perceived risk. However, the authors do not make further comparison to either environmental, socioeconomic, or ethical risks. In this regard, Frewer et al. (1997a) however find that the ethical concerns of British consumers are typically associated with technological applications linked with animals or human genetic material rather than those for plants.

Accordingly, this thesis aims to deliver an evaluation of the significance of the entire range of risk dimensions for consumer evaluations, rather than only focusing on a narrower sample of the risk aspects involved. Risk statements for food end-use, for example, were developed from an extensive literature review conducted by Hess et al. (2016). Given the comparative novelty and paucity in prior research on biotechnology risks for bioenergy production, the risk statements for bioenergy end-use were however, first, deduced from the literature before being subjected to a subsequent explorative analysis with a focus group to validate prior research on food.

As such, risk perception is closely related to perceived controllability and risk responsibility. Accordingly, these concepts are briefly discussed in the subsequent sections.

1.2.2.4. Self-control

Self-control, which refers to the personal controllability of a hazard, is one example of an important factor that exerts a negative effect on risk perception (Slovic, 1987). Risks, that appear to be under one's own control, are thus less uncertain and more acceptable, even if the overall level of danger is higher (Leikas et al., 2009). This phenomenon is also referred to as the optimism bias. Similarly, McKenna (1993), p. 39, argues that the optimism bias may better be termed the "illusion of control" as the individuals' perceived control only reduces the subjective probability of personal risk, and not the objective probability. Even though this generally suggests risk perceptions to decrease in response to greater perceived controllability, a positive relationship has also been observed by Frewer et al. (1994). The authors reported that levels of risk perception for GM crops actually increased with the controllability of risk. One possible explanation is that the awareness of risk would be a necessary prerequisite for consumers to have a concept of what the risks are, and by which means they were controllable at all. Nonetheless, the more general relationship between perceptions of risk and controllability is still confirmed for the context of biotechnology (Lusk et al., 2014).

For the purposes of this thesis, self-control is defined as the perceived ability to personally control for one's own exposure to risk and to take measures to prevent risk. Thus, this concept also entails a volitional component which relates to the voluntariness of risk. Involuntary hazards, for example, are also perceived to be much riskier compared to those resulting from voluntary activities.

1.2.2.5. Risk responsibility

Risk perception is also directly connected to perceptions of how much one is responsible for the risk to which one is exposed (Phares and Wilson, 1972). As such, the severity of consequences of potential hazards can be expected to be negatively related to the level of personal responsibility that is assigned (Walster, 1966). According to Leikas et al. (2009), consumers tend to attribute a relatively high degree of responsibility for biotech risk management to other actors of the supply-chain, especially if they feel unable to personally control for the risk. As such, the lack of control leads to assigning lower responsibility to themselves. Research for health psychology similarly posited that individuals with lower levels of personal responsibility are more prone to employ types of avoidant coping strategies such as denial, and mental and behavioral disengagement (Voth and Sirois, 2009). Regarding consumer research, this can result in lower acceptance of novel technologies as consumers are less likely to either confront potential risks or consider the potential benefits. Conversely, individuals taking greater personal responsibility are more prone to adopt risk-prevention behaviors (Rothman et al., 1993), which results in higher acceptance of innovative technologies. Finally, risk responsibility plays an important role in risk communication. In other words, in order for information to have an effect on consumer evaluations, individuals have to feel personally responsible (Karbalaei et al., 2013).

1.2.3. Contextual factors influencing consumer perceptions

Consumer perception does not emerge in a *vacuum* given that the interaction of factors such as public policymaking, regulatory approaches, consumer decisions, and existing socioeconomic environments will likely influence how technologies are perceived and whether, and to what extent, they will play a role for the emerging bioeconomy (Palacios-Huerta and Santos, 2004; Dries et al., 2016).

1.2.3.1. End-use

The current debate lends support to the notion that biotechnology is rejected more generally which would suggest that consumer perception is independent of the context. However, consumer research emphasized that, in general, consumer perception is influenced by product-related characteristics that correspond to tangible benefits (Bearth and Siegrist, 2016). As a result, we can expect that the consumer perspective on biotechnology is likely to be more product- and end-use-oriented, i.e. rather than evaluations rendered for the technology as a whole. Ignoring this, could prevent products to enter the market that are well regarded by consumers and, as a result, impede efforts in R&D. In fact, with regard to consumer acceptance of biotechnology, the applications to food products are generally perceived to be more risky than for non-food products (Frewer and Shepherd, 1995). Conversely, public support of food applications is lower overall than for non-food applications (Knight, 2006; Christoph et al., 2008). Furthermore, opposition to biotechnology is higher if applied to human or animal genetic material than to plants and microorganisms (Frewer et al., 1997b; Frewer et al., 1997a). Concerning food and medical applications of biotechnology, consumers moreover see two dimensions to be relevant, namely end-use of the application (i.e. food or agriculture and medicine) and the type of organism involved (i.e. animals or plants and microorganisms) (Siegrist and Bühlmann, 1999, cit. Siegrist, 2000).

Relevant applications of biotechnology already exist, such as foods with enhanced micronutrients, and bioenergy crops with higher yields and lower input costs (Qaim and Zilberman, 2003; Klümper and Qaim, 2014). Moreover, such products actually represent a realistic potential choice for respondents. However, there is no research investigating the consumer acceptance of biotechnology for bioenergy production, making it hard to identify potential hurdles for its commercialization. For this reason, Verbeke (2007) called for research on biotechnology acceptance in biorenewables. As Frewer et al. (1997b) has argued, the end-use of the product is a broad determinant of consumer acceptance. Consequently, given that GM food is perceived to be riskier than non-food applications, bioenergy uses are more likely to be acceptable. This motivated the product comparison and therefore, this thesis employs two treatment groups, one for use of biotechnology for the purpose of food, and one for the purpose of bioenergy to account for the contextual factor end-use.

1.2.3.2. Policy regime

Similarly, the influence of the policy context on consumer perception has received limited attention so far. Consumer research suggests, however, that contextual factors are generally important as discussed in the following. As a result, many of the frameworks that have been suggested portray consumer evaluations as affected by both micro-level or proximal factors (i.e. consumer perceptions of risk and support) as well as macro-level or distal factors (e.g. political environment or social system) (Ronteltap et al., 2007; De Steur et al., 2014). This suggests the importance of including both in order to explore the interlinkages between consumer evaluations of risk on the one hand and the policy context on the other.

There has been an overall decrease in support for R&D (Parisi et al., 2016). This legislative reaction to public rejection of biotechnology applications, however, might endanger the EU's global competitiveness in agricultural production. Thus, one important aim of this thesis is to assess how the policy regime broadly affects consumer perceptions of GMOs. An integrated approach, i.e. combining consumer perceptions and the policy context, is therefore formulated on the basis of two policy scenarios, namely Full Commercialization (FC), allowing for the broad use of GMOs for a variety of purposes, and Research and Development (R&D)-only, restricting use of GMOs to R&D. The policy scenarios thus reflect the current regulatory approaches in Germany under the auspices of the EU directives 2001/18/EC on the deliberate release of GMOs and 2009/41/EC on contained use of GMOs. For the sake of clarity, both of the relevant treatment groups for product end-use (food vs. bioenergy) and policy regime (FC vs. R&D) were employed for Chapter 2 and 3, whereas the analysis in Chapter 4 focused on the FC policy scenario, only.

1.2.3.3. Information and emotion

How information is framed plays an important role in consumer acceptance, especially in decision-making. Yet, it can be seen as a contextual factor since evaluations of the products will likely depend on the information that consumers receive about, for instance, risks and benefits of the product end-use through media or labeling. The amount of informational content that is present in risk and benefit messages also plays an important role for consumer perceptions of innovative technologies in food production (Frewer et al., 2016). In specific, the level of content determines whether individuals are likely to process the information in a cognitive way (evaluation of risks and benefits with regard to long-term consequences) or affective way (i.e. feelings and emotions usually used in quick decision-making) way (e.g. Kahneman, 2003). For this reason, Roeser (2012) proposed a risk-as-feelings approach that identifies cognitive and affective reactions to the prospect of risk as two distinct processing streams, while at the same time remaining closely interrelated. In specific, affective reactions are more sensitive to one's actual state of mind, e.g. owing to mood or the imagery presented, and the situational context of decision-making. In contrast, cognitive evaluations of risk, including those broadly associated with expert judgments, are informed by likelihood and severity of objectively measurable outcomes, e.g. annual mortality rates (e.g. Slovic, 1986; Finucane and Holup, 2005; Ueland et al., 2012). Broadly speaking, it is thus the case that the risk judgments of the general public can differ dramatically from those of experts, in part due to the former being much more intuitive and affect-driven (e.g. Slovic, 1979; Slovic, 1987; Loewenstein et al., 2001). Moreover, taking this one step further, those supposedly *irrational* differences in the evaluations of new technologies may arise from the *gut feeling* of the decision-maker, perhaps because of the felt similarity between the current situation and one in the individual's past (Loewenstein, 2000). The risk-as-feelings approach thus posits that emotional factors play an important role for the informed decision-making of individuals (Loewenstein et al., 2001). However, the authors conclude that there is a general lack of research on the influence of visceral or situational factors such as mood or emotions.

To make sense of the public understanding of green biotechnology for the purpose of bioenergy production, this thesis thus employs three information frames in order to control for the valence of the message with respect to information content and emotions.

1.2.4. EXISTING SOCIOECONOMIC ENVIRONMENT AND INDIVIDUAL-LEVEL FACTORS INFLUENCING CONSUMER PERCEPTIONS

1.2.4.1. The supply-chain

Responding to the potential consumer rejection of biotechnology and its relevant products, there is a plethora of attention given to the likely end-users of these products. Nevertheless, the attention to these actors is not repeated for the supply-chain as a whole. Pointing to a potential shortcoming, De Steur et al. (2014) has however suggested that consumer perceptions might also be affected by the perceptions and decisions of other stakeholders, such as policymakers and industry actors. Sapp and Korsching (2004) showed, for instance, that U.S. consumers' acceptance of food irradiation was positively affected by whether opinion leaders had offered their endorsement and similar results were reported for the acceptance of GM food (Pakseresht et al., 2017). However, there is a lack of research overall into the interdependence of consumer perceptions and the stances of supply-chain actors with regard to GM bioenergy. Given that the specific risks in food and non-food production are neither observable nor assessable by individual consumers at reasonable costs, risk management is necessarily assigned to the responsible regulatory authorities. The final products on offer to consumers are thus comprised, at least partly, of attributes that are not directly observable and subject to trust. Such product attributes are also known as credence attributes owing to the role of credibility (Darby and Karni, 1973). Because of their in-depth knowledge about the production process, it is thus producers, and regulatory authorities, who tend to be assigned responsibility to control the associated risks. These supply-chain actors thereby serve as a key source of information and influence. Thus, consumers are likely to orient their decisions on stakeholder decisions which motivated to investigate how consumer perceptions are dependent on upstream support or rejection of the supply-chain.

1.2.4.2. Labeling

Effective ways to avoid suspicion and distrust are communication and transparency (Frewer et al., 1996). The provision of information –through, e.g., labeling, which is one of the least costly sources of information– can tackle the risk of market failure in the agricultural industry, especially when this results from information asymmetry (Verbeke, 2005). One method to reduce this asymmetry is to provide information for credence cues, i.e. product- or process characteristics that cannot be evaluated by consumers at reasonable costs, through labeling (Fernqvist and Ekelund, 2014). Labeling is shown to be important to consumers especially if the product contains GM material (Poortinga and Pidgeon, 2004). As information is often confusing for consumers (McFadden and Lusk, 2015) or even useless to them (Jacoby et al., 1977) information must be tailored to suit the needs of the target audience (Abrahamse et al., 2007). For instance, if an individual has concerns about one of the specific risk dimensions (e.g. economic or environmental), then it would be beneficial to provide them countervailing information relevant to these concerns. What is more, even if a group of individuals are highly concerned about the use of biotechnology for food production, this may not be the case across all applications. Therefore, next to the influence of information framing this thesis investigates how mandatory product labels affect consumer acceptance of biotechnology for the purpose of bioenergy production.

1.2.4.3. Trust

The greater the level of confidence that stakeholders are able to manage the risks of biotechnology or related product applications, the more likely this will factor into consumer evaluations of risks. Thus, trust in responsible institutions or persons is another key determinant of risk perceptions (Siegrist, 2000; Weitze et al., 2013; Aven and Cox, 2016). Especially in cases where little information is available and decisions are subject to high uncertainty, people tend to rely on heuristics. These have been defined as strategies or rules that help to reduce the cognitive burden in decision-making (Shah and Oppenheimer, 2008). Given that one cannot be completely certain about benefits of, for instance, GM food, such decisions must be taken on the basis of trust and credibility (Chen, 2008). Trust is therefore necessary to explain the risk perceptions of the lay public, especially in cases such as biotechnology of which they have little knowledge of the hazard (Fischhoff et al., 1982; Hossain et al., 2003). Consumer understanding in this domain is even lower than for other hazards such as E. coli or BSE, also because there is a lack of public awareness and understanding of the regulatory framework for food safety (McCarthy, 2000). In fact, according to McFadden and Lusk (2016), consumers may actually have less knowledge than even they think. If confronted with facts, they are likely to overestimate their level of knowledge, for instance. The majority of consumers thus prefer that experts take over the responsibility of making decisions about GM food. In addition, due to the complexity of the topic, potential control measures for containment and handling of biotechnologies were only trusted if carried out by experts, i.e. rather than the consumers themselves (Starkbaum et al., 2015). Moreover, Frewer et al. (1996) find that the level of trust that people place in information about food-related risks depends on the information source. While consumer organizations are highly trusted, there is an overall lack of trust in government and industry. Finally, there is a paucity of research investigating the influence of trust in each of the supply-chain actors separately. Current studies in consumer research on biotechnology therefore tend to consider trust in the industry as a whole (e.g. Flynn et al., 1994). Therefore, this thesis takes steps in assessing trust across the supply-chain by including policymakers, scientists, industry actors, and consumer organizations. For the sake of clarification, it is expected that level of trust in the responsible authorities is a general factor, and thus does not vary across, e.g., differences between products, risk dimensions, and policy scenarios. Taking this into account, trust is therefore used as a covariate rather than a variable throughout the analyses in the thesis.

1.2.4.4. Socio-demographic characteristics and involvement

Risk perception is to some extent affected by socio-demographic factors such as age and gender. For instance, women tend to be more concerned about health and safety effects for a given level of technological risk (Davidson and Freudenburg, 1996; Frewer, 1999). However, both Costa-Font and Mossialos (2007) and Siegrist (2000) do not find any significant effects from age and gender on consumers' risk perceptions of GM food. According to Frewer (1999) and Sjöberg (2004), moreover, higher socioeconomic groups tend to have lower risk perceptions than groups with lower socioeconomic status. Given this fact, income has often been included as a proxy for measuring this effect. In addition, Gaskell et al. (2003) finds that a typical supporter of GM is more likely to be male and well-educated. Meanwhile, Heiman et al. (2000) show for the context of Israel that level of education has a significant impact on attitudes towards GM foods, whereas gender does not. Overall, socio-demographic criteria cannot be conclusively shown to affect risk perception in a certain direction.

On the other hand, Consumer involvement has been shown to be connected to perceived risk in many studies (e.g. Karbalaei et al., 2013), but not yet with respect to biotechnology. In specific, Chen (2007) finds that involvement has an effect on food choice, while Foxall and Bhate (1993) argue that involvement is particularly relevant for purchases of innovative foods. Since food is a traditional product and deeply rooted in our culture, individuals' involvement can therefore be expected to be more important for food than for bioenergy, which compared to food is a novel product.

1.3. AIMS AND OUTLINE OF THE THESIS

This section provides an overview of the study designs (see Table 1) and thereby summarizes the research gaps toward which the various studies are oriented. In addition, a diagrammatic visualization of the thesis as a whole has been given (see Figure 1) to improve the reader's understanding of the conceptual model that was used. In this figure, the connections underlying the thesis and linking together the empirical chapters (Chapters 2-4) are made manifest.

Chapters 2-4 present the empirical studies on consumer acceptance of biotechnology against the backdrop of the practical and theoretical perspectives discussed above. The designs for each of the studies are described in Table 1, with respect to the relevant theoretical perspective on acceptance, the unit of analysis, type of measurement, and utilized methodological approach. Chapters 2 and 3 investigate the key determinants of consumer acceptance in relation to the contextual factors end-use and policy regime. Chapter 4, meanwhile, focuses on differences of consumer decision-making between information frames in relation to upstream decision-making. To provide the reader some initial footing for the remainder of this thesis, the rest of this section will outline the research questions for each of the specific chapters.

Table 1: Overview of the study design in thesis

Chapter	Theoretical perspective on consumer acceptance	Unit of analysis	Sample size	Measurement	Approach	Status-quo
2	Risk perception	Consumers	N = 439	Determinants and contextual factors of risk perceptions	Exploratory and confirmatory	Published in the International Journal of Consumer Studies
3	Risk perception	Consumers and their perspective on the supply-chain	N = 436 (builds upon previous data set)	Relationship of risk determinants to contextual factors	Confirmatory	Under review
4	Decision-making	Consumers in relation to the supply-chain	N = 322	Decision-making and risk messages	Confirmatory	Under review

Chapter 2 presents the empirical study exploring risk perceptions of biotechnology for food and bioenergy production with respect to two distinct policy scenarios, namely R&D and FC.

Against the backdrop of the current transition to a sustainable bioeconomy, novel technologies are needed to improve the competitiveness of bio-based products and provide substitutes such as biorenewables (Davison et al., 2015). The acceptance of such products is crucial for market adoption of the related technologies (Bröring et al., 2017). In this regard, biotechnology is a good example – or rather, cautionary tale – for the importance of consumer acceptance as a prerequisite for commercialization and R&D efforts. As such, two of the likely responses available to policymakers to address consumer concerns are modeled, each of which corresponds to a policy regime currently used to regulate biotechnology, namely Research & Development and Full Commercialization. However, it is not yet clear which of these, or indeed whether either response, is wanted by the public. While research on consumer acceptance focused on GM food (e.g. De Steur et al., 2014), further research is thus required to investigate public perceptions of biotechnology for other end-uses such as bioenergy (Verbeke, 2007). To close this gap, the empirical study in this chapter analyzes data from a framed field experiment with 439 randomly selected consumers from citizens in Bonn to investigate the following research questions:

RQ1.1: Are consumers more likely to accept green biotechnology used for the purpose of bioenergy production, i.e. compared to food production?

RQ1.2: Does consumer acceptance of biotechnology differ based on the overarching policy regime?

In this manner, the current literature on consumer acceptance is extended to another application category of biotechnology, and one which has become increasingly important for a more sustainable bioeconomy to be attained.

Moreover, studies assessing risk perceptions of consumers have tended to focus on the health and environmental aspects. This focus, however, results in: i) the unfortunate neglect of socioeconomic and ethical risks, and ii) the failure to simultaneously assess all relevant risk aspects. Although there is evidence that consumers evaluate risks differently depending on the consequences (Martinez-Poveda et al., 2009), in fact, such statements can be difficult to support given that studies tend to focus on only a subset of the potential risk dimensions. As a result, there is a lack of research into evaluations of perceived risk in a comprehensive way. For this reason, this thesis set itself the task of measuring consumer perception in the four dimensions of health, environmental, socioeconomic, and ethical risk (a table containing the risk statements used in this study can be found in Appendix A). The underlying research question is thus:

RQ1.3: Does risk perception differ across risk dimensions?

Lastly, only by including all these various determinants in a single study are we able to consider one of the central questions for such research, namely whether or not it is possible to draw implications about the relative significance of the different variables. Or, in other words:

RQ1.4: What is the most important determinant of consumer risk perception?

An univariate association between the respective determinants of individual acceptance and the practical context is not sufficient, however, to model the relationship in practice given the level of interdependence between the factors. While current research has tended to focus on multivariable relationships that have one dependent variable, the empirical study in Chapter 3 applies a multivariate approach to model and quantify the interrelationships between risk perceptions, the associated constructs of self-control and risk responsibility, and the practical context. The sample of this study partly draws upon data from the previous study. Initially the data entailed 439 observations, but three observations were excluded due to missing data. This leads to the following research question:

RQ2: How are the major determinants of biotechnology acceptance interconnected and related to the practical context?

Consumer decision-making is informed by perceptions of risk and affected by both information communication and social-system characteristics (e.g. Ronteltap et al., 2007). As such the valence of the risk message (positive, negative, and neutral) can affect consumer decision-making with respect to GM food (Frewer et al., 2016). However, no studies have explored perceptions with regard to bioenergy. Moreover, both social-system characteristics and their influence on consumer decision-making have been neglected in prior research. And yet, consumer perceptions are highly likely to be informed by stances and decisions of trusted supply-chain stakeholders who have expert knowledge of the technology itself and its use in agricultural production. To close these gaps, a framed field experiment has been conducted with a random sample of 322 respondents from Bonn. The aim of the empirical analysis in Chapter 4 is thus to investigate how consumer support and rejection of biotechnology in bioenergy production is affected by upstream supply-chain support and rejection, as well as how much such interdependent consumer decisions are affected by positive and negative information which in turn is susceptible to respondents' emotional states. This results in the following research questions:

RQ3.1: Does information framing affect consumer decision-making with regard to the use of biotechnology for bioenergy production?

RQ3.2.1: To what extent are consumer decisions dependent on the stances of supply-chain actors?

RQ3.2.2: Does trust in supply-chain actors have the potential to increase levels of upstream support or rejection?

RQ3.3: Do positive and negative information frames evoke an emotional response consonant to the valence of the framing?

Figure 1 is supposed to visualize the thesis setup by depicting the conceptual framework applied in this thesis as well as how the different components relate to each of the thesis' chapters.

Finally, Chapter 5 summarizes the results from the empirical studies by connecting the respective research questions with the answers provided by the analyses in Chapters 2-4. Subsequently, the overall research questions of this thesis will be discussed and evaluated with respect to the issue of consumer acceptance and how the key individual determinants of acceptance are affected by those of a more contextual nature. The chapter concludes by discussing practical implications, limitations of the thesis and directions for future research, and by giving a brief outlook.

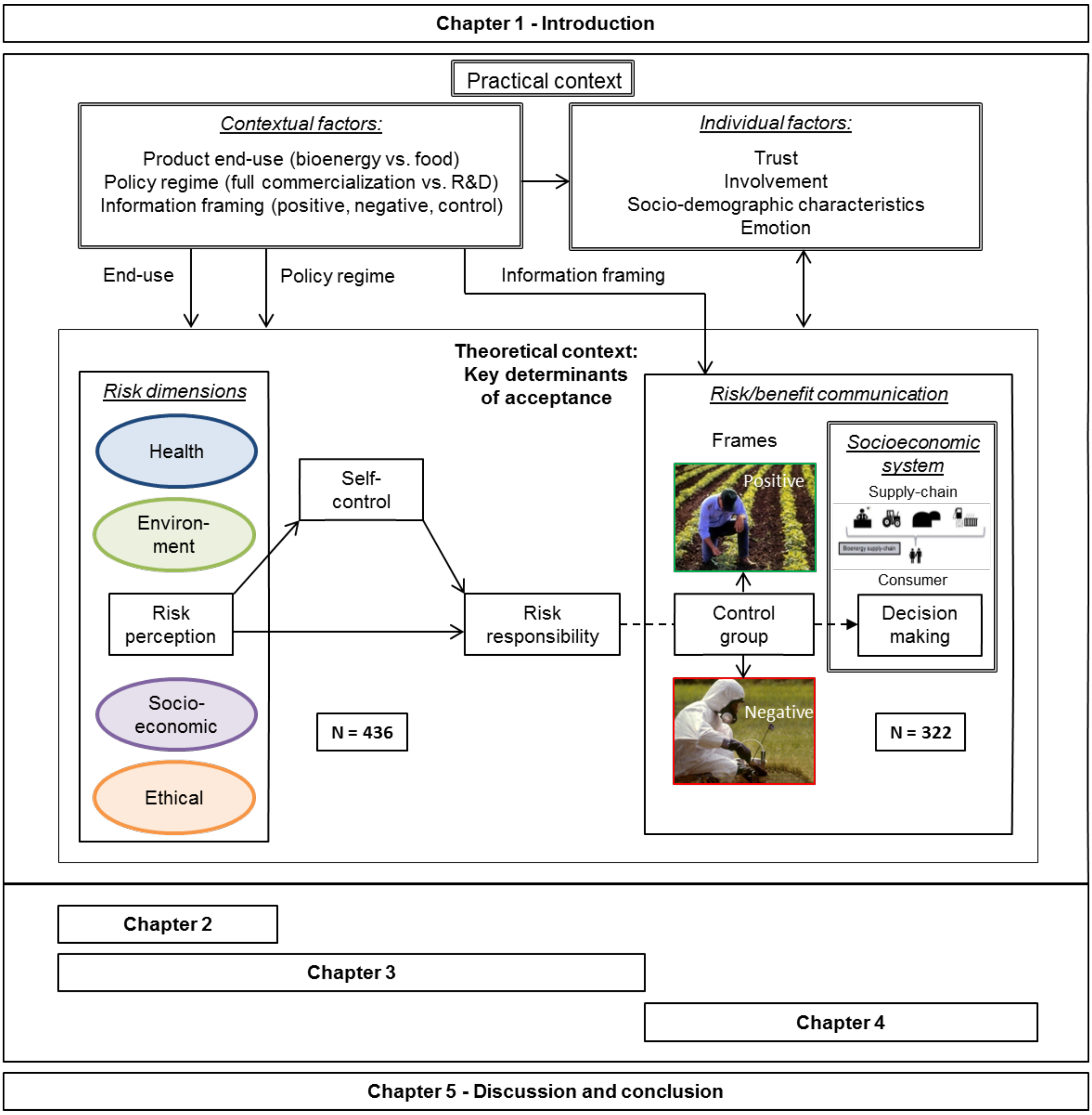

Figure 1: Thesis setup. Picture sources: colourbox.de and Lang et al. (1999).

2. DEBUNKING THE MYTH OF GENERAL CONSUMER REJECTION OF GREEN GENETIC ENGINEERING: EMPIRICAL EVIDENCE FROM GERMANY

RQ1.1: Are consumers more likely to accept green biotechnology used for the purpose of bioenergy production, i.e. compared to food production?

RQ1.2: Does consumer acceptance of biotechnology differ based on the overarching policy regime?

RQ1.3: Does risk perception differ across risk dimensions?

RQ1.4: What is the most important determinant of consumer risk perception?

This chapter is based on the following publication:

Butkowski, O. K., Pakseresht, A., Lagerkvist, C. J., Bröring, S., 2017. Debunking the Myth of General Consumer Rejection of Green Genetic Engineering. Empirical Evidence from Germany. International Journal of Consumer Studies. 41, 723–734.

Abstract

The emergence of a more sustainable economy in Europe was accompanied by a range of bio-based products and technologies. As a prominent example, green genetic engineering opens up multiple options to increase agricultural production, but its public acceptance seems to vary by application area. Risk perception explains consumer acceptance of green genetic engineering, which is a necessary pre-condition for wider technology adoption. This study investigates risk perceptions for four major sources of risk: Health-related, environmental, socioeconomic, and ethical. Data was collected in a laboratory experiment in Germany, with a total of 439 participants. A between-subject design was employed. The four experimental treatment groups comprised two policy scenarios, namely one only permitting research and development and the other allowing for full commercialization of genetically modified products, and two product end-uses, bio-energy and food. The study shows significant end-use differences in both the type of policy scenario and the risk dimension in question. In particular, health risks were generally perceived to be lower for bio-energy than food whenever full commercialization was pursued. Furthermore, full commercialization of genetically modified food prompted higher concerns about personal health, whereas use of crops for bio-energy production was broadly related to higher levels of socioeconomic risk. Finally, although the majority of consumers identified health risks as being most relevant, the consequences for the environment evoked the greatest degree of risk perception. In general, our findings lend support for the notion that the policy regime is the most important determinant for risk perception, followed by the type of risk dimension and level of trust in industry.

2.1. INTRODUCTION

Green genetic engineering (GE) applies novel technologies in the plant and agricultural domain to increase crop yields, foster abiotic and biotic stress resistance, and/or optimize chemical and physical crop characteristics. However, consumer acceptance is a pre-condition for the marketability of the resultant products. In this regard, the current policy regime regulating the release and use of genetically modified organisms (GMOs) in Europe, as well as the biotech industry's actions to move its research centers outside Europe, reflects the assumption that the public is averse to green GE. However, results from a recent study by Lusk et al. (2015) indicate that GE food with tangible benefits is less likely to be rejected by consumers, thereby suggesting another way forward.

Underlying much of the interest of green GE is the desire to promote an economy that is more sustainable and makes more efficient use of its resources. In specific, the transition from a fossil-based economy to a more sustainable bioeconomy can thus potentially offer tangible economic, environmental, and societal benefits (European Commission, 2012). However, this transition also increases the intensity of biomass usage across different industrial sectors: From food to fiber and even fuels. As a result, there is increasing need for innovations that enable efficiency gains in biomass production so as to keep up with higher demand. The tendency for extant research to primarily focus on the food sector is thus problematic, especially since the innovative applications of GE might be differentially received by the public. This study therefore takes a broader perspective by jointly investigating how specific product end-use and type of policy regime affect the public's risk perception of green GE.

The following section provides a brief overview of the literature and Section 2.3 describes the study design and methodological approach. Section 2.4 presents the experimental results with regard to the influence of product end-use and policy scenario on the level of risk perception. Section 2.5 discusses the results, and Section 2.6 concludes the paper.

2.2. BACKGROUND

Many relevant genetically modified (GM) applications, such as food with enhanced micronutrients and bio-energy crops with higher yields and lower input costs already exist (Qaim and Zilberman, 2003; Klümper and Qaim, 2014). Furthermore, as reflected by the reasonably high levels of acceptance, such products are increasingly seen as a potential choice for respondents. In specific, the support GE increases with the tangible benefits that consumers can expect (Hossain et al., 2003). However, De Steur et al. (2014) argue that any positive perceptions of the benefits of such products have the potential to be undercut if consumers are concerned about the adverse consequences as well. As such, consumers are only likely to place emphasis on the beneficial attributes when the associated risks are low. Levels of acceptance and risk perception thus tend to vary inversely to one another. Furthermore, extant research broadly demonstrates that levels of both factors are influenced by product end-use. Notably, while public support for GM food is lower than for nonfood products (Knight, 2006; Christoph et al., 2008), levels of risk perception are typically higher for food-related applications (Frewer and Shepherd, 1995). In this respect, Frewer et al. (1995) find that use of GE is seen as more risky for food production than medical applications. This finding reinforces those of both the European Commission(EC) (1997) and Heijs and Midden (1995), both of which established the broader degree of public support for GM medical products. Broadly speaking, and as Frewer et al. (1997b) have argued, it is thus the end-use of the product that determines the potential for consumer acceptance. Consequently, if it is the case that GM food is perceived to be riskier overall, then it stands to reason that bio-energy applications are more likely to be found acceptable.

Despite extensive research, actual GE application remains a highly controversial topic in the EU, with public acceptance being quite heterogeneous across the member states (Lucht, 2015). Dunwell (2014) argued that Germany, France, and Poland are conflicted countries, in which scientists, farmers, and industry support GE crop cultivation, although consumers and governments, which are principally influenced by political parties and NGOs, resist such efforts (Katzek, 2014). The EC recently released a new directive (2015/412/EC), enabling member states to opt out from the Europe-wide approval of foods derived from biotechnology, and restrict their release and use on a national level. Reflected by the recent amendments on both deliberate release of GMOs (2001/18/EC) and contained use of GMOs (2009/41/EC), the German government decided to opt out from using the GM maize variety MON810, meaning that its commercialization and R&D uses were no longer allowed (BMEL, 2015). Although this measure did not directly target research and development (R&D) for GM crops, a decline in these areas accompanied the restriction on full commercialization (FC). As a result, Europe seems to be falling behind in developing and market launching new GM varieties. This ranks Europe fourth in the number of GM product applications in the advanced R&D pipeline, behind North America, Asia, and Africa (Parisi et al., 2016). According to the location register of the BVL (2005) on the deliberate release of GMOs, virtually no R&D in the form of field trials has taken place in Germany since 2015. Even the more R&D-oriented states, such as North-Rhine Westphalia, no longer support GMO research, and generally available research funding is still restricted for GE.

Therefore, the question arises as to what degree this situation is based on the negative public perception of GE. However, differences in the degree of risk perception between the distinct policy regimes for GM crops have not yet been explored. In view of this gap, this study employs two experimental treatments with respect to type of policy regime to consider the potential impact of existing regulatory systems. In the R&D-only regime, market applications of GM crops are generally restricted. In the FC regime, such products are deemed legal. In this manner, it is possible to control for the contextual effects of the policy regime and the extent of potential exposure. For instance, since consumers are not exposed to the technology or end product in the R&D-only scenario, it can be hypothesized that the level of risk perception will be lower compared to a FC policy regime. In addition, both the EU and German regulations for GMOs exclusively focus on the potential risks to human health and the environment. However, four distinct risk dimensions were identified to accompany applications of GE, according to scientific literature: Human health and safety, environmental quality, socioeconomic issues, and ethical concerns (Stirling and Mayer, 1999; Peterson et al., 2000; WHO, 2014). Although some studies investigated public risk perception for some of these risk dimensions (Bawa and Anilakumar, 2013), there is a lack of research investigating all four simultaneously. As an additional objective, we seek to explore how differences in the perceived riskiness of GE can vary across the relevant dimensions. As a point of clarification, in this study risk perception is assessed using a formative measure that includes all relevant aspects from the multiple risk dimensions relevant for the release and use of GE. The ensuing analysis can offer a comprehensive, valid, assessment of perceived risk because of this approach.

Understanding how the level of risk perception varies by product end-use and policy regime further enables us to examine to what extent such differences can be attributed to other relevant consumer-specific determinants. Notably, trust in the responsible institutions or people tasked with handling GM products is a central (negative) explanatory variable of risk perception (Siegrist, 2000; Costa-Font and Gil, 2012). Involvement, or the subjective importance of, and interest in, a given subject, is generally relevant for perceived risk in many studies. However, this is not shown yet the case for GE. Furthermore, the level of risk perception is also affected by sociodemographic factors such as income, education, age, and gender. Gaskell et al. (2003) found that a person who is more likely to accept GM food is male and well-educated which is contrasted by findings from (Hossain and Onyango, 2004) who found no evidence for education. The authors show that education only played a role if the plant was altered by DNA from animals. Costa-Font and Mossialos (2007) and Siegrist (2000) both failed to find any significant effect from either age or gender in terms of perceived riskiness of GM food. Overall, sociodemographic criteria cannot be conclusively linked with risk perception in any certain direction. This is why it is necessary to investigate the relevance of factors such as end-use, policy regime and risk dimension, which may explain differences in risk perception.

The extant literature suggests that risk perception is a crucial explanatory factor for green GE acceptance, which is a necessary pre-condition for wider technology adoption in society. However, if the level of risk perception is generally negative under all circumstances, we would not expect it to vary between end-uses, policy regimes, and/or types of risk dimension. To shed light on the legitimacy of this assumption, this study explores the potential variability of risk perceptions, specifically, if the level of perceived risk differs for the respective GE applications of food and bio-energy in Germany. Despite its understandable relevance for a range of stakeholders, this question has not yet been investigated, to the best of our knowledge. As such, this study contributes by increasing the present understanding of risk perceptions related to biotechnology, with specific relevance for two types of products that are likely to be an important part of both the EU's and Germany's future bioeconomy strategies. Further insights can be drawn regarding the introduction of different policy scenarios likely to have implications for implementing and communicating the advantages of green biotechnology. In a larger context, this study also seeks to provide greater insight into the ongoing transformation toward a more bio-based economy in the EU (European Commission, 2012).

2.3. MATERIALS AND METHODS

2.3.1. SAMPLE AND STUDY DESIGN

A sample of 439 German consumers participated in a laboratory experiment based on a between-person design combining different policy regimes (R&D or FC) with product end-use (bio-energy or food)[1]. We used a 2×2 design. The two policy scenarios represented government institutional approaches to regulating the use of biotechnology in food and bio-energy production. The R&D scenario served as a baseline and represented a policy in which research on the application of biotechnology was permitted, but not the importation, cultivation, or commercialisation of GM products. The FC scenario represents a policy in which GM products can be domestically produced or imported and marketed.

The sequential order of the experiment was as follows:

(i) Questions about sociodemographic factors and the level of involvement are completed during the online registration before the experiment.

(ii) Information about biotechnology and its potential applications, as well as the relevant supply chain and type of policy regime were provided.

[1] The sample size is different from the one that was reported in the summary, i.e. n = 436, but it refers to the same sample except that three observations were exluded in the study in Chapter 3. Therefore, it was decided to report the lower value. The two different values for sample size have not been reported in the summary to improve its readability.

(iii) Participants were asked to rank four risk dimensions (health, environment, socioeconomic, and ethical) according to their relative importance: Which of the following aspects are most relevant to you for the evaluation of the above [policy] scenario? Rank 1–4 (1 = least relevant and 4 = most relevant). Using the results, participants are allocated into 16 distinct subgroups (see Figure 2).

(iv) Assessment of risk perception for the risk dimension selected in step (iii). For each participant, risk perception was further assessed. Specifically, a set of risk statements for each dimension was rated (see Section 2.3.2) according to: Degree of agreeableness to implied risk; likelihood of risk occurring; and severity of its consequences.

(v) Participants were presented with a table that provided an overview of their responses related to agreeableness, likelihood, and severity, and then asked to judge how confident they were about their assessment.

(vi) Finally, consumers answered the trust and personal involvement scales.

The product risk statements rated by the consumers made use of findings from Hess et al. (2016), Klümper and Qaim (2014) and Brookes and Barfoot (2014) about GM crop characteristics for different end-uses.

Respondents were provided with information about biotechnology, related products and policies, and the role of supply-chain actors (see Appendix B) to ensure that there was a basic awareness about the specific consequences of using green GE. The information was formulated in a neutral tone to avoid manipulation of consumers' opinions. The technology information was in accordance with the EC's definition of GMOs in Article 2(2) of Directive 2001/18/EC. The policy regimes were presented to include a description of the GMO regulatory approach and information on the resulting behavior of major value chain actors. The level of consumers' knowledge can be expected to affect levels of risk perception (Klerck and Sweeney, 2007) and acceptance (Hossain et al., 2003). By providing information we aimed to minimize response biases that might arise from lack of subject knowledge. Inaccurate judgments under time pressure and little knowledge about the topic has been shown to base the use of heuristics (Tversky and Kahneman, 1974).

2.3.2. Measures

We used Hess et al.'s (2016) extensive literature review to identify the types of risks that were relevant for each dimension. Risks attributable to individuals, certain groups, or society were developed into risk statements that expressed either direct or indirect risks. For each dimension, the statements encompassed a broad range of documented risks, such that the statements could be understood as formative indicators from a scale-development perspective. This meant that the corresponding measurement of the item were directly attained from the individual assessments, rather than as latent constructs through factor-analysis (Lagerkvist et al., 2013).

Rayner and Cantor's (1987) approach was adopted for measuring risk perception. However, the variable agreement was added in the measure of risk perception to enhance construct validity. Accordingly, participants were first asked if they agreed with the relevance of the specific risk statement on a 5-point scale (0 = totally disagree to 4 = totally agree). They were next asked to indicate the perceived likelihood of the respective statement on a 6-point scale (1 = not likely at all to 6 = almost entirely certain that this will happen). They were then asked to rate the severity of the event, if it was to actually occur, on a 5-point scale (1 = not severe at all to 5 = very severe).

Because of correlation between the three components, risk perception was defined as the average multiplicative measure comprised of the items: Level of agreement (a) to the risk statement; perceived likelihood (l) of risk occurrence; and perceived severity (s) of its consequences.

$$RP \ = [\prod_{i=1}^{n}(a_i \times l_i \times s_i)]^{\frac{1}{n}}.$$

The index i denotes the specific statement being rated (which varies depending on the product end-use), policy regime, and risk dimension. The maximum level of risk perception amounts to RP = 1x6x5 = 30.

Participants evaluated how confident they were about their evaluations of the agreement, likelihood, and severity of risk on a 5-point scale (1 = not confident at all to 5 = completely confident). This step facilitated identifying potential measurement biases.
Following Siegrist (2000), trust reflected the general level of credibility that individuals had in the various stakeholders involved with handling GMOs (How much trust do you have in the following institutions or persons that they are conscious of their responsibilities in doing genetic engineering or handling the modified products?). Respondents were asked to indicate on a 5-point scale if they trusted (1 = no trust at all to 5 = completely trust) scientists and researchers at universities, relevant industry actors, farmers, companies or producers, policy-makers, and consumer organizations. Finally, the level of involvement with GM crops was assessed using a revised version of the Personal Involvement Inventory (PII) from Zaichkowsky (1994). This revised version included 10 items that were rated on a 7-point scale for each of the products

(To me, genetically modified plants in bio-energy/food production are to be judged… for example important or unimportant, and worthless or valuable).
Sociodemographic characteristics comprised age, gender, education, and household income.

2.3.3. Empirical approach and data analysis

Kruskal-Wallis tests of the independent samples were performed to check for equality between the distributions of risk perception for the 16 subgroups. Post-hoc pairwise comparisons were then used to identify any differences between more than two groups, such as for differences in levels of risk perception across risk dimensions. Moreover, a factor-analytical approach was used to identify the latent variables for PII and trust. Data was analyzed using SPSS version 24.

The complex interrelationships between the various product end-uses, risk dimensions and policy regimes made it necessary to simultaneously take several explanatory factors into account. Given that these factors were not exhaustive, but from a much larger set, a probabilistic, conditional, binary, recursive inference algorithm (HHZ) was adopted (Hothorn et al., 2006). The underlying algorithm in this method successively performed binary splits of the sample according to the variable with the most explanatory power in terms of the estimated p values, so could identify the most relevant factor at each node. This approach accounted for any simultaneity bias and/or endogeneity problems that could emerge and provided the set of variables that best reflected the main drivers of risk perception in the research setting. The model estimation was performed using the party package (Hothorn et al., 2006) for the R software (R Core Team, 2014).

2.4. Results

2.4.1. Sample characteristics

The sociodemographic characteristics of the sample partly represented the German population. Specifically, the sample reflected the German population with regard to both gender distribution (51 percent female) and secondary-education level (approximately 30 percent). However, it was over-sampled at the tertiary-educational level (51.3 percent vs. 28.8 percent), whereas the mean values for both age (44.3 years) and monthly household net income (€3,132) were within sample medians of 36 to 60 years and €1,800 to €3,600, respectively.

2.4.2. ANALYSIS OF RISK PERCEPTIONS

The bar graph in Figure 2 illustrates the share of the total sample belonging to each treatment group. Moreover, the subgroups are depicted with the respective colors in every bar, according to the risk dimension that is identified as most relevant.

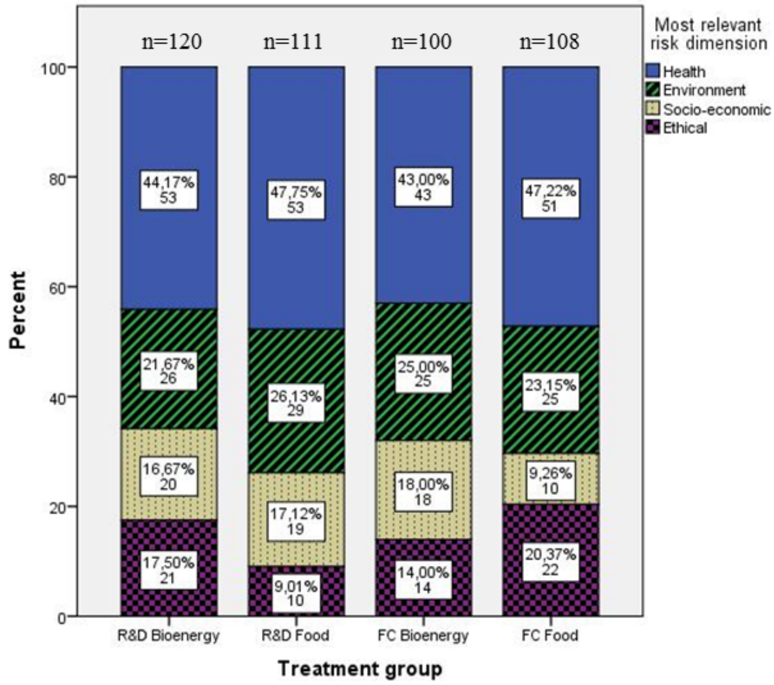

Figure 2. Subsamples characteristics for treatment groups, with the share of the total sample depicted above each bar. Further subgroups are represented with a respective color, according to risk dimension.

According to the sample, the most relevant risk dimensions were health (n = 200, 46 percent), followed by environment (n = 105, 24 percent), socioeconomic (n = 67, 15 percent) and ethical (n = 67, 15 percent). Overall, respondents were generally confident about their evaluations during the experiment, with 93 percent of respondents (408/439) at least to some degree confident and 71 percent (313/439) confident to a great degree or completely. Furthermore, the level of agreement with the risk statements was positive for 42 of the 54 items (78 percent), suggesting high validity of the formative risk measurement.

2.4.2.1. Full sample results for product and scenario comparison

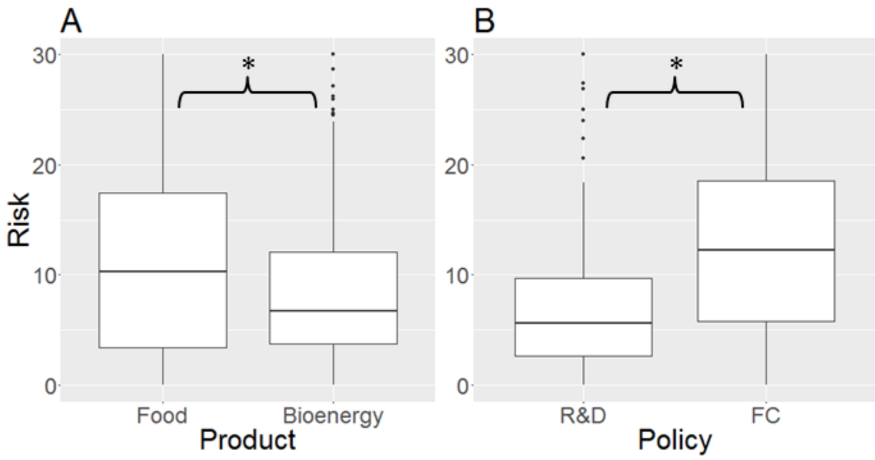

Figure 3. Box plots comparing levels of risk perception for the total sample between (panel A) product end-use and (panel B) regulatory scenario. Risk perception is displayed along the y-axis and can reach maximum values up to 30. Significant group differences, according to Kruskal-Wallis one-way ANOVA, are denoted by: * $p<0.05$, ** $p<0.01$, and *** $p<0.001$.

According to the Kruskal-Wallis test (K-W = 5.042, p = 0.025, r = 0.241), the hypothesis that risk perception is lower for bio-energy than for food can be accepted. The respective box plot is displayed in Figure 3 (panel A). The effect size r = 0.241 indicates that there is a small effect of product end-use on perceived risk. Moreover, there is more heterogeneity in the data for food end-use, while there are more outliers in the case of bio-energy.

As predicted, perceived risk is much higher in the FC policy regime than for R&D only (K-W = 50.622, p = 0.000, r = 2.416; see box plots in Figure 3, panel B). However, similar to the pattern for bio-energy, there are more outliers in the R&D scenario.

2.4.2.2. Differences by product end-uses

The analysis in the remainder of this section will investigate how the levels of perceived risks depended on product end-use and policy regime with risk dimensions.

With regard to the dimensionality of risk, perceived risk for the health dimension was higher for food than for bio-energy under the FC scenario (see Figure 4). No other statistically significant difference was found for the other risk dimensions, or for the R&D-only scenario as a whole.

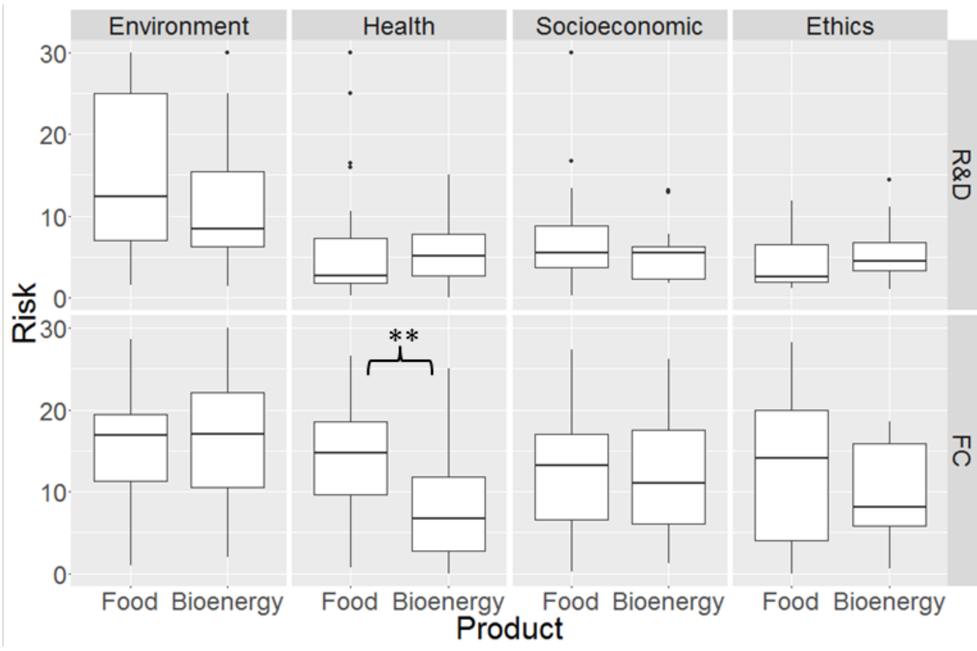

Figure 4. Box plots showing level of risk perception by product end-use and risk dimension. Significant group differences, according to Kruskal-Wallis one-way ANOVA, are denoted by: * $p<0.05$, ** $p<0.01$, and *** $p<0.001$.

2.4.2.3. Policy scenario-related differences

In Figure 5, permission to fully commercialize GM crops was generally perceived as riskier than the R&D-only scenario, regardless of the pairing of product end-use and risk dimension. Overall, 34 percent of the sample had a high level of risk perception, or a value of 12 or higher. This corresponded to higher than neutral ratings for agreement, likelihood, and severity. Furthermore, while 18 percent had a high risk perception of GM crops being used for R&D-only purposes, this share grew to 51 percent of respondents under the full-commercialization scenario. In the case of food-product end-use, there were further significant differences in perceived risk in the health and ethical dimensions. Conversely, the socioeconomic and ethical dimensions were significantly different between the respective policy scenarios for bio-energy end-use. Moreover, there was less variance in risk perception in the R&D-policy scenario, except for environmental risks, compared to the full-commercialization scenario.

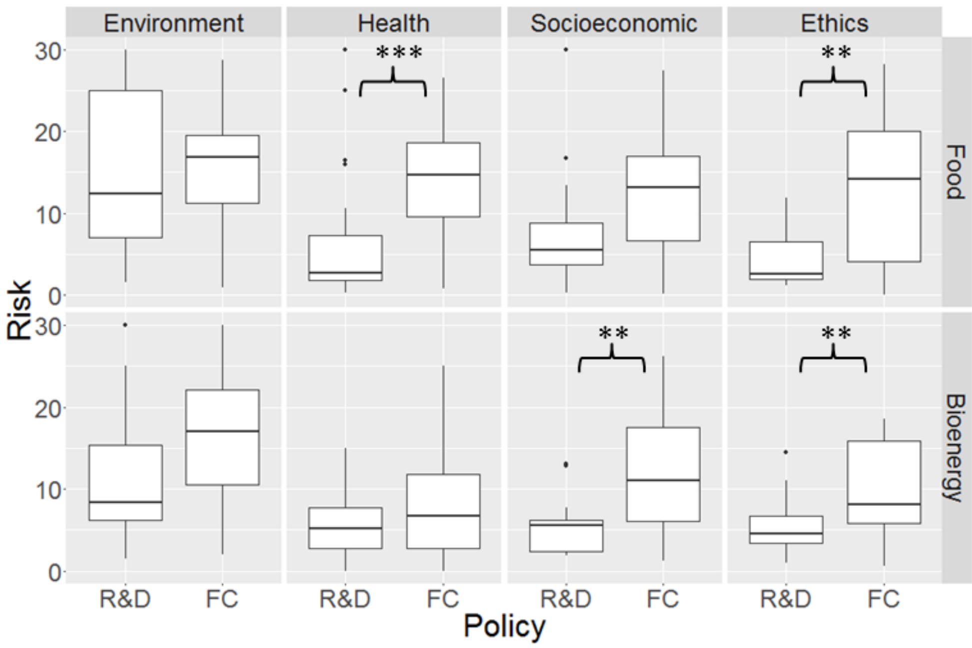

Figure 5. Box plots comparing levels of risk perception by policy scenario, risk dimensions, and product end-use. Significant group differences, according to Kruskal-Wallis one-way ANOVA, are denoted by: * $p<0.05$, ** $p<0.01$, and *** $p<0.001$.

2.4.2.4. Risk-dimension differences

Regardless of product end-use, participants generally perceived health risks to be the most relevant category. This was specifically shown by the greater frequency of health (n = 200) than environmental (n = 105) concerns in participants' ranking of risk dimensions. Nevertheless, on average, median levels for risk perception were actually highest for environmental risks in the study itself (see Figure 6). For both product end-uses under the R&D-only scenario, environmental risks were perceived to be significantly more important than any of the other dimensions. Under FC of bio-energy, environmental risks were also deemed more severe than both the health and ethical dimensions, although it was joined in this respect by socioeconomic risks. However, in the case of food under FC, perceived risk levels are equal across all risk dimensions.

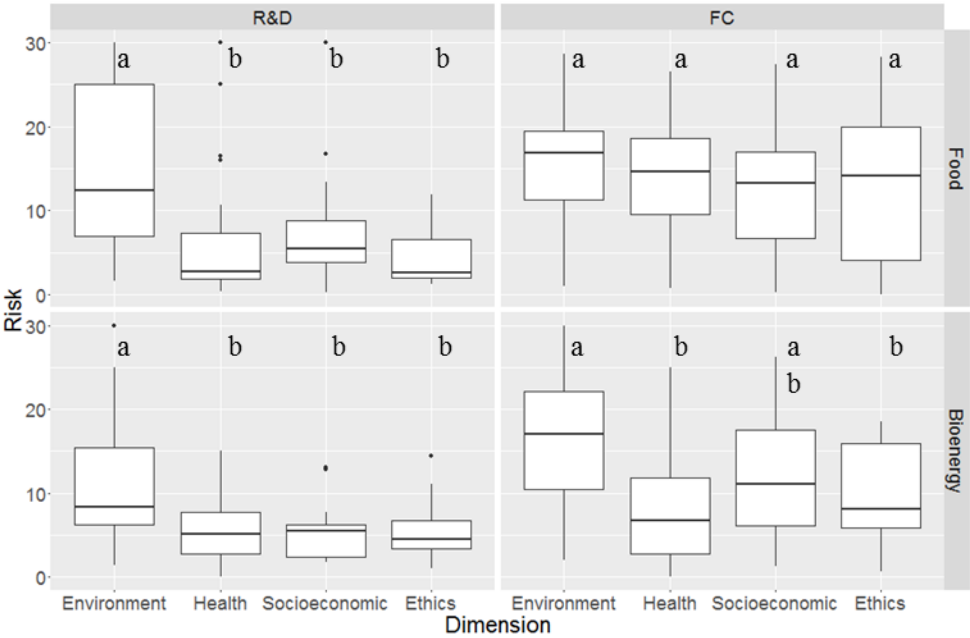

Figure 6. Box plots comparing risk dimensions for all treatment groups. Group differences with respect to risk dimension (at 5% significance level) are denoted by a and b (pairwise comparisons conducted with Kruskal-Wallis one-way ANOVA).

2.4.3. RECURSIVE PROBABILISTIC REGRESSION ANALYSIS

The assessment of perceived risk illustrates that consumers' risk perceptions are likely to differ across product end-uses, policy regimes, and risk dimensions. However, this conclusion does not allow for concluding which of these factors is the main driver of risk perception, nor how these factors relate to other determinants of risk perception, such as sociodemographic variables, involvement (PII), and trust. For the purpose of the recursive, probabilistic regression analysis, trust and PII were rescaled to three categories to increase statistical power of the estimation. Similarly, age was transformed into a binary variable. A factor analysis of PII revealed two separable components, one cognitive and one affective, which was in line with Zaichkowsky (1994). Similarly, trust also had two principal components, one referring to academia, government and consumer organizations (mean = 3.56, s.d. = 0.6), and the other linked to trust in industry (mean = 2.46, s.d. = 0.6). Accordingly, the trust measure that was used in the following analysis somewhat differed from that of Siegrist (2000). In order to avoid the possibility of pathological splits (Hothorn et al., 2006), we also restricted the size of the possible subsets to at least n=30 observations, yielding a more parsimonious model as a result.

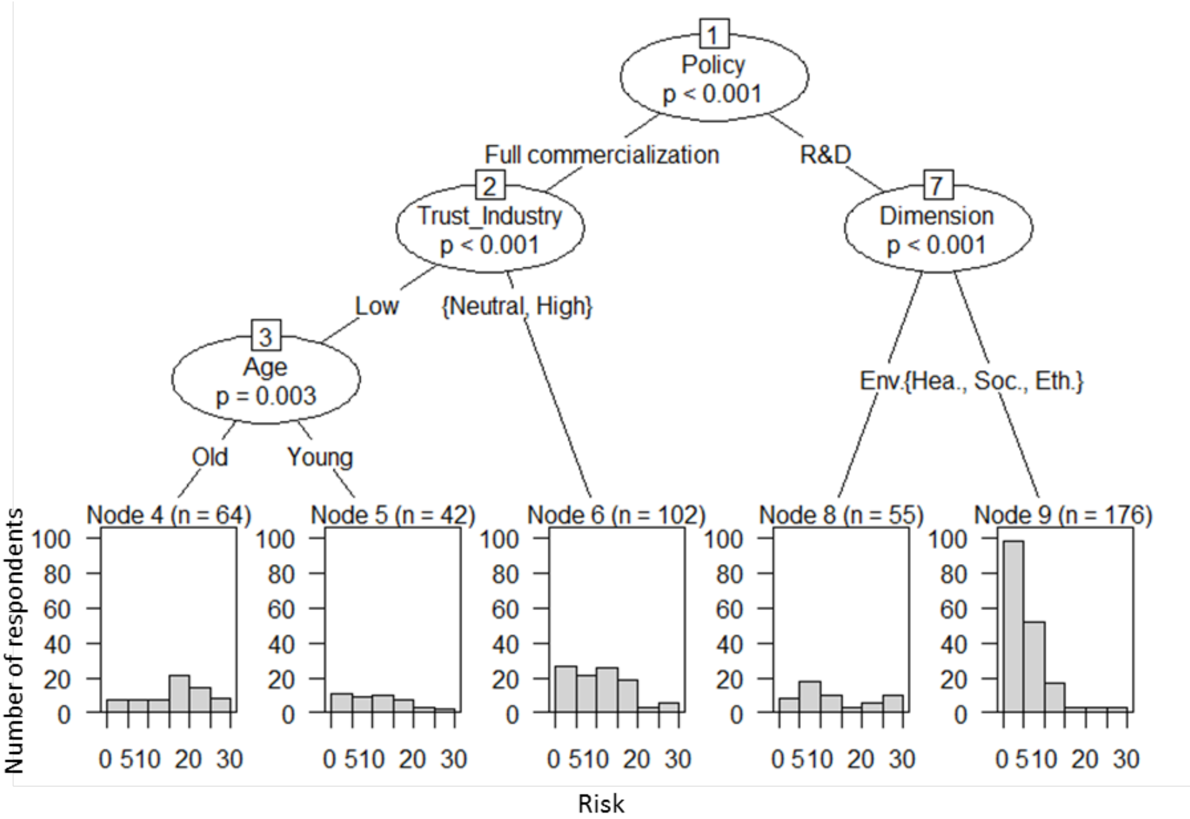

Figure 7. Conditional, recursive inference tree for consumer risk perception. Distributions of risk perception are displayed by histograms at the terminal node, with risk perception on the x-axis and number of respondents on the y-axis.

Figure 7 shows the conditional, recursive inference tree for the set of determinants from the previous section (product end-use; policy regime; and risk dimension), together with other relevant indicators for perceived risk (sociodemographic factors; trust; and involvement). This tree reveals the structure of the survey data in terms of statistical relevance for risk perception. At the crown of the tree, risk perception levels significantly differ between the R&D and FC regimes, as policy regime is the most important of the determinants. At node 2, there is a significant difference in perceived risk between respondents with low trust in industry and those with neutral or high trust. At node 3, we can see a significant difference in levels of perceived risk between the younger (18 to 35 years) and older (>35 years) respondents, such that older people tended to associate higher risk (median at node 4 = 16.903) with the FC of biotechnology applications than their younger counterparts (median at node 5 = 11.225), regardless of product end-use. Branching off on the right side of the tree, the data splits between risk dimensions at node 7, indicating that perceived risk in the R&D scenario depended on the type of risk. Notably, risk was perceived to be higher within the environmental dimension (median at node 8 = 13.845) than health-related, socioeconomic and ethical risks (median at node 9 = 5.915). As seen by its absence from the tree, other sociodemographic factors and involvement were not an important factor for risk perception.

2.5. Discussion

The guiding question of this study was whether or not consumers are likely to reject green GE under all circumstances. For our purposes, this would be reflected by the level of risk perception remaining the same across each product end-use, type of policy regime, and risk dimension. However, this supposition was immediately contested by the fact that risk perception of green biotechnology depends on product end-use. This finding has important implications, since it suggests that biotechnological applications are evaluated at both the technological and the product levels, specifically in relation to the intended end-use. In general, food applications are perceived to be riskier than those for bio-energy, suggesting that nonfood products might find greater public acceptance. This supports other findings for the German population in the literature (Frewer et al., 1995; Christoph et al., 2008; Klümper and Qaim, 2014). However, in contrast to the available literature on risk perception, this study has two crucial advantages with regard to the importance of product end-use. First, the formative risk measurement approach circumvents issues such as measurement error that tend to plague the reflective scales that are typically applied. As a result, the measure for risk in this study better reflects the actual, unbiased level of perceived risk that exists. Second, since this study compares two specific end-uses – food and bio-energy – instead of more general areas such as industrial applications, this research is less likely to yield biased consumer responses from differences in risk perception between end-uses in the same application area. Taking these two points together, the study provides risk measures with improved validity.

Another relevant contribution of this study is the ability to better understand the overarching regulatory context. Specifically, the results show a large difference in risk perception between the FC and R&D-only policy scenarios. This suggests that consumers generally favor further R&D, so long as it is not accompanied with immediate, inevitable market availability of products engineered with biotechnology. In fact, almost half of the sample attached high risks to the marketing of GM crops, while a contrasting 82 percent associated low risks with further R&D efforts. Differences in risk perception between policy regimes seemed to reflect the extent to which consumers were ultimately exposed to GM crops and how directly they perceived the potential risks that were involved. For this reason, an effective approach to address public risk concerns might be to tailor communication strategies to the type of end-use, such as information about the nature and extent of exposure that can be expected in everyday life.

Interestingly, while the health dimension was selected almost twice as frequently as the environmental dimension as the most relevant to the respondents, the degree of perceived risk (medians as calculated by the formative risk measure) was actually highest for environmental risks. Since this is the case for every treatment group, it was generally relevant, regardless of product end-use or policy regime. This suggests that, even if a multitude of consumers are mainly concerned about the perception of health risks, their biggest fear is environmental consequences. Our results show that both health and environmental concerns are central to consumer understandings of risk. Nonetheless, given our findings, an increasing focus of risk communication should be the environmental risks that are involved with broader applications of biotechnology.

With regard to potential commercialization of bio-energy, risk perceptions of both the socioeconomic and environmental dimensions were higher than for either the health or ethical aspects. This indicates that when it comes to bio-energy production, consumers are not only concerned about the environment, but also the economic and legal implications involved with the use of GM crops. In part, this extends Lusk et al.'s (2015) findings, which showed how consumer acceptance of GM food increases if socioeconomic benefits are present and emphasized. At present, the dominant narrative of GE risk perceptions claims that health and environmental risks play a similarly important role for consumers' understandings about risk. However, this is not generally the case. By looking more closely into the differences across risk dimension (see Figure 6), we observed that compared to environmental risks the perception of health risks was lower for bio-energy production under both policies and for food under the R&D-only policy. For food in the FC policy, health and environmental risks were equal, but perceived risks for ethical and socioeconomic aspects were just as high. Consequently, there is a clear distinction to be explored between perceptions of health and environmental risks in further research on the nonfood applications of GE and more emphasis to be put on the other risk aspects. Moreover, as environmental risks are of particular concern under the R&D scenario, the further field release of GMOs should be accompanied by greater dialogue with the public about potential risks and benefits.

However, the recursive probabilistic regression analysis generally indicates that aspects other than the types of risk dimensions are more important for risk formation. First and foremost, the type of policy regime tends to be the most important determinant, followed by risk dimension, trust in industry actors, and the respondent's age. Potential FC of GM crops is associated with higher risks, compared with a R&D-only policy scenario. Trust in industry actors is specifically relevant for risk perceptions in the FC scenario. In other words, the lower the respondent's level of trust in industry actors, the higher the perceived risk is likely to be. This finding is in line with Flynn et al. (1994) and Cvetkovich and Lofstedt (2013) and supports the claim for bridging the communication-gap between industry and consumers (Vilella-Vila et al., 2005). Moreover, older respondents tend to have higher risk perceptions, which are also influenced by the level of trust in industry. Consequently, a potential strategy could be fostering trust in industry by creating transparency in these actors and institutions, instead of enhancing the already relatively high trust in academia, government, and NGOs. Neither the level of involvement with GM food or bio-energy nor the gender, education, or income of respondents was found to be important.

In addition, the results of this study outline a path for further research by showing the importance of controlling for the context, given that both risk perceptions and their determinants are likely to differ across diverse types of policy regimes. Although risk perception varies by end-use, the policy regime is ultimately the most important for determining the extent of perceived risk. A possible explanation for this finding might be differences in the perceived controllability of the risks involved (Slovic, 1987). Notably, both end-use and policy regime can be interpreted as a measure of potential exposure to biotechnology. In this regard, consumers can avoid buying products they find to be risky, but they will necessarily have less control over the regulatory context as a whole.

Finally, results show that our measurement approach successfully mirrors the broader public perception of the risks of biotechnology. Brauerhoch et al. (2007) argued that scientific communication to the public requires both detailed reflection on the part of the scientist and further reconciliation of their underlying risk perceptions with society's corresponding perceptions. The fact that respondents expressed agreement with almost 80 percent of the risk statements extracted from scientific literature suggests that consumers can potentially follow the reasoning in the scientific literature, which has important implications for developing risk-communication strategies.

2.6. CONCLUSION

Against the broader backdrop of an emerging bioeconomy and the increasing importance of biomass for a number of sectors (Diamond, 2009), this study undertakes a direct comparison between consumers' risk perceptions of applications of GE for bio-energy and food end-uses. In view of the widespread public resistance to green GE, this topic is highly relevant, especially given the strongly rooted negative perceptions of GM food in many European nations. However, far less is known about the contrasting perceptions of green GE for product end-uses other than food, notably biorenewables. Therefore, the purpose of this study was to examine how product end-use (bio-energy vs. food), along with type of policy regime and risk dimension, might affect consumers' risk perception of green GE. Results clearly indicate that the level of perceived risk depends on product end-use, specifically with respect to health-related risks. Nonetheless, the prevailing policy setting predominantly determines levels of risk perception, while both type of risk dimension and level of trust in the industry also play a crucial role. Since consumers' perceptions about risk have a potential negative impact on acceptance (De Steur et al., 2014) our findings are broadly contradictory to the notion that GM products are likely to be rejected under all circumstances. Rather, the fact that risk perception is tied to the specific end-use, risk dimension, and type of policy regime provides an initial basis for debunking the myth that consumers are generally rejecting green genetic engineering. Conversely, the higher acceptability of policy regimes, product end-uses, and dimensions that were perceived to be less prone to risk suggests that the greater investment and development of GE technologies is not generally adverse to societal interests. Further research in this field should proceed by paying closer attention to the range of both contextual and individual factors that are likely to be relevant.

Given the relevant similarities to the study context of Germany, the conclusions of this study are also likely to be relevant for countries such as France and Poland, which are confronting similar issues regarding consumer acceptance and market potential of biotechnology applications. Furthermore, as these three countries accounted for 46.9 percent of total cereal production in the EU-28 in 2014 (Eurostat), our findings can offer a number of wide-ranging implications for European agricultural production. In specific, under the recently established opt-out measure (Directive 2015/412/EC), every country now can decide whether or not to cultivate GM crops. The results from this study suggest that, through informed dialogue with the general public about the potential risks and benefits (with particular consideration to environmental aspects and the responsibilities of industry actors), further R&D in green biotechnology is likely to be more socially desirable than might be expected. Contrary to expectations, Germany has the opportunity to act as a role model to encourage other major

European cereal producers to put greater emphasis on R&D and enhance the EU's global position in agricultural production and innovation.

In sum, by shining a greater light on how levels of risk perception can vary by both product end-use and type of policy regime, this study enables us to more deeply describe which potential biotechnological applications are best able to overcome any consumer resistance. Notably, we find that not only is product end-use an important determinant but that the end-use for nonfood applications, such as bio-energy, is likely to be less controversial overall. However, in spite of the importance of product end-use, we conclude that it is actually the broader regulatory context in which decisions about uses of these different applications take place that is even more important for potential acceptance. In particular, a R&D-first approach proves to be more generally conducive as an initial step to address and reduce the degree of perceived risk, although both trust and sociodemographic factors such as age are also likely to play an important role for effective and targeted communication with the wider public.

3. THE INFLUENCE OF POLICY AND PRODUCT END-USE ON THE INTERRELATIONSHIP BETWEEN PERCEIVED RISK, SELF-CONTROL, AND PERSONAL RISK RESPONSIBILITY REGARDING BIOTECHNOLOGY

RQ2: How are the major determinants of biotechnology acceptance interconnected and related to the practical context?

This chapter is based on the following publication:

Butkowski, O. K., Pakseresht, A., Lagerkvist, C. J., Bröring, S., 2018. The influence of policy and product end-use on the interplay between perceived risk, self-control and personal risk responsibility. Under review in Risk Analysis.

Abstract

Achievement of a more sustainable bioeconomy requires further technological innovation, such as green genetic engineering. However, this requires consumer acceptance, for which perceived risk, self-control, and risk responsibility are major determinants. Previous research has documented bi-directional associations between these key variables. This study examines the interrelationship between these variables and a policy and product context. A framed field experiment with 436 German consumers employed four randomized treatment groups. Experimental treatments comprised two product end-uses, namely bioenergy and food, and two policy scenarios, one only allowing for research and development and the other permitting full commercialization of GM crops. A serial multiple-mediator analysis revealed that perceived risk and self-control mediate the relationship between policy regime and risk responsibility. Furthermore, simultaneous moderation analysis revealed that type of product end-use is a moderation within this mediation relationship, suggesting the existence of strong differences between food and bioenergy. The results showed that higher levels of risk lead to a lower degree of perceived self-responsibility. However, consumers take more responsibility vis-à-vis the commercialization of food biotechnology if they feel that they can better control for the risks. This suggests that, contrary to past findings, the riskier the circumstances of risky decision-making, the lower the likelihood of avoidant coping behavior whenever the individual feels more capable of exercising control. Consequently, higher risk can induce higher acceptance in a biotechnology context.

3.1. INTRODUCTION

A major future challenge is to ensure environmental, economic, and social sustainability for a growing global population set to rise to 9 billion by 2050. A high priority is to increase the share of renewable energy (UN, 2015). Biomass dominates the global renewable energy portfolio and is projected to remain the main source of renewables by 2030 (IRENA, 2014). However, Europe's bioeconomy strategy puts pressure on biomass supply, as different industrial sectors (food, feed, fuels) compete for the same raw materials, leading to resource conflicts such as food versus energy (Oborne, 2010; SCAR, 2015). Green biotechnology offers the potential to alleviate such conflicts by enhancing chemical and physical crop characteristics (European Commission, 2012) and increasing crop yields (Lusk et al., 2017). In addition, novel genome-editing techniques promise to make genetic engineering faster, more specific, and thus more controllable. However, pessimism about biotechnology has increased in Europe since 2002 and, although public acceptance is heterogeneous across European countries, it is generally low for food products (Lucht, 2015). Consumers tend to be more accepting of biotechnology when applied to non-food products (Frewer et al., 2013) or when it can offer specific benefits (Lusk et al., 2015). Against the backdrop of a growing bioeconomy and variety of products, the question is whether applications of green biotechnology to non-food end-uses such as bioenergy will achieve the degree of public and political support needed for market adoption. Consumer perceptions of genetically modified (GM) food and how these perceptions vary between countries are well understood (Grunert et al., 2001; Knight, 2006; Christoph et al., 2008).

Previous research focusing on public understanding of green biotechnology has highlighted the relevance of risk perceptions for consumer acceptance (Frewer et al., 2013; De Steur et al., 2014; Hess et al., 2016), suggesting that the riskier a product or technology, the lower its acceptance. Furthermore, there is evidence to suggest a major influence of self-control (Slovic, 1987; Brun, 1994; Leikas et al., 2009) and personal risk responsibility on the degree of perceived risk (Walster, 1966; Phares and Wilson, 1972; Leikas et al., 2009), as well as the correlation between self-control and risk responsibility (Redmond and Griffith, 2004). In general, the higher the perceived controllability of risk and personal risk responsibility, the greater the consumer acceptance. However, the underlying processes are not yet fully understood, because there is a lack of research on the interrelationship between these determinants of consumer acceptance. No research has yet explored whether the determinants of consumer acceptance differ for biotechnology applications with food and bioenergy end-uses (Verbeke, 2007).

Moreover, consumer acceptance and public policies are not independent from one another. In particular, European Union (EU) member states that opt to grow GM organisms (GMOs) tend to have higher public support, suggesting a link between consumer perceptions and regulation (Gaskell et al., 2010). However, there has been little research on how types of public policies can themselves impact consumer acceptance of biotechnology.

Hence in this study, an integrated model was used to investigate the interrelationships in the context of biotechnology between perceived risk, self-control, and risk responsibility in relation to external factors that affect consumer judgments, namely policy context and product end-use. The overall aim was to shed light on key determinants of consumer acceptance of biotechnology in a more sustainable bioeconomy.

3.2. BACKGROUND

3.2.1. FACTORS IN CONSUMER ACCEPTANCE

Increasing use of biotechnology brings risks, but also offers benefits to individuals and society in general. However, public acceptance is a pre-condition for market adoption and diffusion of innovations within a socio-economic system (Rogers and Shoemaker, 1971; Rogers, 1983). The main determinants of research on consumer acceptance of GMOs are existing perceptions of risks and benefits, institutional factors such as trust (Rollin et al., 2011; Frewer et al., 2013), and also individual differences in relation to values (Costa-Font and Gil, 2008), attitudes (Bredahl et al., 1998; Frewer et al., 2013), knowledge, and information (Costa-Font and Gil, 2008; Rollin et al., 2011). For this reason, De Steur et al. (2014) argue that risk perception is a major determinant of acceptance. Indeed, in some EU countries, the fact that perceptions of benefits are unable to outweigh perceptions of risk (Costa-Font and Gil, 2008) suggests the pivotal role of perceived risk in consumer studies on GMOs.

Most existing studies focus on GM food and the risks that raise public concerns about GM food and crops mostly relate to human health, environmental safety, and economic and ethical aspects (Bawa and Anilakumar, 2013). Current EU regulations mainly focus on the risks to human health and the environment, but the use of biotechnology also includes socioeconomic and ethical risk aspects (Stirling and Mayer, 1999; WHO, 2014). Such dimensions of risk are seldom discussed; existing consumer studies tend to reduce this complexity by concentrating on only a few specific aspects, rather than taking into consideration all four risk dimensions of biotechnology.

3.2.2. Interrelationships between perceived risk, controllability, and personal responsibility

The existence of a general association between consumer perceptions of risk and controllability (Slovic, 1987) has been confirmed for innovative food technologies, particularly genetic engineering (Lusk et al., 2014). Notably, the degree of self-control is subject to the illusion of control (Langer, 1975), i.e., the existence of an inappropriately high expectation of one's personal likelihood of success probability given the objective probability that exists. This is further illustrated by the existence of an optimism bias, where those risks seen to be under one's own control are understood to be less uncertain and thus more acceptable, even if the degree of objective risk is higher (Klein and Helweg-Larsen, 2002). Accordingly, risk is perceived to be lower in active rather than passive situations. For example, a car driver has a lower perceived likelihood of an accident than a car passenger. Nordgren et al. (2007) posited that volition has the potential to reinforce perceptions of risk, suggesting a positive relationship between risk and perceived controllability whenever the risk is taken voluntarily. In perspective, work by Slovic (1979) and Fischhoff et al. (1978) has suggested that the controllability of risk precedes risk perception whenever risk is imposed from outside and exposure is therefore unavoidable through preventive measures. However, if self-control is a construct that combines the voluntariness to take risks (i.e. the extent of one's belief in the ability to exert action to accept or avoid exposure to the risk that has been perceived) and control (i.e. the possibility of preventing an adverse outcome for oneself), then the awareness of the underlying risk precedes the individual's ability to avoid involuntary risk and prevent the risk outcome. Thus, it is plausible that risk perception precedes self-control.

Perceptions of risk are also directly related to level of risk responsibility such that, for example, we tend to assign responsibility to a car driver to do what it takes to avoid accidents. We are also more prone to assign more responsibility to someone who caused a severe accident, rather than if the crash had a non-severe outcome (Phares and Wilson, 1972). However, in a situation with less self-control over outcomes, the more severe the perceived consequences of a given hazard, the lower the personal responsibility assigned (Walster, 1966). According to research in health psychology, assignment of limited responsibility to oneself is likely to foster avoidant coping strategies, such as denial or mental and behavioral disengagement (Voth and Sirois, 2009). Consequently, by not having to confront potential risks or consider potential benefits, individuals become less likely to be accepting of novel technologies. Conversely, consumers who take personal responsibility for their exposure to risk are more likely to adopt risk-prevention behaviors (Rothman et al., 1993), resulting in higher acceptance for novel technologies. This mechanism could serve as one explanation for consumer acceptance of green biotechnology. Given that both of these outcomes are desirable from a societal perspective, the nature of risk responsibility requires further attention. In particular, since taking responsibility is affected by both individual and external forces (Davis and Davis, 1972), it is vital to consider the type of risk and the circumstances in which decisions occur.

3.2.3. Influence of contextual factors

Extant literature reports the importance of contextual factors for consumer behavior. De Steur et al. (2014) examine the market potential of GM food with health benefits and propose a framework with factors on both micro (consumer perception and acceptance) and macro (societal benefit) level. Although focusing on ex-ante evaluations, which are independent of the actual market situation, those authors emphasize that consumer perceptions may also be influenced by other stakeholders' opinions. This suggests the usefulness of determining consumer perceptions in a societal context, i.e., product- and policy-related. In this regard, Lusk et al. (2014) even suggest that such evaluations can be affected by social and political factors, including e.g., the actions and decisions of other members of the supply chain and of regulatory officials. Pakseresht et al. (2017) showed that acceptance of GM food with health and environmental benefits decreases with increasing restrictions in the policy context, suggesting that policy restrictions could induce consumer opposition. For this reason, Ronteltap et al. (2007), p. 5, delineated the determinants of food innovation into "proximal" and "distal" factors. The former relate to consumer perceptions of risk and its personal controllability, while the latter include contextual factors, namely characteristics of the technology and aspects of the social system. This framework thus suggests interlinkages between consumer evaluations of risks and the broader context.

The relevance of the broad/regulatory context in which risk perceptions are formed cannot distinguish between the types of benefits that are most significant to consumers. It is plausible that consumer evaluations are affected more by product-related characteristics that correspond to personal and direct benefits, rather than process-related traits that have benefits for society as a whole (Bearth and Siegrist, 2016). This suggests that consumers are likely to have a more product-oriented perspective on GMOs. Perhaps for this reason, previous research has tended to focus on product-related differences when exploring consumer evaluations of GMOs. For instance, the review Hess et al. (2016) found that, although evaluations of GM foods generally did not differ, they were generally more negative when livestock genes were modified directly and more positive when there was a medical benefit involved. Other studies have found that the level of support seems to vary according to the application area, with the use of biotechnology in food being less likely to be accepted than in non-food products (Knight, 2006; Christoph et al., 2008) as the associated risks are higher (Frewer et al., 1995).

The specific risks involved with food and non-food applications are difficult for consumers to evaluate, however, given that they cannot directly track and assess production processes. As a result, risk assessment ultimately rests with regulatory authorities and/or certification agencies, with the final products available to consumers broadly comprising various credence attributes which cannot be directly verified by consumers, but have to be taken on trust (Chen, 2008). The responsibility of regulatory bodies can therefore be seen, from the perspective of consumers, to involve implementation of risk management strategies that guarantee a safe, affordable food supply. Consumers for their part are tasked, depending on the level of risk aversion, with addressing the remaining sources of risk by e.g., seeking relevant information and performing the necessary risk-prevention behaviors. However, if consumers feel unable to control risks from biotechnology applications, they are much more likely to attribute greater responsibility for managing the related risks to other actors in the supply chain and a relatively low degree of responsibility to themselves (Leikas et al., 2009).

Apart from consumer perceptions, Costa-Font et al. (2008) highlight the important role of knowledge for acceptance of GM food. In the literature, attempts are therefore often made to correct for potential lack of knowledge of genetic engineering by highlighting the importance of trust (Aven and Cox, 2016). As consumers are broadly unable to verify the quality of products or assess all the consequences, understanding of the effects of genetic engineering is typically limited (Fischhoff et al., 1982). Thus, the overall level of trust in institutions, individuals, labels, and brands, and the information they convey, is an important factor for perceptions about risk hazards and the management of adverse outcomes. Trust in the ability and integrity of supply-chain actors and regulatory authorities to effectively manage risks therefore plays an important role for consumer perceptions of risk and responsibility. Indeed, the existence of such relationships has been confirmed in research (Siegrist, 2000; Weitze et al., 2013).

The literature also discusses differences in perceived risk owing to differences in sociodemographic characteristics, such as age, gender, education, and income. Evidence suggests that, for instance, women and middle-aged individuals are generally more skeptical to the use of biotechnology (Siegrist, 2000), whereas higher income results in lower rejection (Sjöberg, 2004). However, the direction of such effects and their magnitude are widely debated in the literature and, overall, sociodemographic characteristics are not considered to be strong predictors of risk perceptions (De Steur et al., 2014).

3.3. THE PRESENT STUDY

An integrated analysis of consumers' perceived risk, self-control and, particularly, perceived risk responsibility in the context of green biotechnology was performed using a moderated-mediation model (Hayes, 2015). In particular, we examined how the risk-related constructs and their interplay are influenced by the policy context and type of product application. This was achieved through specifying two policy regimes (scenarios): full commercialization (FC) and research and development (R&D), and two product end-uses: food and bioenergy. Previous studies have considered e.g., the "possible unknown risk of genetically modified food" (Leikas et al., 2009), p. 124, but this study focused specifically on consumer evaluations of the perceived likelihood and severity of risks along four dimensions (health, environment, socioeconomic, ethical).

The data for this study were collected in Germany in 2015. Dunwell (2014), p. 120, argues that Germany is a "conflicted" country, where science, farmers, and industry all tend to support cultivation of GM crops, but consumers and government are broadly resistant. In general, German consumers tend to be skeptical about GMOs, as reflected by the decrease in the optimism index with respect to biotechnology from 33 in 2005 to 12 in 2010 (Gaskell et al., 2010). Within the EU-27, the corresponding values were 50 and 40, respectively. The decision of the Federal Ministry of Food and Agriculture (2015) to opt out of permitting the GM non-food maize variety MON810, due to associated risks to the environment, is thus reflective of the presumption that consumers tend to reject GMOs in agricultural production. In fact, according to data held by the Federal Office of Consumer Protection and Food Safety (2005) on the release of GMOs, R&D efforts in Germany in 2015, represented by number of field trials, are practically non-existent. This is evidence of declining innovativeness of the agricultural sector in both Germany. Given that similar developments have been observed in other EU countries, such as France and Poland, it is important to scrutinize consumer perceptions of biotechnology, in order to enable successful dialogue between the public and science, and to investigate whether GMOs are generally rejected or whether it depends on the type of end-use. As German consumers are strong supporters of sustainable biofuels (Gaskell et al., 2010), this begs the question of whether use of biotechnology for bioenergy purposes would result in a lower level of rejection compared with GM food. Perceptions about the use of GM in bioenergy production have not been investigated previously.

Methodological framework

Figure 8 shows the conceptual model, which is structured into two parts: The first part defines the relationship between the behavioral variables and the second part represents the statistical model representation of the behavioral model.

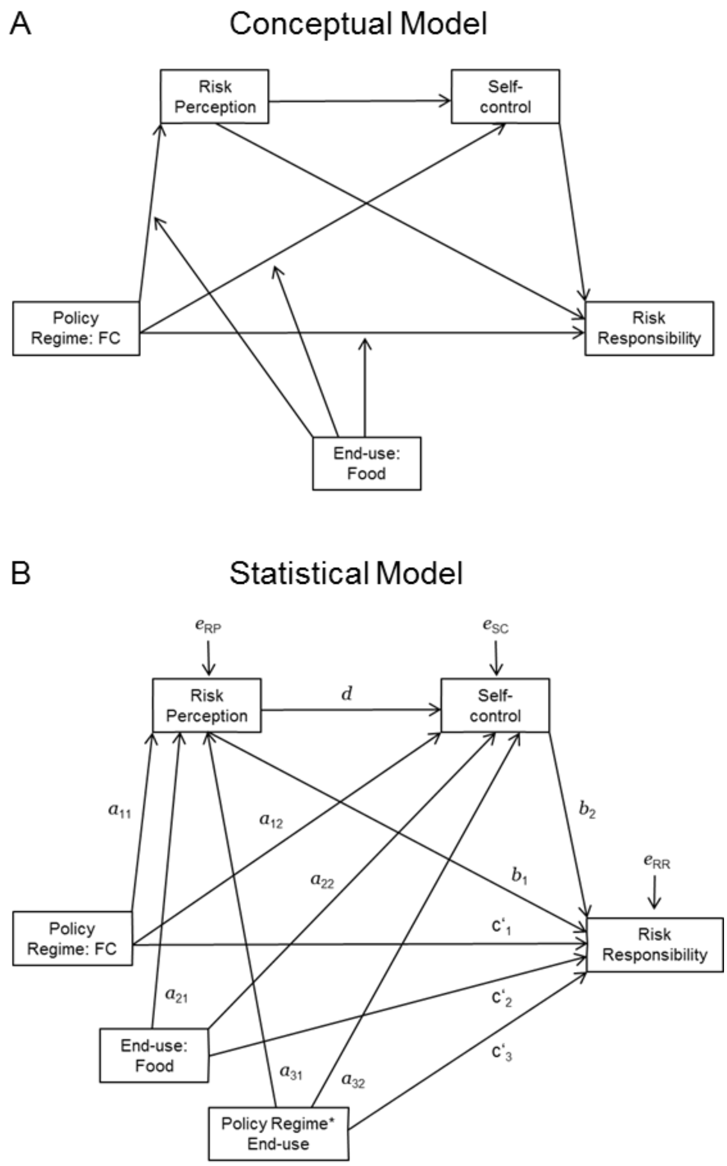

Figure 8: Basic conceptual and statistical model integrating the associations between perceived risk, self-control, and risk responsibility with contextual variables, i.e., policy regime and product end-use. The model covariates trust, socio-demographic factors, and risk dimensions are not shown.

The behavioral model includes the individual or ‘proximal’ factors, i.e., individual perceptions about risk, self-control, and responsibility. Evaluations of risk responsibility generally depend on the degree of perceived risk and its level of controllability. Hence, controllability has a major positive influence on personal risk responsibility (Leikas et al., 2009). This suggests that the attribution of risk responsibility is likely to be a function of perceived controllability of risk.

Accordingly, we applied a structural model that expresses the relationship between perceived risk and personal risk responsibility as mediated by self-control (see Figure 8).

The contextual variables, or 'distal' factors, include product end-uses and policy regimes. Notably, the choice of these factors stems from the desire to explore consumer perception of biotechnology in light of a product and process-based regulation that is applied in the EU. Davis and Davis (1972) argue that the degree of perceived personal responsibility is determined by both personal and external forces. Personal forces, such as ability or effort to cope with risks, are more inherently controllable, while external forces, such as regulatory context, are less controllable for individuals. Previous research suggests that policy regime and product end-use are both important factors for risk perception (Butkowski et al., 2017). The relevant question is thus to what extent policy-making decisions or, more generally, the nature of the policy environment, and different product end-uses affect perceptions of one's risk responsibility, and the level of acceptance of biotechnology.

In this study, the two policy scenarios (FC, R&D) and two product end-uses (food, bioenergy) were introduced as additional factors to the basic structural model, in order to help to determine 'where' and 'how much' exposure to GMOs is likely to take place. To capture the influence of the policy context, the scenarios made use of existing EU regulations by restricting the use of biotechnology to research and development purposes only (R&D scenario) or allowing full commercialization (FC scenario). Since the expected exposure was likely to be higher in FC, levels of risk perception were expected to exceed those for R&D. Accordingly, perceptions of controllability were also expected to be higher in the R&D scenario. In addition, we compared use of biomass for food and bioenergy as product end-uses. In fact, foods with improved levels of micronutrients (Qaim and Zilberman, 2003) and more efficient energy crops (Klümper and Qaim, 2014) have already been implemented in agricultural production. These two applications therefore represent realistic product end-uses for our study. We tested the hypothesis that perceived levels of risk for food applications exceed those for bioenergy. Furthermore, while policy regime was included as a general predictor of individual perceptions, the role of end-use was as a moderator. Accordingly, a serial-mediation relationship was used to specify how perceptions of risk, self-control, and risk responsibility are a function of the product in question.

Finally, trust and a set of socio-demographic characteristics, i.e., age, gender, education, and income, were included in the model. While policy regime and product end-use were included as dummy variables, these contextual factors were included as covariates. In order to compare the different types of risks that are relevant, the four dimensions of risk were specified to take the form of dummy covariates and then compared against an arbitrary baseline.

3.4. METHOD

3.4.1. PARTICIPANTS

The study sample comprised 436 German consumers, who participated in a laboratory experiment. Table 2 shows the sample demographics compared with national levels, based on 2011 census data from the German Federal Statistical Office. Although the sample was over-representative of those with tertiary education, the remaining characteristics matched the census data rather well. The study itself is based on a 2×2 design with between-person effects. The design thus comprised four treatment groups, reflecting the combinations of the two different policy regimes (R&D, FC) and two product end-uses (bioenergy, food). Policy regime represented the overall regulatory system in place for the use of GM in bioenergy and food production: the FC scenario broadly permitted domestic production and importation of GM products, while the R&D scenario restricted importation, cultivation, and commercialization of GM products. Accordingly, the R&D policy regime served as a baseline representing the current governance approach in Germany to use of GMOs. Moreover, respondents were allocated into one of 16 subgroups based on the experimental treatment and the self-selected ranking of risk dimensions.

Through visual and oral presentations, we provided the subjects with relevant information on GM technology itself and the risks involved, so that individual knowledge could be expected to be on a more comparable level (see Appendix B). Respondents were then asked to form their evaluations exclusively on the basis of the scenarios presented and the materials provided. Information about supply-chain actors and their respective roles was also presented for each end-use. The food supply chain described to consumers included government actors, farmers, food processors, retailers, and consumers, while the bioenergy supply-chain included government actors, farmers, energy producers, energy companies, and consumers. In addition, all scenario and information materials were presented to the respondents in the form of handouts distributed during the experiment, the content of which varied according to the treatment. The handouts included a summary of the scenario description, supply-chain actors, and their actions in the given scenario.

Table 2: Sample demographics and corresponding 2011 census data for Germany

Variable	Definition	Sample (N=436) (mean/median range)	2011 census Germany* (mean)
Gender	1=female, 0=male	51%	51%
Age	in years	36-60	44.3
Education	- Primary	17.6%	33.8%
	- Secondary	31.1%	29.6%
	- Tertiary	51.3%	28.8%
Income	Monthly household net income	1800-3600 EUR	3132 EUR

*Source: German Federal Statistical Office, Census 2011.

3.4.2. PROCEDURES

The sequential order of the experiment was as follows. First, consumers registered online to participate in the laboratory experiment. The experiment then started with the provision of information about biotechnology, product end-uses, policy scenarios, and relevant supply-chain actors. At this point, participants were asked about the relative importance of four risk dimensions (health, environment, socioeconomic, ethical): Which of the following aspects are most relevant to you for evaluation of the above [policy] scenario? Rank 1–4 (1 = least relevant and 4 = most relevant). Next, risk perceptions for participants were calculated using risk statements for the relevant risk dimension from the earlier step. Participants were then asked to rate how much they agreed with: the degree of risk that was implied; the likelihood of risk occurrence; the severity of consequences; the personal controllability of the event; and level of responsibility ascription across the entire supply chain, including to oneself. Next, participants were asked to rate how confident they were about the responses they had given in relation to agreeableness, likelihood, severity, perceived self-control, and responsibility. Finally, participants were asked to provide ratings for the trust scale and information about sociodemographic factors.

3.4.3. MEASURES

Risk statements that were relevant for each dimension were identified using Hess et al.'s (2016) literature review. Concrete risk statements regarding cause-effect relationships for using biotechnology were presented to respondents (see Appendix A). As a point of clarification, we used a formative risk measure which includes all risks of biotechnology use identified in relevant literature. Thereby it is possible to minimize possible errors in measurement. For further discussion, see Section 2.3.

To measure risk perception, we adopted Rayner and Cantor's (1987) approach, although we also added the variable agreement to enhance construct validity. In contrast to Fife-Shaw and Rowe's (1996) approach, we used this variable as a weight, where respondents could decide whether the respective risk statement was relevant for them or not (ratings about both the likelihood and severity of risk only enter into the risk function if participants agree that the risk actually exists). The specific risk statement was presented to the respondents and they were first asked: 'To what extent do you agree with the statements related to [e.g.] Ethical aspects as below?' on a 5-point scale (0 = totally disagree to 4 = totally agree). Next, they were asked about the perceived likelihood of the respective statement by the following item: 'Please indicate your perception of the likelihood of occurrence of each risk. How likely do you think it is that the risk described in the statements will actually happen?'. A 6-point scale was used to yield a higher rate of discrimination in responses (1 = not likely at all to 6 = almost entirely certain that this will happen). Finally, they were asked to indicate the perceived severity of the event by this item: 'Please indicate your perception of the degree of severeness related to the risk of each statement. The level of severeness represents how harmful the risk will be to you, should it actually happen' on a 5-point scale (1 = not severe at all to 5 = very severe).

Because of the potential for correlation among the three components, we defined risk perception as the average multiplicative measure of the following items: level of agreement (a) to the risk statement; perceived likelihood (l) of risk occurrence; and perceived severity (s) of its consequences:

$$RP = [\prod_{i=1}^{n}(a_i \times l_i \times s_i)]^{\frac{1}{n}}.$$

where index i denotes the specific risk statement rated. Each risk dimension comprised three or four risk statements, depending on the product end-use, policy regime, and risk dimension considered. Risk perception was thus a maximum of 30, (i.e., 1x6x5).

Consumers were then asked to indicate how they felt about the personal controllability of the risk, using a self-control measure adapted from Sparks and Shepherd (1994). Similarly to Leikas et al. (2009), personal controllability of risk was included to account for situations where risk perception is intensified because the consumer either feels helpless to control the actual risk or the ultimate outcome depends on the decisions and actions of others. Personal controllability of risk was measured by the following item ‘Please indicate your ability to control the risks associated with each statement. Controllability represents your ability to command the situation in which you are exposed to each risk. (Can you avoid the risk or prepare yourself by taking preventive measures to avoid it, or reduce its impact to yourself?)’ on a 5-point scale (1 = I cannot control my exposure to the risk at all to 5 = I can totally control my exposure to the risk).

Next, participants indicated how much risk responsibility they would ascribe to each of the five stakeholders of the supply chain, namely politicians, farmers, food processors or energy producers, food retailers or energy companies, and the respondents themselves (i.e., personal responsibility) by the following item: ‘Please allocate your view on the share of responsibility that each decision maker in the supply-chain should have by distributing between 0 to 100 per cent (where 0= No responsibility, 100= Full responsibility) in total for all targets’.

Participants were then asked to indicate their confidence with their evaluations of agreement, likelihood, and severity of risk on a 5-point scale (1 = not confident at all to 5 = completely confident). This step facilitated identification of any measurement bias.

The credibility of the various stakeholders was measured using the trust scale (Siegrist, 2000). Trust was assessed by asking: How much trust do you have in the following institutions or persons that they are conscious of their responsibilities in doing genetic engineering or handling the modified products?. Accordingly, participants indicated their trust on a 5-point scale (1 = no trust at all to 5 = completely trust) for scientists and researchers at universities; relevant industry actors; farmers; companies, or producers; policy-makers; and consumer organizations.

3.4.4. Data analysis

Data analysis was carried out using the PROCESS syntax version 2.16 (Hayes, 2013) for SPSS version 24, which allows for the estimation of a serial multiple-mediator (SMM) model (Hayes, 2015). This model estimated both the direct effects and the serial correlations between the mediators, namely perceived risk and self-control. Specifically, it modeled the relationship between the predictor variable of policy regime and the outcome variable of perceived responsibility, through which, either directly or indirectly, the mediators have an influence on the outcome variable. In addition, the index of linear moderated mediation was applied (see Hayes (2015) for details), in order to assess the moderating influence of product end-use on the SMM model. This estimation, following Hayes (2015), employed heteroscedasticityconsistent bootstrapped standard error estimators. The bootstrapping approach represents a non-parametric resampling procedure that repeatedly estimates the variables' indirect effects which will fit asymmetric confidence intervals around the coefficient estimates (Terpstra et al., 2014 p. 1513). It can thus account for the non-normal sampling distribution of indirect effects, which is usually asymmetric (Hayes, 2009).

3.5. Results

3.5.1. Serial multiple-mediator model

Normality of distributions for the variables perceived risk, self-control, and risk responsibility was rejected across the respective treatments (i.e., R&D, FC, food, bioenergy) according to both the Kolmogorov-Smirnov and Shapiro-Wilk tests (at 95% confidence level). Application of the natural logarithm therefore led to a better fit regarding skewness and kurtosis of a normal distribution. Moreover, factor analysis revealed two separable components of trust, one referring to researchers at universities and consumer organizations (Academia), the other to the remaining supply-chain actors (Industry).

The following analysis quantifies the relationship between the model variables, experimental treatments, and covariates. The SMM model, which consisted of the independent categorical variable policy regime (P), two mediators of risk perception (RP) and self-control (SC), and the dependent variable risk responsibility (RR), was estimated. In addition, product end-use (E) was included as a moderator. The ethical risk dimension served as the baseline, because this risk type tends to have the lowest levels of risk perception across all treatment groups. The estimated regression coefficients are presented in Figure 9.

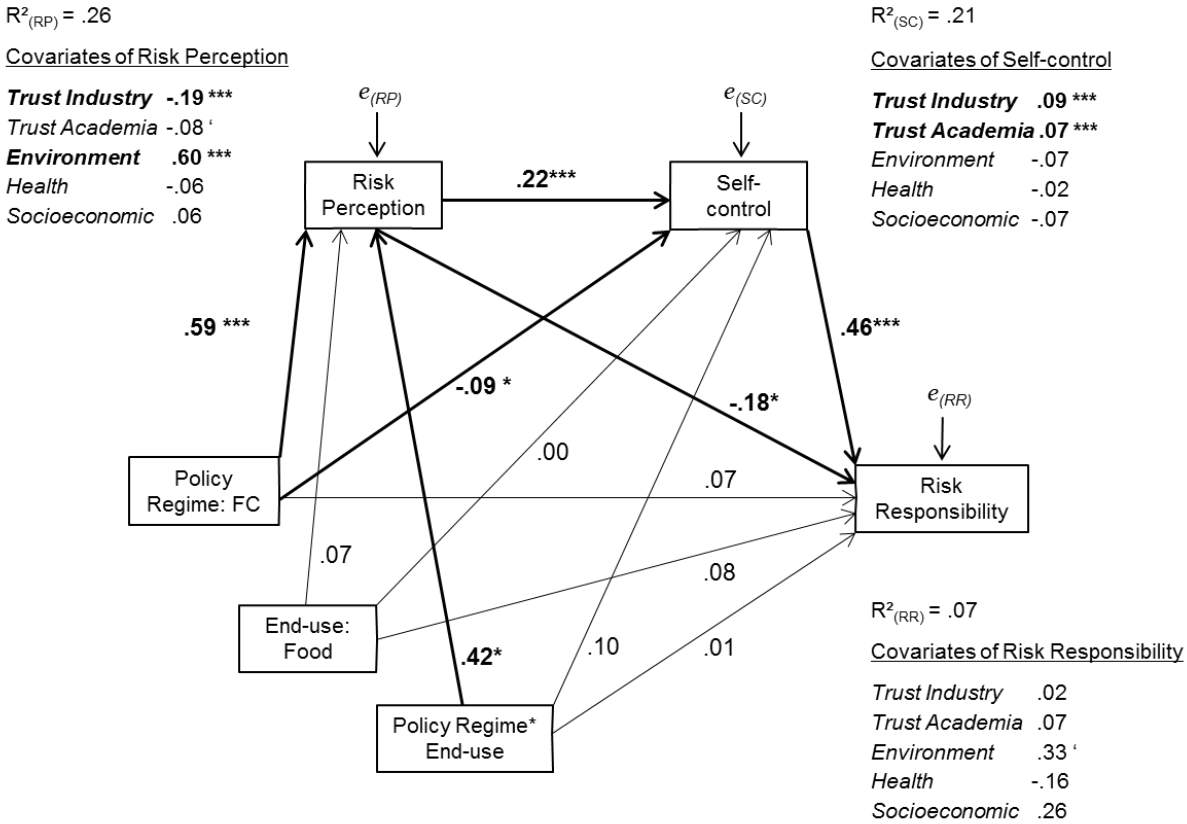

Figure 9: Coefficients and covariate estimates. Results are shown for both paths between model variables and covariates next to each dependent variable. Significant group differences are denoted by * p<0.05, ** p<0.01 and *** p<0.001.

The overall model significance for the separate model regressions indicated significant results: ($F_{(RP)}$ (12, 420) = 13.21, p < .000, $F_{(SC)}$ (13, 419) = 9.41, p < .000, $F_{(RR)}$ (14, 418) = 2.51, p = .0019). The explained variance ranged from moderate ($R^2_{(RP)}$ = .26, $R^2_{(SC)}$ = .21) to low ($R^2_{(RR)}$ = .06).

In general, the FC policy scenario had a positive effect on risk perception (a_{11} = .59, 95% CI = .43, .75, p < .001), whereas higher trust in industry decreased levels of perceived risk (Trust $\text{Industry}_{(RP)}$ = -.19, 95% CI = -.27, -.11, p < .001). Concern for environmental risks led to higher risk perception than concerns over ethical risks ($\text{Environment}_{(RP)}$ = .60, 95% CI = .34, .87, p < .001). The influence of health and socioeconomic risks was not significantly different from ethical risks. Conversely, a comparison of these two against environmental risks yielded significant negative parameters for the other dimensions, without any effect on the other estimates.

The results for self-control revealed that this factor was positively influenced by risk perception (d = .22, 95% CI = .17, .27, p < .001), whereas FC resulted in lower perceptions of self-control (a_{12} = -.09, 95% CI = -.17, -.01, p = .03). Furthermore, the more trust consumers placed in industry or academia, the higher the perceived degree of self-control (Trust $Academia_{(SC)} = .09$, 95% CI = .05, .13, $p < .001$; Trust $Industry_{(SC)} = .07$, 95% CI = .03, .11, $p < .001$). However, there was no evidence of any difference between the risk dimensions.

Finally, in the full model, personal risk responsibility was positively affected by self-control ($b_2 = .46$, 95% CI = .20, .72, $p < .001$). In addition, the level of perceived risk exerted downward pressure on the perception of risk responsibility ($b_1 = -.18$, 95% CI = -.32, -.04, $p = .0117$). Environmental concerns tended to positively influence perceived responsibility, albeit only at 90% confidence level. Trust did not directly affect perceptions of risk responsibility.

The coefficients for the product terms between policy regime and product end-use (a_{31}, a_{32}, c'_3) reflected greater positive effects of FC on perceived risk, control, and responsibility when the end-use was food. However, the effect of policy regime on risk perception seemed to be moderated by product end-use ($a_{31} = .42$, 95% CI = .10, .74), suggesting that the FC scenario was perceived to be riskier for food than for bioenergy applications.

When the model was extended through inclusion of covariates for age, gender, education, and income, the estimation results remained robust. However, some results are worth mentioning. For example, older people tended to have both higher levels of risk perception ($Age_{(RP)} = .11$, 95% CI = .03, .20, $p < .01$) and lower degree of self-control ($Age_{(SC)} = -.05$, 95% CI = -.09, -.01, $p = .0159$). Female respondents tended to have slightly higher levels of controllability and felt moderately more responsible than men. However, these effects were only significant at 90% confidence level.[2]

While the above analysis provided insights into direct effects, it is also important to consider indirect effects. Table 3 (a) shows the indirect effects (IE), defined as the product of the paths between the model variables (see Figure 8).). According to the results, the negative influence of FC on levels of responsibility was mediated by either perceived risk ($IE_{RP} = -.11$, 95% CI = -.20, -.02) or self-control ($IE_{SC} = -.04$, 95% CI = -.100, -.001). Furthermore, given that the indirect effect between P and RR was positive if mediated by both perceived risk and self-control, this suggested the presence of full mediation between policy regime and risk responsibility ($IE_{RP,SC} = .06$*, 95% CI = .02, .11). The total effect of P on RR is the sum of all IE. The overall impact of FC on risk responsibility was negative ($IE_{P \rightarrow RR} = -.09$, 95% CI = -.180, -.002).

[2] In a further extension to the model, Zaichkowsky's (Zaichkowsky (1994)) personal involvement inventory was added. Inclusion of this factor did not yield a significant change in R^2. In addition, the results are robust in that exchanging risk perception and self-control did not change the results for risk responsibility.

Table 3: Bootstrapped 95% confidence intervals for indirect effects and indices of moderated mediation.

Statistics							
	(a)				(b)		
	Indirect Effect	Percentile 2.5	Percentile 97.5		Index	Percentile 2.5	Percentile 97.5
IE_{RP}	-.11*	-.20	-.02	ω (IE_{RP})	-.08 *	-.18	-.01
IE_{SC}	-.04 *	-.10	-.001	ω (IE_{SC})	.04	-.03	.13
$IE_{RP,SC}$	.06 *	.02	.11	ω ($IE_{RP\ SC}$)	.04 *	.01	.10
Total $IE_{P \to RR}$	-.09 *	-.18	-.002				

3.5.2. Index of moderated mediation

To test the relevance of end-use as a moderator in the model, we adapted the Hayes (2015) index and test of linear moderated mediation. Since end-use is a dichotomous moderator, the index represented a test of difference between indirect effects in the food and bioenergy groups. Table 3 (b) shows the results for the indices ω and tests (percentiles) of the linear moderation of product end-use for the three indirect mediation relationships, i.e., IE_1 to IE_3. These results are then visualized in Figure 10 for easier understanding in relation to the SMM model. The indirect effects IE_{RP} and $IE_{RP,SC}$ depended linearly on product end-use, as illustrated by the fact that the bootstrapping confidence intervals did not include zero. However, the negative indirect effect between P, RP, and RR was weaker for the food end-use (ω (IE_{RP}) = -.08, 95% CI = -.18, -.01), which means that consumers tended to shift less responsibility to other targets in the case of a riskier end-use (i.e., food). Consequently, in the case of bioenergy, consumers were less reluctant to assign more responsibility to others, even in the case of higher perceived risk. Moreover, the indirect effect between P, RP, SC, and RR was stronger for food (ω ($IE_{RP,SC}$) = .04, 95% CI = .01, .10), suggesting that consumers ascribed more responsibility to themselves if the application involved commercialized food. In simpler terms, this means that, if consumers feel able to control the greater risks involved with full commercialization, they are likely to assume more responsibility overall, especially if the end-use is food.

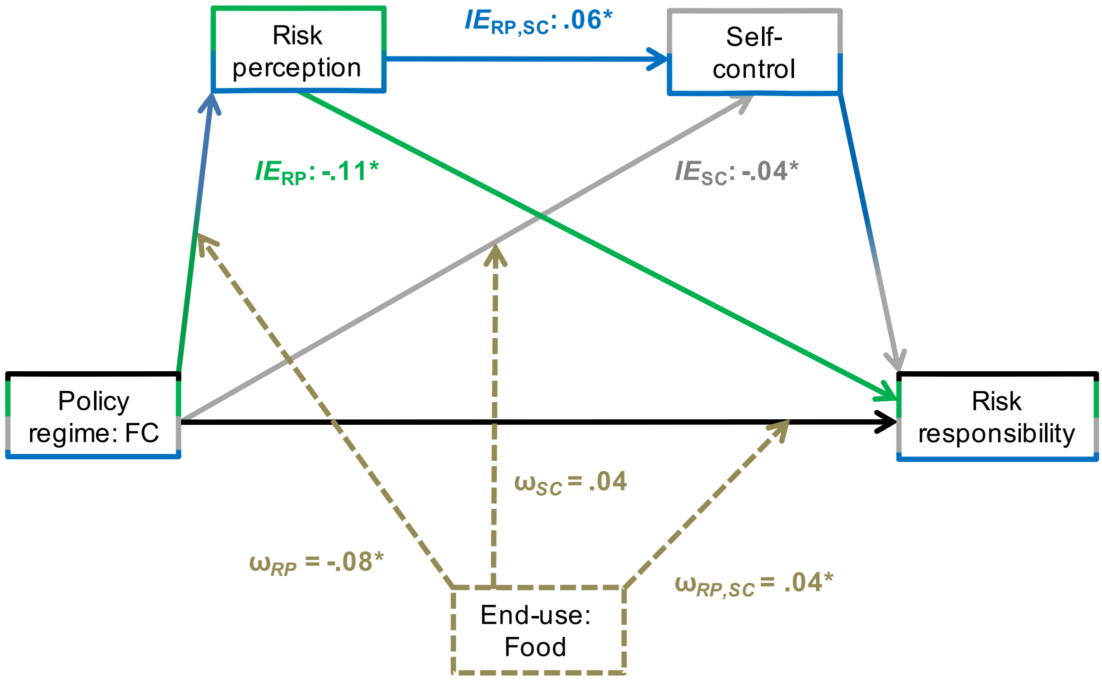

Figure 10: Model with paths of indirect effects (IE_{RP} green, IE_{SC} grey, $IE_{RP,SC}$ blue) and indices (ω) of moderated-mediation (dashed paths). Significant bootstrapping intervals at $p < .05$ are denoted *.

3.6. Discussion

With respect to the interrelationships, previous research suggests that the presence of severe risks is likely to reduce one's personal responsibility and foster avoidant coping (Leikas et al., 2009). Similarly, we found that food-related applications of genetic engineering were associated with higher levels of risk perception, resulting in a reduction in consumers' personal risk responsibility. This was reflected by the significance of the two parallel indirect effects (IE_{RP} and IE_{SC}), each of which accounted for the separable (and negative) influence of one mediator on personal responsibility. This suggests that risk responsibility is likely to decrease in a full-commercialization policy regime compared with an R&D-only scenario. As a potential mechanism, it can be noted that FC caused consumers to have both higher levels of perceived risk and diminished perceptions of control, thereby fostering a lower sense of responsibility for potential risks and a higher incidence of avoidant-coping behaviors. This result is in line with previous findings suggesting negative relationships between personal responsibility and risk (Walster, 1966) and personal responsibility and self-control (Leikas et al., 2009). Thus we concluded that avoidant-coping behavior as a result of risk perceptions, i.e., taking less personal responsibility in risky situations, is more likely in the presence of higher levels of risk, and thus consumer acceptance is likely to be lower (Voth and Sirois, 2009).

However, in contrast to the prevailing narrative, we found that this effect also depends on the degree of perceived self-control. The SMM model revealed that higher perceived controllability enables consumers to take personal responsibility even for higher levels of risk, i.e., in the context of full commercialization vis-à-vis R&D-only policy. This was shown by the positive indirect effect in the SMM model ($IE_{RP,SC}$) from the policy regime through the mediators of risk perception and self-control to risk responsibility. Hence, if the risks of green genetic engineering are more controllable, consumers will tend to demonstrate a lower frequency of avoidant coping, i.e., they will shift less responsibility to other targets. This extends findings by Leikas et al. (2009), who showed that a higher degree of control leads to more personal responsibility. Since previous research has not investigated the interplay between perceived risk, self-control, and risk responsibility, it was not possible to show that higher risk can cause consumers to do the opposite if risks feel controllable, i.e., take more responsibility rather than less.

More generally, our findings thus confirmed previous indications of a negative relationship between risk and acceptance (Frewer et al., 2013; De Steur et al., 2014; Hess et al., 2016). Interestingly, one exception to this stylized fact arose when consumers felt that they were able to control for risks. As a result, it can be concluded that all efforts to increase consumer perceptions of the degree of controllability of potential risks offer a broad strategy for promoting higher acceptance.

With respect to the influence of contextual factors, we found that the decision-making context mattered, namely on product end-use and type of policy regime. This was demonstrated by the negative impact of the end-use moderator for food (ω_{RP}), compared with bioenergy production, on the indirect effect of policy regime on risk responsibility (IE_{RP}). This suggests that avoidant coping is lower for food than bioenergy end-use. Consequently, and contradicting prior expectations, it is possible for bioenergy end-use to be associated with lower acceptance, i.e., when considering only the indirect effects of risk perception. A possible explanation is that environmental risks are perceived to be higher for bioenergy production, given that e.g., the potential impacts of monoculture production on plant and insect biodiversity are a major concern among both consumers and regulatory officials (BMEL, 2015).

In reality, regulation and commercialization pose risks that cannot be directly controlled by consumers, as reflected by the overall negative impact of policy scenario on risk responsibility (Total $IE_{P \rightarrow RR}$). Thus, consumers generally tended to prefer a R&D-only approach for GM, emphasizing the precautionary principle applied in regulatory practice for the commercialization of GMOs. This indicates the importance of efforts in R&D on GMOs to ascertain their safety. The consequence is that acceptance of both full-commercialization and food-related applications is likely to be higher than expected if measures aimed at increasing consumer perceptions of self-control are successful. Clear labeling that provides relevant information and thereby improves transparency is likely to achieve this goal (Rollin et al., 2011).

In the broader context, of the four risk dimensions and trust, we found that perceptions of environmental risks had a positive influence on overall risk perception vis-a-vis concerns over risks of an ethical nature. Regarding sociodemographic variables, age had an effect, as older respondents tended to have higher levels of risk perception, which supports earlier findings (Siegrist, 2000). With respect to the role of trust, our results suggest that the greater the degree to which consumers place trust in industry, the lower their risk perceptions. This is in line with findings by Flynn et al. (1994) and Cvetkovich and Lofstedt (2013), which highlighted the relationship between trust and risk. Moreover, higher trust in both industry and academia had the potential to increase perceptions of risk controllability. On this basis, it would be possible to encourage consumers to take greater responsibility for known risks, and thereby cultivate greater acceptance. Finally, our findings supported the assumption that credence attributes, which require consumers to trust, are even more relevant against a backdrop of novel genome-editing technologies such as CRISPR-Cas9 or TALENs, which cannot be detected in the final product. Accordingly, the greater reliance on credence attributes and increasing uncertainty of consumers in this domain necessitates new types of labels and/or a new foundation to establish trust in supply-chain actors. Specifically, stakeholders' decisions also become more relevant as a way to illustrate, especially with regard to biotechnology, how consumers (and value chains) might seek to resolve this uncertainty.

The focus of this paper was to investigate the interrelationships between key determinants of biotechnology acceptance. Notably, perceived risk and personal risk responsibility are found to have moderate to low explained variance, which suggests that any conclusions about this factor should be taken with caution.

Moreover, awareness of the current policy regime on GMOs could have varied among the respondents. However, this was not assessed before the experiment, which could have resulted in higher risk perceptions for consumers that were not aware that even though the commercialization of approved crops was deemed to be legal, in practice, the R&D scenario is the one currently in place. To account for individual differences in risk perceptions across policy scenarios and product end-uses, future research should therefore assess knowledge of the current regulation and commercial status of biotech products at the onset of the experiment. In addition, it would be useful to further explore the mechanisms linking risk responsibility and acceptance, to provide stronger evidence for the relationship between our behavioral model and consumer acceptance of GMOs. Specifically, the interplay with information, knowledge, and labeling should be investigated, to achieve a deeper understanding of the determinants of controllability for the interrelationship with perceived risk and risk responsibility. Lastly, the contextual variables in this study have been kept rather specific, i.e. with regard to opportunities for commercialization and the related regulatory approaches. Further extensions to the understanding of practical context could therefore be meaningful, for instance, to include factors related to the cultural or informational context.

3.7. CONCLUSIONS

Green genetic engineering offers the potential to tackle societal challenges such as global growth in food and energy consumption, and thereby to contribute to solving resource conflicts between food and fuel end-uses. Consumer acceptance of GM technology is still low in some European countries, which can be attributed to high risk perception and low controllability of potential adverse outcomes. Consequently, consumers tend to ascribe responsibility to other supply chain stakeholders rather than taking personal responsibility themselves.

However, little is known about the underlying processes that determine personal responsibility and how this process relates to a broader economic context. This study was the first to perform a serial multiple-mediator and simultaneous moderation analysis to assess the relationships between perceived risk, self-control, and responsibility in relation to biotechnology policy and product end-use.

The results clearly indicate that controllability undermines the negative impact of risk perception on risk responsibility and thus acceptance. If consumers feel able to control risks, they are more likely to accept technology innovation, even if it is associated with higher risks. In addition, this effect is dependent on the product end-use. However, the question is whether wider market adoption of biotechnology is desirable. There is no conclusive evidence of non-contagiousness of GM crops in human and animal health in the long-term, but also little evidence of actual adverse effects. The decision must be based on socioeconomic considerations and involve public opinion. To get to the heart of things, it is thus important to foster credibility of risk managers and create more transparency and traceability across the supply chain, in order to convey controllability at any point during the production process and enable consumers to make a free and informed choice, before addressing further communication to the wider public. This points to the importance of objectively verifiable information as a means to foster consumer perceptions about self-control at both the technology and product levels and accordingly, to facilitate research in this area identifying the criteria able to enhance consumer perceptions of self-control (e.g. product labels). In addition, a more product-oriented policy could reduce both the complexity and tardiness of the approval process for GMOs in the EU and consumer concerns induced by unsettled and unsteady policy. Moreover, in light of new breeding techniques, such as genome editing, it could help to orient the public debate about the need for genetic engineering that is more controllable than prior approaches. If the associated risks are perceived to be more controllable by consumers, then acceptance can be expected to increase as well. In fact, CRISPR-edited plants have recently been brought to market in the U.S., with initial consumer reactions found to be positive when knowledge about the product is higher (Waltz, 2018). Concerning Europe, a shift from an orientation of the GMO directives towards a rather process-based to a more product-based approach could thereby solve the two main problems currently encountered, i.e., fostering future research and development in biotechnology and increasing acceptance of innovations that could help to achieve the UN sustainable development goals.

4. THE INFLUENCE OF INFORMATION FRAMING AND UPSTREAM ACCEPTANCE ON CONSUMER DECISION-MAKING FOR BIOENERGY FROM GM CROPS

RQ3.1: Does information framing affect consumer decision-making with regard to the use of biotechnology for bioenergy production?

RQ3.2.1: To what extent are consumer decisions dependent on the stances of supply-chain actors?

RQ3.2.2: Does trust in supply-chain actors have the potential to increase levels of upstream support or rejection?

RQ3.3: Do positive and negative information frames evoke an emotional response consonant to the valence of the framing?

This chapter is based on the following publication:

Butkowski, O. K., Baum, C.M., Pakseresht, A., Lagerkvist, C. J., Bröring, S., 2018. The influence of information framing and upstream acceptance on consumer decision-making for bioenergy from GM crops. Under review in Risk Analysis.

Abstract

Risk communication and the framing of information are essential for consumer acceptance of novel technologies. However, prior research shows more limited consideration of bioenergy as an end-use and whether socioeconomic and emotional circumstances of decision-making also have an impact. We thus conducted a framed field experiment with German consumers (N = 322) to investigate how support of genetic engineering in bioenergy can be influenced by the informational and emotional valence of information by employing three frames, each promoting a distinct hedonic tone of feelings through the risk and benefit message (positive, negative, neutral). To account for the existing environments and policies affecting preferences, we investigate the extent to which the upstream decisions of supply-chain actors impact consumer decisions as well as the influence of other key determinants of decision-making such as labeling and trust. Overall, we determine that consumer support (rejection) declined (increased) if the message had a negative tone, but did not change in response to a positive frame. In addition, labeling and the expressed support of energy companies were both found to increase consumer support, even more so in combination. We argue that trust and labeling represent distinct types of support-building mechanisms, which may even be complementary to one another. This represents a challenge however to the frequent opposition of industry actors to introducing labeling schemes. In general, attempts to cultivate more informed decision-making should therefore look to the influence of upstream actors and how their respective decisions to support or reject act as determinants of consumer choices.

4.1. Introduction

Acceptance of innovative technologies such as green genetic engineering (GE) is crucial for the continued development of more sustainable systems of agricultural production. However, the regulatory approaches and commercial receptiveness of genetically modified (GM) plants and derived products remain quite heterogeneous across the world, not least because consumer acceptance is subject to a variety of individual and social factors. Besides making it difficult to predict the acceptance of novel products and applications in any kind of general fashion, this also makes it difficult to craft risk messages to inform the public about expected advantages. For instance, it is generally established that food-related applications are perceived in a more negative light than use for, e.g., pharmaceuticals, plant protection, and bioenergy (Frewer and Shepherd, 1995; Knight, 2006; Christoph et al., 2008; Butkowski et al., 2017). One strategy to promote acceptance would therefore be to tailor the content of risk messages to better reflect the end-use context, e.g. by highlighting specific benefits (Lusk et al., 2004; Lusk et al., 2015). While extant research has broadly investigated the influence of information provision on acceptance of GM food (Frewer et al., 2016), there is however a lack of attention to non-food applications such as bioenergy (Verbeke, 2007). This represents a notable shortcoming given that bioenergy is not only a highly relevant application, due to its role as a source for more sustainable production of primary energy (IRENA, 2014; Rockström et al., 2017), but is also generally well-regarded by the public (Gaskell et al., 2010).

Generally speaking, and given the typically controversial nature of biotechnology, there is a broad focus on the determinants of consumer acceptance in the literature (Costa-Font and Gil, 2008). Yet, even as this literature has become increasingly complex (Gupta et al., 2012), there is limited attention to more contextual determinants of decision-making, such as the influence of other actors (Lusk et al., 2014) and emotional factors (Roeser, 2012). However, the literature does suggest that emotions can impair individuals' abilities to make decisions in complex situations, thereby leading to more simple, stereotyped forms of behavior (Forgas, 2002) that often differ from predictions. In general, practical decision-making is also shown to be prone to situational factors (Ariely and Norton, 2008) and existing socioeconomic environments and policies can affect preferences (Palacios-Huerta and Santos, 2004). For instance, Pakseresht et al. (2017) demonstrated how information about the practical context – that is, with regard to existing legislation and the stances of supply-chain actors – is broadly influential for decision-making. Given the relatively limited attention to such factors in the literature, this paper intends to build upon and extend these findings, thereby affording a stronger basis for risk communication.

The primary aim of this study was to elucidate the role of information-framing for consumer decision-making, focusing on the use of bioenergy from GM crops. Accordingly, we investigate and distinguish three key determinants of decision-making in designing our experimental manipulation. First, we manipulated the valence of information in messages about the risk and benefits of using GE crops for bioenergy production, that is, whether information about this application was generally positive or negative. Second, we included information about the decisions of other supply-chain actors, regarding their support or rejection for the broader use of GE for bioenergy production. Although multiple studies have explored the general influence of trust or trust in scientists (Frewer et al., 1996; Siegrist, 2000; Siegrist and Cvetkovich, 2000), the relevance of more economic actors on decision-making is broadly neglected. Third and finally, we controlled for emotional mood in order to understand how this impacts information processing. Even though the importance of emotional factors is widely acknowledged in the research (Roeser, 2012), it is much less clear what exact role they might play. We therefore traced participant mood at three distinct points in the experiment (i.e. before, during, and after) to control for their influence on decision-making. By accounting for these two streams of decision-making, this study is better able to explore how information-framing affects consumer decision-making, not to mention whether people are indeed susceptible to their emotions when it comes to risk perceptions of GM.

4.2. LITERATURE REVIEW

4.2.1. EFFECT OF INFORMATION ON RISK PERCEPTION AND CONSUMER DECISION-MAKING

Public communication about the risks and benefits of new technologies has typically focused on food, possibly because such applications are broadly seen to be the most problematic (Lusk et al., 2005; Frewer et al., 2013). Indeed, the controversy over genetic modification only became truly ‘amplified’ once it had been applied for food production (Frewer et al., 2002; Pidgeon et al., 2003). In general, Frewer et al. (2016) propose three main themes that underlie risk and benefit communication, namely the content, target, and source of information. The content entails not only words and symbols but also visual information. Hence, when positive or negative feelings are attached to images, it is possible to speak of the hedonic tone or valence of a message. For instance, such attached or learned emotions can be associated with certain cues, e.g. keywords or related images (Leiserowitz, 2005). As a result, this combination of cognitive information and non-cognitive (or affective) attributes poses a potential difficulty when it comes to predicting how the overall message could be interpreted. Previous research related to GM food has therefore explored how the framing of information in this fashion, i.e. by manipulating the valence, can affect consumer preferences. In particular, use of framing is shown to potentially increase overall acceptance (Siegrist, 2008), favorability (Sparks et al., 1994), and the perceptions of net benefits (Park and Lee, 2003). Moreover, information provision can even decrease the ability of to make decisions (Scholderer and Frewer, 2003), suggesting that simply presenting individuals with more information was likely to make them more concerned or insecure than before. In another domain, Terpstra et al. (2014) have shown that communication messages about flood risks are generally more effective when framed by negative affect and with an emphasis on the potential risks. Overall, there is however no consensus about the direction of influence between conflicting information and perceptions of risks and benefits (De Steur et al., 2014).

Building on related work on how information framing influences preferences for GM food (Sparks et al., 1994; Frewer et al., 2003; Park and Lee, 2003; Scholderer and Frewer, 2003; Siegrist, 2008), we therefore examine the role of framing on consumer decision-making for bioenergy made from GM crops by proposing the following hypothesis:

H_1. Positive (negative) framing of information fosters consumer support (rejection).

One potentially unexplored source of information is the actions and words of actors across the supply-chain. Notably, given that actors have different perspectives of the potential risks and benefits of a particular application, the decisions that they take with regard to the support or rejection of specific product applications. More directly, it has been established that consumers are more supportive (opposed) of GE applications to food if other supply-chain actors are supportive (opposed) as well (Pakseresht et al., 2017). Based on this, we can expect that consumers will use the behavior of these actors to orient their decisions, especially if they either do not possess detailed knowledge about the production process or are unwilling to devote the cognitive effort to explore it in depth. Nonetheless, little is known about how upstream support affects consumer decision-making, and with the limited research that does exist tending to focus on actor characteristics. Looking at risk perceptions of nanotechnology, for instance, Schütz and Wiedemann (2008) revealed that if a small- or medium-sized enterprise is portrayed as the beneficiary, i.e. and not a multinational corporation, individuals tend to assign lower risk probability to the potential for toxic damages, negative environmental consequences, and even unknown risks. The authors therefore underscore that risk perceptions are contingent on the characteristics of the actors – even where these do not necessarily have a direct relationship to risk.

Besides the characteristics of the actors involved, we wish to explore how the type of supply-chain actor itself matters, specifically for bioenergy production. Accordingly, we examine what role supply-chain actors (e.g. the policymakers, farmers, energy producers, energy companies) may themselves play consumer decision-making processes. In this regard, we argue that decisions of other supply-chain actors can provide orientation to consumers, as expressed by the following hypothesis:

H_2. Upstream support (rejection) increase consumer support (rejection).

4.2.2. THE RISK-AS-FEELINGS HYPOTHESIS

If we look to the growing literature on visceral and intuitive factors, another sort of story begins to emerge. Notably, those supposedly 'irrational' evaluations of new technologies may arise from the 'gut feelings' of individuals, likely reflecting the use of another basis for taking decisions (Loewenstein, 2000). The 'risk-as-feelings' literature has therefore introduced the concept of the 'affect heuristic' in order to reflect how decision-making is also determined by emotional aspects (Alhakami and Slovic, 1994; Loewenstein et al., 2001; Slovic et al., 2004). Accordingly, Roeser (2012) points out that the 'risk-as-analysis' approach runs the risk of disregarding the role of emotional aspects in decision making, and specifically those relating to the information target. Pointing to potential interactions between the two strands of literature, the author therefore concludes that emotional aspects are a crucial feature of decision-making given that they allow for "a broader view of risks that does include important ethical considerations", p. 1035 (Roeser, 2012 p. 1035). In order to understand whether or not the influence of information framing (H_1) is biased by current emotional states, we thus conduct a manipulation check that controls for the mood and feelings of participants during the experiment, leading to the following hypothesis:

H_3. Positive and negative framing of information will evoke an emotional response consonant to the valence of the message.

4.2.3. THE ROLE OF TRUST IN RISK COMMUNICATION

Besides information-framing, it is broadly established that trust, e.g., in scientists or regulatory officials, also serves as a heuristic for decision-making. For instance, to the tendency to defer to scientific authority, e.g. because one believes that scientists are best-situated to make decisions about new technologies, is found to be a crucial determinant of support for novel technologies, including agricultural biotechnology (Nisbet and Scheufele, 2009), nanotechnology (Lee and Scheufele, 2006), and synthetic biology (Akin et al., 2017). Trust in the individuals and institutions responsible for the production, distribution, and regulation of GM products and technologies (Siegrist, 2000) has also been shown to affect risk and benefit perceptions which, in turn, influences attitudes and purchase intentions (Costa-Font and Gil, 2009). As such, this relationship suggests that a higher level of trust is likely to induce greater support (H4a). Accordingly, consumers can be expected, for instance, to utilize *trust* in the responsible actors as a heuristic for evaluating the accuracy of information, e.g. about the risks and benefits of GM food (Verbeke, 2005). Indeed, the influence of new information on consumers' beliefs is greatly dependent on the source of information, which is the third factor mentioned by Frewer et al. (Frewer et al., 2016). In specific, trust in the responsible actors determines how risk and benefit messages are likely to be perceived by consumers. For instance, sources that are seen to be less motivated by their own self-interest and a desire for profits, such as consumer organizations and scientists at universities , are more generally trusted than, for instance, multinational corporations in the food sector (Frewer et al., 1996). This highlights the importance of trust in relation to information and its potential influence on consumer support (H4b).

Moreover, what is broadly absent within the literature is whether and how trust in other actors may also factor in. After demonstrating how trust in scientists influences perceptions of global warming, Hmielowski et al. (2014) underscore the need to explore the relevance of trust in other prominent institutions as well, and specifically noting the relevance of decision-makers in the political and commercial spheres. Influence of the type of economic actor, let alone how this differs depending on how support is expressed, is considered much more sparsely. Nonetheless, trust in supply-chain actors can be expected to influence the decision to support or reject innovative products and technologies, namely, by increasing the extent to which upstream decisions impact consumers when actors are perceived to be trustworthy (H4c). Thus, trust is expected to be influential both on its own and in interaction with other crucial factors, such as the framing of information and upstream decisions of supply-chain actors. This is reflected by the following three hypotheses:

H_{4a}. Higher trust increases (decreases) consumer support (rejection) of GE in bioenergy production.

H_{4b}. Higher trust increases the impact of information framing on consumers' decisions.

H_{4c}. Higher trust in supply-chain actors increases the influence of upstream support and rejection on consumer decision-making.

4.3. MATERIALS AND METHODS

4.3.1. STUDY DESIGN AND PROCEDURE

A group of 325 German consumers participated in a framed field experiment in Bonn. Consumers were recruited through postal invitation from a random sample of the municipal population. Each participant received 25€ for completing the experiment. Regarding the experimental design, we use a between-subjects design that varied along one dimension: the valence of information about risks and benefits of using GE for bioenergy production and commercialization in Germany. The valence was manipulated by using positive, negative, or neutral (control) information, thereby resulting in three treatment groups (see Appendix D). Participants were randomly assigned to one of the three treatments. Information was then presented to the participants via slides projected by a beamer, as well as with printed handouts.

With regard to the decision-making task, participants were specifically asked to assume the role of consumers and to indicate their decision based on those of the other supply-chain actors. The decision alternatives for consumers vis-à-vis GE bioenergy were: supporting the regulation and being willing to use it; supporting the regulation in general but not being willing to purchase it for their families; supporting the regulation but accepting the situation if the product is not available (i.e. agree); not supporting and not purchasing (i.e. disfavor and outlaw); and having a preference for domestically grown (i.e. domestic) or imported produce (i.e. motivate). The resulting chains of cumulative decision-making options for supply-chain actors and consumers resulted in a total of 20 possible decision profiles (see Appendix E). In this regard, the types of alternatives available for a given actor depend on the previous decisions that were taken. Respondents indicated their choice based on the previous decisions, each of which was presented to them as separate profiles, one page at a time.

Lastly, we applied the experience sampling method (ESM) in order to examine changes in emotions throughout the decision-making task (i.e. before, during, and after) (Larson and Csikszentmihalyi, 2014).

4.3.2. STIMULI

The information messages presented to participants was composed of a short text and two pictures, together with a visual symbol (though not in the control group) (see Appendix D). The valence of text and visual information was varied across the three frames. While risks and benefits were balanced in the control group, the positive and negative treatments focused only on benefits and risks, respectively. In addition, affect was evoked by using pictures shown to engender positive or negative feelings about agriculture and biotechnology. Pictures from the international affective picture system (IAPS) were thus used to ensure the visual cues result in the intended positive or negative valence (Lang et al., 1999). For instance, the symbol that was presumed to foster positive affect was a plant that was placed on a human hand, suggesting that involved actors care about nature and the environment in agricultural production. To elicit a negative connotation, conversely, we used a biohazard symbol, generally shown to signal a warning for bioactive substances that threaten human health. Finally, we utilized Hess et al.'s (2016) review to guide the composition of the message content. This content was thus classified into four types of risks and benefits of GE, namely health, environmental, socioeconomic, and ethical aspects. Agronomic traits were then related to these dimension to demonstrate the real-world consequences.

4.3.3. MEASURES

During the decision-making task, participants were asked to evaluate the potential combinations of decisions that could arise across the supply chain, with each actor selecting from among a set of pre-determined alternatives. A visualization of one exemplary decision profile that was given to respondents in the positive information treatment group can be found in Appendix C.

The ESM was developed to assess individual emotions at the moment of measurement (Larson and Csikszentmihalyi, 2014). We were thus able to measure mood asking participants to indicate their hedonic well-being (How have you been feeling during the last 30 minutes? 1 = positive, 2 = negative, or 3 = both positive and negative).

In the context of this experiment, trust represented the level of confidence that respondents had in the supply-chain and external actors involved with handling GMOs (i.e. How much trust do you have that the following institutions or persons are conscious of their responsibilities related to use of genetic engineering or handling the modified products?) (Siegrist, 2000). Respondents indicated on a 5-point scale how much they trusted (from 1 = no trust at all to 5 = completely trust) not only scientists and researchers at universities, but also industry, policy makers, farmers, bioenergy producers, energy companies, and consumer organizations. Accordingly, the measure from Siegrist (Siegrist, 2000) was adjusted to distinguish between trust in the supply-chain actors that were important for the economic scenario presented to respondents and the external actors (i.e. scientists and consumer organizations) that evaluate and control production processes and convey information through, for instance, labeling schemes.

In order to control for other factors that might influence a participant's receptiveness to information framing, we also inquired after a handful of sociodemographic characteristics: namely, age, gender, education, and household income.

4.3.4. Empirical approach and data analysis

To explore whether differences in consumers' responses might be caused by the prior decisions of supply-chain actors, we conducted Stuart-Maxwell (S-M) tests to examine the equality of consumers' choice frequencies among the 20 different decision profiles. Appendix E shows how SM-tests were conducted. Consumers' choices were collected in K x K frequency tables, which were then tested for consistency and internal validity whereby identical consumer profiles, e.g. P_x and P_y, were checked for not only differences in the stances of the supply-chain actors (a(x) = a(y), b(x) = b(y), c(x) = c(y), d(x) = d(y), and e(x) = e(y)) but also whether the changes in consumer decisions could have resulted by chance (null hypothesis) or due to the decisions of other actors. The test statistic has an approximate chi-squared distribution with k − 1 degrees of freedom (Everitt, 1992). Accordingly, mixed-effects logistic regressions (MELR) were used to quantify the effects of other actors' decisions on consumer support and rejection of GE for bioenergy production. Overall, the information frames, decisions taken by other supply-chain actors, and trust were all modeled as linear fixed effects. Individual differences between respondents, on the other hand, were captured by including random intercepts. Final models were selected via likelihood ratio tests (LRT). Separately, the final factors for trust were assessed using principal component analysis by means of oblimin rotation method, and with final factors selected on the basis of the corresponding scree-plots. Lastly, to account for the impact of information frames on participants' emotions, we estimated a mixed-effects regression model for three-level ordinal response data. In this manner, we were able to control for the possible effects of emotions on consumer decision-making.

The data was analyzed using the R software version 1.0.136 (R Core Team, 2014) with the packages irr – version 0.84 (Matthias et al., 2012), lme4 - version 1.1-12 (Bates et al., 2016).

4.4. Results

4.4.1. Sample characteristics

Overall, the sociodemographic characteristics of the sample were somewhat representative of the German population (Table 4). Notably, median age of the sample was in the range of 36-60 years. On the other hand, the sample was under-representative regarding females (42 percent vs. 51 percent) and income was lower than average (<1800 € vs. 3128 €).

Furthermore, the sample was generally more educated, especially in terms of tertiary education (50.8 percent vs. 28.8 percent).

Table 4. Demographic characteristics of the sample against German household data.

Variable	Definition	Sample (N=325) (mean/median range)	2011 Census Germany* (mean)
Gender	1=female, 0=male	42%	51%
Age	in years	36-60	44.3
Education	- Primary	19.3%	33.8%
	- Secondary	30.0%	29.6%
	- Tertiary	50.8%	28.8%
Income	monthly household net income	< 1800 EUR	3132 EUR

*Source: German Federal Statistical Office, Census 2011.

4.4.2. SM-TESTS AND MIXED EFFECTS LOGISTIC REGRESSIONS

The S-M test indicates that consumer decisions differ considerably between the profiles (Appendix F). Because of the constraints imposed by the multiple comparisons, a p-value < 0.005 was considered as the cut-off value for significance of pair-wise comparisons. Mixed-effects logistic-regression (MELR) analysis is therefore used to estimate how exactly supply-chain decisions could influence consumer support and rejection of GE bioenergy production. In specific, our analysis investigates the influence of the key determinants of decision-making identified in the literature review section, i.e. information framing, choices of supply-chain actors, participant mood, trust variables, plus the relevant interactions. Factor analysis indicated that trust should be grouped in the two principal components of ‘supply-chain actors’ (mean = 3.96, SD = 0.69), comprised of policy makers, farmers, energy producers and companies, and scientists in industry, and ‘external actors’ (mean = 2.51, SD = 0.68), namely, scientists at universities and consumer organizations. Importantly, given that we are dealing with two distinct types of decisions (i.e. support and rejection), we will outline the relevant findings for each separately.

Table 5 and Table 6 present the stepwise regressions and related estimation results for consumer support and rejection, respectively. Estimation coefficients represent the log-odds that the decisions of consumers are affected by the respective explanatory variables.

Furthermore, both modeling sequences begin by including type of information frame, decisions of supply-chain actors, and trust as fixed effects. Subsequently, participant mood at the start of the experiment was added as a fixed effect to control for its potential influence. Models 3 through 6 are then estimated to include those two-way interactions central to hypotheses H_{4b} and H_{4c}. As a last step, Model 7 includes the socio-demographic factors. All models also include a random intercept to account for the overall heterogeneity in consumer choice. Likelihood-ratio tests were then used to identify the best overall model for support and rejection (i.e. Model 7 in both Table 5 and Table 6).

4.4.2.1. Examining consumer support for GM bioenergy

As the first step in our stepwise regression analysis, we begin by exploring how support decisions are influenced by the type of information frame, the decisions of supply-chain actors, and the two trust variables. Through this, we determine, first of all, that those participants who were presented with negative information about the use of bioenergy were less likely to support it. In contrast, the framing in either positive or neutral terms did not significantly differ. Turning to supply-chain actors, we find that the choices of both farmers and energy companies to support and/or grow and sell biotech crops have a positive influence on consumer support. Indeed, the impact of energy consumers is especially prominent, with the largest (absolute) coefficient estimates for the entire model. Conversely, we fail to find any influence from choices of energy producers on consumer support, suggesting that consumers instead orient their decisions vis-à-vis the support expressed by farmers and energy companies. One crucial qualification must be entered here however, given that not all the variables related to energy companies are significant. Notably, as we find that support without selling is not impactful, it would appear that it is the activity of selling GM bioenergy, rather than the expression of support, which is the driving factor for consumer support. Moreover, respondents tend to be more supportive if the trust in supply-chain actors is higher. As a final illustration of how information matters, there is also a strong (negative) effect of a lack of product labeling on overall support. Even controlling for all the above factors, it is therefore shown that the decision by policymakers not to label GM bioenergy could present an obstacle for cultivating the consumer support of such products.

Table 5. Log-odd ratios for fixed-effect estimates of consumer support.

Support ('Receptive')[a]	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
(Intercept)	-5.53 ***	-6.26 ***	-6.24 ***	-6.06 ***	-6.12 ***	-6.08 ***	-4.05 ***
	(0.60)	(0.65)	(0.65)	(0.65)	(0.66)	(0.71)	(1.09)
No labeling	-1.95 ***	-1.95 ***	-1.95 ***	-2.11 ***	-2.15 ***	-1.68 ***	-1.69 ***
	(0.13)	(0.13)	(0.13)	(0.15)	(0.15)	(0.24)	(0.24)
Farmers support[b] & grow	0.60 **	0.60 **	0.60 **	0.47 *	0.48 *	0.16	0.28
	(0.19)	(0.19)	(0.19)	(0.2)	(0.2)	(0.26)	(0.23)
Energy producers support & produce	0.14	0.14	0.14	0.15	0.16	0.24	0.18
	(0.22)	(0.21)	(0.22)	(0.22)	(0.22)	(0.23)	(0.23)
Energy producers support & produce imported	0.05	0.05	0.05	0.05	0.06	0.11	0.09
	(0.19)	(0.19)	(0.19)	(0.2)	(0.2)	(0.2)	(0.2)
Energy companies not support & but sell an promote domestic	3.44 ***	3.44 ***	3.44 ***	3.27 ***	3.30 ***	3.54 ***	3.72 ***
	(0.24)	(0.24)	(0.24)	(0.25)	(0.25)	(0.34)	(0.28)
Energy companies support & sell	3.21 ***	3.21 ***	3.21 ***	3.05 ***	3.08 ***	3.35 ***	3.49 ***
	(0.18)	(0.18)	(0.18)	(0.19)	(0.19)	(0.27)	(0.22)
Energy companies support & sell directly	2.85 ***	2.85 ***	2.85 ***	2.69 ***	2.72 ***	3.14 ***	3.21 ***
	(0.21)	(0.21)	(0.21)	(0.22)	(0.22)	(0.28)	(0.27)
Energy companies support but not able to provide	0.21	0.21	0.21	0.04	0.02	0.24	0.37
	(0.25)	(0.25)	(0.25)	(0.26)	(0.26)	(0.33)	(0.28)
Positive information	0.61	0.7	0.65	0.7	0.73	0.74	0.56
	(0.72)	(0.71)	(0.72)	(0.71)	(0.72)	(0.73)	(0.71)
Negative information	-2.63 ***	-2.73 ***	-2.67 ***	-2.74 ***	-2.76 ***	-2.80 ***	-2.86 ***
	(0.75)	(0.74)	(0.74)	(0.74)	(0.75)	(0.76)	(0.75)
Trust in SC-actors	2.84 ***	2.74 ***	2.81 ***	2.23 ***	2.22 ***	2.25 ***	2.11 ***
	(0.33)	(0.33)	(0.55)	(0.36)	(0.37)	(0.37)	(0.37)
Trust in scientists at universities and consumer organizations	-0.46	-0.42	-1.16 *	-0.42	-0.26	-0.25	-0.13
	(0.30)	(0.30)	(0.50)	(0.30)	(0.34)	(0.35)	(0.34)
Mood before experiment		1.66 **	1.54 **	1.67 **	1.69 **	1.73 **	1.48 **
		(0.54)	(0.54)	(0.54)	(0.54)	(0.55)	(0.55)
Positive information*Trust in SC-actors			0.03				
			(0.74)				
Positive information*Trust in scientists & cons. org.			1.64 *				
			(0.75)				
Negative information:Trust in SC-actors			-0.17				
			(0.77)				
Negative information*Trust in scientists & cons. org.			0.74				
			(0.77)				
Trust in SC-actors*no labeling				0.31 *	0.39 **	0.37 **	0.41 **
				(0.14)	(0.14)	(0.14)	(0.14)
Trust in SC-actors*Farmers support				0.30 *	0.29 *	0.31 *	0.32 *
				(0.13)	(0.13)	(0.13)	(0.13)
Trust in SC-actors*Energy producers support				0	-0.02	-0.02	-0.02
				(0.12)	(0.12)	(0.13)	(0.13)
Trust in SC-actors*Energy companies support				0.38 *	0.38 *	0.41 **	0.41 **
				(0.15)	(0.16)	(0.16)	(0.16)
Trust in scientists & cons. org.*Labeling					0.56 ***	0.52 ***	-0.52 ***
					(0.13)	(0.14)	(0.13)
Trust in scientists & cons. org.*Farmers support					0.09	0.09	0.08
					(0.13)	(0.13)	(0.13)
Trust in scientists & cons. org.*Energy producers support					0.14	0.15	0.15
					(0.12)	(0.12)	(0.12)
Trust in scientists & cons. org.*Energy companies support					-0.14	-0.19	-0.19
					(0.15)	(0.16)	(0.16)
No labeling*Farmers support						0.31	-0.31
						(0.24)	(0.24)
No Labeling*Energy companies support						-1.01 ***	-0.98 ***
						(0.26)	(0.26)
Farmers support*Energy companies reject						-0.26	-0.39
						(0.27)	(0.29)
Age							-0.4
							(0.29)
Female							1.91 ***
							(0.63)
Income							0.13
							(0.45)
Education							-0.69 *
							(0.28)
AIC	2875.48	2867.66	2870.28	2856.43	2841.44	2830.59	tbi
BIC	2970.40	2969.36	2999.09	2985.24	2997.37	3006.86	tbi
Num. obs.	6500	6500	6500	6500	6500	6500	tbi
Num. groups: Subjects	325	325	325	325	325	325	tbi
Var: Subjects (Intercept)	22.47	21.51	21.45	21.8	22.1	22.74	tbi
Log Likelihood	-1423.74	-1418.83	-1416.14	-1409.21	-1397.72	-1389.30	tbi
#Df	1	2	3	4	5	6	tbi
Df		1	4	0	4	3	tbi
χ 2		9.8228	5.3842	13.8500	22.9847	16.8493	16.0534
Pr(>χ 2)		0.0017 **	0.2501	< 0.001 ***	< 0.001 ***	0.0014 **	0.0030 **

* p < 0.05, ** p < 0.01, *** p < 0.001, ' p < 0.10

[a] Consumer choices more receptive to bioenergy from GM crops, i.e. categories 'Buy', 'Family', 'Domestic' and 'Motivate', were collated into 'Receptive'.

[b] Support in this table refers to the support of the FC scenario by bioenergy supply-chain actors.

Having explored the main effects, we next turn to the effect of the emotional factors, and specifically the moods of participants during the experiment (see Model 2). It was only one's mood before the experiment started, however, which had a significant influence on consumer support. In specific, we find that the more generally positive one's mood, the more likely s/he was to express support for use of GM bioenergy. All other coefficients remain robust when mood is added.

Accordingly, we then considered the various interactions to understand how the variables might potentially influence each other, focusing specifically on those between the type of information frame and the trust variables (Model 3). Among these, the only significant interaction is between the positive frame and trust in scientists and consumer organizations. The fact that this effect is positive specifically suggests that those people with higher trust are more likely to support GM bioenergy if given positive information. Nevertheless, use of LR tests finds that this set of interactions does not help to improve model fit, which is why we exclude them from subsequent models, and instead use Model 2 as the template for further models. Next, we include the range of interactions among the trust variables and the decisions of supply-chain actors. To simplify interpretation, we begin with the set of interactions with trust in supply-chain actors (Model 4) before turning to the set of interactions with trust in the actors external to the supply chain (Model 5). As a general note, the introduction of two-way interactions with external actors' decisions is rendered somewhat difficult by the number of options that are available to the various actors. Especially in the case of energy companies, it is possible to either not support, not support but sell, support and sell, or support and sell directly. To reduce model complexity and improve the interpretability of the interaction terms, we thus opted to collate the decision categories so that the choice for actors is now represented in the broader terms of support and rejection.

Among the four interactions considered in Model 4, we find three to be significant: i.e. interactions between trust in supply-chain actors and farmer support, the support of energy companies, and absence of a labeling scheme, all of which are positive. Regarding the first, the positive interaction indicates that support by farmers has a larger impact on consumer support among those individuals who have higher trust in supply-chain actors. Once we included all the relevant interactions (see Model 6), the main effect of farmer support is then insignificant. This suggests that the impact of farmers' decisions is better understood as moderating the influence of higher trust in supply-chain actors. Similar to the case for farmers, the positive interaction of trust and support of energy companies (in Models 4-6) underscores that the influence of energy-company decisions is even greater for those with higher trust. As a result, greater trust in supply-chain actors appears to have the potential to counteract the negative effect of there not being any labeling scheme. With regard to the interactions involving trust in external actors, we moreover find that the only significant (but negative) interaction corresponds to the absence of a labeling scheme. As was the case for the main effect (see Model 3), it thus appears that those individuals with higher trust in such actors are even less likely to offer any support for GM bioenergy when it is not labelled. Therefore, trust in scientists and consumer organizations would seem to have the potential to amplify the perceived lack of transparency that is created from such products not being labeled.

Next, we include the interactions among the decisions of the different supply-chain actors to explore whether such decisions can have a cascading effect along the supply chain (Model 6). In specific, we find a negative interaction between support of energy companies and failing to label GM bioenergy. As the main effect of energy-company support is positive, this indicates that lack of a labeling scheme has the potential to undermine the purported commitment of energy companies.

Finally, socio-demographic characteristics were included. Notably, we find female respondents to be more generally supportive of GE bioenergy, while the opposite is true of the more educated.

Table 6. Log-odd ratios for fixed-effect estimates of consumer rejection.

Rejection ('Outlaw')[a]	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
(Intercept)	1.95 *** (0.55)	2.71 *** (0.59)	2.69 *** (0.59)	2.64 *** (0.59)	2.68 *** (0.59)	3.02 *** (0.65)	0.06 (1.01)
No labeling	2.35 *** (0.12)	2.35 *** (0.12)	2.35 *** (0.12)	2.31 *** (0.13)	2.32 *** (0.13)	2.33 *** (0.21)	2.30 *** (0.13)
Farmers support[b] & grow	-0.32 (0.17)	-0.32 (0.17)	-0.32 (0.17)	-0.20 (0.18)	-0.21 (0.18)	-0.46 (0.25)	-0.21 (0.25)
Energy producers support & produce	0.07 (0.19)	0.07 (0.19)	0.07 (0.19)	0.06 (0.20)	0.08 (0.20)	0.15 (0.21)	0.15 (0.21)
Energy producers support & produce imported	-0.04 (0.17)	-0.04 (0.17)	-0.04 (0.17)	-0.04 (0.17)	-0.04 (0.17)	-0.01 (0.17)	-0.01 (0.17)
Energy companies not support & but sell an promote domestic	-0.32 (0.21)	-0.32 (0.21)	-0.32 (0.21)	-0.27 (0.21)	-0.28 (0.21)	-0.80 ** (0.30)	-0.28 (0.21)
Energy companies support & sell	-0.25 (0.14)	-0.25 (0.14)	-0.25 (0.14)	-0.20 (0.14)	-0.21 (0.14)	-0.62 ** (0.22)	-0.21 (0.14)
Energy companies support & sell directly	0.04 (0.18)	0.04 (0.18)	0.04 (0.18)	0.09 (0.18)	0.1 (0.19)	-0.16 (0.24)	0.1 (0.19)
Energy companies support but not able to provide	-0.39 (0.21)	-0.39 (0.21)	-0.39 (0.21)	-0.34 (0.21)	-0.34 (0.21)	-0.84 ** (0.29)	-0.34 (0.21)
Positive information	-0.67 (0.71)	-0.77 (0.69)	-0.78 (0.69)	-0.77 (0.69)	-0.81 (0.69)	-0.81 (0.69)	-0.52 (0.69)
Negative information	2.51 *** (0.72)	2.61 *** (0.71)	2.59 *** (0.71)	2.60 *** (0.71)	2.61 *** (0.71)	2.61 *** (0.71)	2.65 *** (0.71)
Trust in SC-actors	-2.90 *** (0.32)	-2.80 *** (0.32)	-3.15 *** (0.55)	-2.64 *** (0.33)	-2.64 *** (0.33)	-2.63 *** (0.34)	-2.46 *** (0.34)
Trust in scientists at universities and consumer organizations	0.67 * (0.30)	0.64 * (0.29)	1.28 ** (0.48)	0.65 * (0.29)	0.74 * (0.31)	0.73 * (0.31)	0.65 * (0.31)
Mood before experiment		-1.65 ** (0.51)	-1.51 ** (0.51)	-1.65 ** (0.51)	-1.65 ** (0.51)	-1.66 ** (0.52)	-1.42 ** (0.52)
Positive information*Trust in SC-actors			0.33 (0.72)				
Positive information*Trust in scientists & cons. org.			-1.24 (0.70)				
Negative information:Trust in SC-actors			0.68 (0.71)				
Negative information*Trust in scientists & cons. org.			-0.7 (0.73)				
Trust in SC-actors*no labeling				0.15 (0.13)	0.08 (0.13)	0.08 (0.13)	0.08 (0.13)
Trust in SC-actors*Farmers support				-0.36 ** (0.11)	-0.32 ** (0.12)	-0.33 ** (0.12)	-0.33 ** (0.12)
Trust in SC-actors*Energy producers support				0.01 (0.11)	0.05 (0.11)	0.05 (0.11)	0.05 (0.11)
Trust in SC-actors*Energy companies support				-0.15 (0.11)	-0.15 (0.12)	-0.16 (0.12)	-0.16 (0.12)
Trust in scientists & cons. org.*Labeling					-0.35 ** (0.13)	-0.35 ** (0.13)	-0.35 ** (0.13)
Trust in scientists & cons. org.*Farmers support					-0.20 (0.12)	-0.19 (0.12)	-0.19 (0.12)
Trust in scientists & cons. org.*Energy producers support					-0.25 * (0.11)	-0.25 * (0.11)	-0.25 * (0.11)
Trust in scientists & cons. org.*Energy companies support					-0.02 (0.11)	-0.01 (0.12)	-0.01 (0.12)
No labeling*Farmers support						-0.17 (0.22)	
No labeling*Energy companies support						0.14 (0.22)	
Farmers support*Energy companies reject						-0.58 * (0.24)	
Age							0.32 (0.27)
Female							-1.89 ** (0.59)
Income							0.4 (0.42)
Education							0.62 * (0.26)
AIC	3242.43	3233.89	3237.89	3230.22	3223.18	3222.55	tbi
BIC	3337.34	3335.58	3366.70	3359.03	3379.11	3398.81	tbi
Num. obs.	6500	6500	6500	6500	6500	6500	tbi
Num. groups: Subjects	325	325	325	325	325	325	tbi
Var: Subjects(Intercept)	20.96	20.11	20.05	20.22	20.20	20.33	tbi
Log Likelihood	-1607.21	-1601.95	-1599.94	-1596.11	-1588.59	-1585.27	tbi
#Df	1	2	3	4	5	6	tbi
Df		1	4	0	4	3	tbi
χ 2		10.5379	4.0050	7.6709	15.0321	6.6376	13.7761
Pr(>χ 2)		< 0.001 ***	0.4053	< 0.001 ***	0.0040 **	0.1013	< 0.001 ***

* p < 0.05, ** p < 0.01, *** p < 0.001

[a] Both 'Outlaw' and 'Disfavour' are coded as 'Outlaw'. '[b] Support in this table refers to the support of the FC scenario by bioenergy supply-chain actors.

4.4.2.2. Examining consumer rejection for GM bioenergy

Having explored determinants of consumer support, we shift our attention to what underlies the decision to reject (or not) use of GM crops for bioenergy. The first finding that can be observed from comparing Table 5 and Table 6 is that consumer support and consumer rejection represent two distinct types of decisions. As reflected by differences in the types of determinants found to matter for each, it would thus be incorrect to presume that rejection can be explained by assuming the inverse of support. Rather, even though some commonalities do exist, it is crucial to analyze the two as different types of decisions, which are moreover subject to different kinds of influences.

Following the same stepwise approach as for support, we identify a handful of the variables, notably 'no labeling', negative information frame, and trust in supply-chain actors, to be similarly significant for rejection – although in the opposite direction. As a result, we conclude that the absence of product labels increases rejection and reduces support, whereas provision of negative information about GM bioenergy would have the opposite effect. As was true for support, neither positive nor neutral information also proved to be significant. What is more, since the main effect of trust in supply-chain actors is negative, this indicates that those with higher trust are less likely to reject use of GE bioenergy. Overall, given the greater support and lower degree of rejection, these findings recognize those individuals with higher trust in supply-chain actors as a key potential target group for GM bioenergy. However, we also find that those with greater trust in external actors (i.e. scientists and consumer organizations) are more likely to reject the use of biotechnology.

Next, we turn to the influence of emotional factors (Model 2), where we find that participant mood at the beginning of the experiment has a negative effect on overall rejection. As such, we can expect that those who feel more positively, whatever the reason, are less likely to reject GM bioenergy, and vice versa. Again, this underscores the importance of looking deeply into all the different aspects that factor into individual decision-making, whether they are informational, emotional, etc. In addition, and just as with support, once we factor out the influence of mood, the size of the intercept increases. Neglect of the seemingly extraneous factors (e.g. mood) is therefore shown to create a biased estimate of the intercept.

To further explore the role of emotional factors, we then proceed to consider interactions between trust and the other variables. First, we looked at interactions between the two trust variables and the types of information frames (Model 3). However, not only was no such interaction significant but their inclusion resulted in a poorer model fit overall. For this reason, they are excluded from further steps of the analysis.[3] The next step was to explore the respective interactions between the two trust variables and the decisions of supply-chain actors, starting with those for trust in supply-chain actors (Model 4). We find only the (negative) interaction with farmer support to be significant however. Out of all the various actors, it is therefore only farmers who might decrease rejection among those with higher trust in supply-chain actors by lending their support. Given that this specific interaction is also found to further increase consumer support, it appears that farmers have a key role to play with individuals of this group.

Model 5 indicates that those individuals with higher trust in external actors are more likely to find the absence of labels to be problematic, indeed problematic enough to be more likely to reject GM bioenergy. In addition, given that this finding mirrors that for consumer support, this provides further evidence that decisions of this group are motivated by the absence of labeling schemes for biotech products. Finally, there is also a significant (negative) interaction of trust in external actors with the support of energy producers. Notably, this is the only occasion that support of energy producers is shown to matter throughout our analysis. Importantly perhaps, the fact that their support can decrease rejection for those with higher trust in external actors could present a strategy for communicating with this group, who recall tend to be generally rejecting of GM bioenergy. Along with the use of labeling schemes, the decisions of energy producers are in fact the only type of supply-chain actors which we find to have an influence on this group. None of the other significant (or non-significant) findings are affected by the inclusion of the two-way interactions.

Next, we tested a model with two-way interactions among the decisions of supply-chain actors. In specific, it turned out that a few of the main effects then became significant, all of which involved energy companies. Namely, the decisions to support and sell, to support and promote domestic products, to support but not sell were all found to reduce the likelihood of rejection.

Turning to Model 7, the results for socio-demographic characteristics indicate the opposite of those for support. Namely, while female respondents are less prone to rejection of GM bioenergy, higher educated individuals are more likely to reject.

4.4.3. ESM MANIPULATION CHECK

To examine the effect of information frame on mood, we assess individual mood before, during, and after the decision task. This thus serves as a kind of manipulation check where we observe how mood evolves over time.

[3] Recall that this was also the case for support decisions (see Table 5, Model 3).

Table 7: Mixed-effect multilevel regressions and likelihood-ratio tests.

	Model 1	Model 2	Model 3
(Intercept)	0.29 ***	0.62 ***	0.62 ***
	(0.02)	(0.05)	(0.06)
Positive		-0.10	-0.10
		(0.06)	(0.06)
Negative		-0.08	-0.07
		(0.06)	(0.06)
Time		-0.14 ***	-0.14 ***
		(0.02)	(0.02)
AIC	1471.38	1417.30	1423.12
BIC	1486.03	1446.59	1496.36
Num. obs.	975	975	975
Num. groups: id	325	325	325
Var: id (Intercept)	0.12	0.13	0.07
Var: Residual	0.18	0.16	0.14
Var: id Positive			0.04
Cov: id (Intercept) Positive			-0.06
Var: id.1 (Intercept)			0.06
Var: id.1 Negative			0.03
Cov: id.1 (Intercept) Negative			-0.03
Var: id.2 (Intercept)			0.08
Var: id.2 Time			0.02
Cov: id.2 (Intercept) Time			-0.04
Var: id.3 (Intercept)			0.03
ICC	0.40	0.45	0.33
Log Likelihood	-732.69	-702.65	-696.56
#Df	1	2	3
Df		3	9
χ 2		60.083	12.175
Pr(>χ 2)		p < 0.001 *	0.2036

* p < 0.05, ** p < 0.01, *** p < 0.001

Table 7 shows the mixed-effects multilevel regression estimates for Mood (effect coded: -1 = negative, 0 = both positive and negative, 1 = positive) in the three models: i.e. Model 1, which is the null model with a random intercept; Model 2, which has a random intercept and fixed effects for the information frames (Positive and Negative relative to Control) and a time index included to observe changes in mood during the experiment (Time: 0 = before the experiment, 1 = during, and 2 = after); and finally Model 3, which tests for a random slope and intercept in these coefficients. The intraclass correlation (ICC) values for the three models indicate that 40, 45 percent and 33 percent of the variance of Mood lies between persons for Models 1, 2, and 3, respectively – with the rest as the result of intra-individual differences. Higher ICC values also indicate higher inter-rater reliability (Hallgren, 2012) and, thus, more agreement between the three assessments of emotions. According to Ciccetthi (1994), a sensible ICC value cutoff-point is between 0.4 and 0.59. This suggests a multilevel model would be applicable for Models 1 and 2, but not Model 3. However, we find that the change in emotional state was not caused by the type of information frame but rather decreased over time. Since the likelihood-ratio tests indicate that Model 2 is preferred to Models 1 and 3, we ultimately conclude that information framing does not affect Mood. This supports our hypothesis that differences in decisions between the information-treatment groups result from the distinct valences of the information, and not reflecting changes in mood throughout the experiment.

4.5. Discussion

This study serves to elucidate how information-framing can influence consumer decision-making, taking aim at the specific case of GM bioenergy. Of course, there is no shortage of research into the determinants of decision-making, and this is especially true for biotechnology. Nevertheless, there are a host of shortcomings that limit the potential to draw implications from this research. For instance, insights related to how information provision influences acceptance of GM food, e.g. Frewer et al. (2016), cannot necessarily be applied to non-food applications like bioenergy (Verbeke, 2007). Furthermore, it is crucial to understand how information can be relevant for reasons other than its positive or negative valence. In this regard, we underscore that the effect of supply-chain actors has been generally neglected in the literature. To fill this gap, a precursor study has already explored the relationship between decisions of supply-chain actors, e.g. to support or reject the broader use of GE in food production, as well as the likelihood of consumer support (or rejection) (Pakseresht et al., 2017). Without also including those other factors that are likely to influence decision-making, it is not possible to draw broader implications about the importance of decisions of supply-chain actors. Accordingly, this study is unique on account of its emphasis on both the bioenergy end-use and the decisions of economic actors and, moreover, its ability to investigate and distinguish between three major determinants of consumer decision-making at the same time (i.e. information, emotion, and upstream decisions).

A key determinant for consumer acceptance is the formulation of scientific information regarding the relevant technology, the related product applications, and the risks and benefits with which they are associated. Investigating the effects of positive and negative information messages and how they are processed by individuals can offer valuable insights in consumer acceptance. In this regard, we specifically identified effects from information framing, decisions of other supply-chain actors, and trust with regard to consumer decision-making for bioenergy from GM crops. Most prominently, information frames were found to affect support and rejection, though only if the information was negatively framed, which corroborates the findings of Terpstra et al. (2014). Accordingly, we only partly accept H1 since decision-making on GM bioenergy is not influenced by positive messages to consumers. In fact, there is no difference between provision of positive and balanced messages, i.e. presenting both the risks and benefits, which suggests a potential intervention to increase support or decrease rejection by only promoting benefits is unlikely to be effective. However, consumer decisions are likely to be impacted when information is framed negatively, which is in line with the broad attitude of *better safe than sorry* as expressed for both societal perceptions of GM food (Nelson, 2001) and the precautionary principle in the EU legislation for GMOs. Even though bioenergy production is well-regarded by society in general, and despite the potential risks for land-use conflicts and resource allocation, the use of GE tends to raise skepticism if the information is framed negatively. The decision to use a balanced risk message is in so far always preferable to positive and negative framing because it involves recipients and communicators at the same level. Suggestive framing in either direction implies that the communicator does not think that the recipient is sufficiently qualified for making own decisions. Manipulation can lead to loss of control, involvement, and finally trust (Arnstein, 1969). This implies that the potential commercialization of GE bioenergy would benefit from avoiding either positive or negative frames, and instead make use of balanced messages about risk and benefits. Even if consumers tend to rely on and place trust in supply-chain actors, scientists and consumer organizations, a balanced message of the merits and demerits of GE is likely to be more transparent and more credible.

Source of information is another major factor for decision-making. This study specifically explored how the decisions of other supply-chain actors can explain consumer support, but not rejection, of GM bioenergy. This finding is partly in line with Pakseresht et al. (2017). Therefore, while H2 can be accepted for consumer support, it must be rejected for rejection. In specific, we find that energy companies tend to be more influential for consumer decision-making than producers or farmers, perhaps because they are perceived to be more crucial in the (bio)energy supply chain. Interestingly, when firms gave support to the selling of bioenergy, this not only had a positive influence on consumer support but also decreased rejection. Thus, consumers orient their decision toward whether a company's support for a product is expressed in a tangible form, such that they actually 'put their money where the mouth is'. This implies that an actor's decision to not support bioenergy commercialization has the potential to reinforce existing consumer concerns about this technology. Moreover, the positive impact of energy-company support on consumer support is even higher if products are subject to mandatory labeling. Contrary to complaints on the part of industry, labeling schemes could therefore represent an important tool for cultivating trust and promoting the commercialization of GE bioenergy alongside, and in tandem, with the upstream support of supply-chain actors.

However, the introduction of GE bioenergy is also a potentially risky proposition for the industry, especially if consumers are expected to reject the final product. This could however be a misconception, given that trust in supply-chain actors and the presence of labeling are shown to increase consumer support and reduce rejection. Accordingly, we characterize trust and labeling as different types of support-building mechanisms, which could even complement one another. Indeed, if such a complementary relationship exists, this would further undercut the broader opposition of industry actors toward labeling schemes, whether on the basis of higher expected costs or a perceived negative impact on consumer support. Furthermore, while the level of trust in supply-chain actors was found to increase support and reduce rejection, trust in scientists at universities and consumer organizations was found to have no effect on support. Instead, insofar as it had an effect, such trust tended to work in the opposite direction by fueling rejection. Hence, we partly accept H4a, i.e. for trust in supply-chain actors, but must reject it for trust in scientists and consumer organizations.

Regarding the various interactions of trust with information frames, we find no evidence to support H4b, irrespective of which factor is considered. As such, we conclude that the impact of information frames and trust are independent from each other. Conversely, those interactions between trust in supply-chain actors and the expressions of upstream support are found to be highly relevant. In this regard, higher trust seems to amplify the impact of energy-company support. Similarly, we find that farmer support can increase consumer support and attenuate rejection whenever greater trust is lodged with supply-chain actors. Hence, H4c cannot be fully accepted. Even though higher trust in supply-chain actors does increase the influence of levels of upstream support by farmers on consumer decision-making, this is only partly the case for energy companies – and not at all true for energy producers. In sum, the nature of the interaction between trust and upstream support differs depending on the actor's position in the supply chain. However, what is generally interesting is that higher trust in the supply chain seems to (partly) compensate for the absence of labeling. This, in turn, suggests that labeling could itself be of further benefit in such cases, and especially among those groups where trust in supply-chain actors is generally low.

Finally, this study does not support the presumption that emotions affect decision-making processes for the support or rejection of bioenergy from GM crops (reject H3). Mood was not affected by information framing, which suggests that consumers were not misled by emotional aspects during the decision-making process. However, it seems that mood is mostly relevant before information is provided, that is, only until the cognitive process 'kicks in'. This is remarkable for a couple of reasons, most notably because this suggests that, even after controlling for a range of informational factors, people are likely to express higher support simply because they feel generally better at a given moment. Thus, emotions before the experiment affected consumer decision-making such that positive feelings were conducive to support and attenuating rejection. Similarly, Forgas (2002) claims that mood (i.e. affective state) compromises complex decision-making and must therefore be taken into account. Whereas much of the literature tends to highlight the role of attitudes, this study seems to lend credence to the idea of behavior as an expression of enduring (cognitive) preferences.

Presented in this manner, such behavior is therefore susceptible to the in situ context of decision-making (Ariely and Norton, 2008). In this regard, the 'risk-as-feelings' literature has suggested that visceral factors such as mood and feelings are insufficiently considered when assessing the effect of information framing on consumer decision-making. In our case, we however find only muted support for the broader influence of moods and emotions. Although mood decreased after the start of the experiment across all information-treatment groups, this change ended up not being relevant for explaining consumer choice. Instead, a direct effect of mood before the experiment was observed for consumer decision-making, which moreover had an influence for not only support but also rejection. As such, this speaks to the existence of a stream of affective processing that works in parallel to that of cognitive processes. Both processes must therefore be recognized as part of the decision-making process, and jointly positioned as the focus of future research into risk perceptions and technology acceptance.

Interestingly, we find that higher trust in scientists and consumer organizations did improve the effects of labeling. A possible explanation is that, since labels are evaluated and controlled by external actors, consumers are likely to feel more assured if the content of labels is also confirmed by actors that are supposed to have no commercial interest. Taken together, one could thus modify 'H2' for future research to reflect how upstream support is likely to increase consumer support (and decrease rejection) insofar as supply-chain and external actors are trusted.

4.6. Conclusion

Acceptance of novel technologies is crucial for both the further diffusion of these innovations and their ability to play a facilitating role for sustainable development. We show that negative framing, that is, how the technology is sometimes conveyed, for instance, in the popular media, can reduce support and increase rejection. Nonetheless, it cannot be concluded that a more positive framing will necessarily enhance support and accordingly, one way forward may be to promote more balanced information. Moreover, this study has established how emotional factors feature in the decision-making process for GM bioenergy. Namely, consumers are generally susceptible to the vagaries of their mood, and yet this does not mean that they are closed off to new information which would enable them to make more informed decisions. In this regard, it is not only level of trust in supply-chain and external actors that matters, given how consumers also make use of labeling schemes and any expressions of upstream support in order to inform their decisions.

As Bredahl et al. (1998) observe, the goal should thus be to allow consumers to make an informed choice, rather than convincing them of whether the technology is or is not beneficial for society. This begs the question of how best to facilitate the ability of consumers to make such choices, especially amidst some concern over the general trustworthiness of industry actors. Maybe the prominence of such doubts is a matter of perspective, however, given that the decisions of supply-chain actors is a crucial determinant of the overall support (or rejection) of novel technologies. As such, this paper suggests that consumers might use different types of cues for making decisions than those that are typically considered. If we were to ignore the influence of upstream support, we then run the risk of misunderstanding the importance of supply-chain actors for decision-making processes, not to mention how exactly an individual comes to a decision. Greater appreciation of the types of cues that are relevant moreover presents new opportunities for helping individuals to make more informed decisions. In this regard, one implication of the importance of upstream support for consumer decisions relates to the value of product labels. Notably, industry would be well-advised to make use of any trust-forming mechanisms available to it. In the first place, this can be achieved by the provision of balanced, complete, and transparent information about risks and benefits (Wegwarth et al., 2014). Given the potential complementary relationship between labeling schemes and upstream support, this study moreover proposes that mandatory labeling also seems to have an important role to play alongside expressions of support from supply-chain actors.

5. Discussion and conclusion

Principal research question of the thesis:

To what extent does the practical context determine the level of public acceptance of green biotechnology?

This chapter aims to provide an answer to the principal research question of the thesis and to discuss the practical implications for this research as a whole. Thus, Section 5.1 discusses the contributions from the empirical work of the previous chapters against the respective backdrops of the pertinent research questions. Section 5.2 explicates the theoretical and methodological contribution of the thesis in relation to the principal research question and with regard to the broader relevance of the public understanding and acceptance of biotechnology for a sustainable bioeconomy. In Section 5.3 practical implications are discussed. Section 5.4 discusses the thesis' limitations and directions for future research, before Section 5.5 concludes with some final remarks on the outlook.

5.1. Distinct contributions to our knowledge about consumer acceptance by empirical study

The overall aim of the thesis was to better understand public perceptions of biotechnology and how the practical context relates to consumer acceptance. The importance of risk perceptions in order to understand consumer acceptance suggests the need to look further into the dimensions of risk and how they are perceived against the practical context which has been done in Chapter 2 and 3. Risk perception thus serves a key antecedent of consumer acceptance and, as such, a crucial determinant of consumer support or rejection. As discussed in Chapter 4, while the decision-making process is generally informed by risk perception, ultimate support or rejection still depends on how risks are communicated to consumers. Moreover, the influence of information communication is dependent on other factors such as the trust in the source of information. As such responsibility for communicating risk messages about credence goods is usually assigned to experts such as policymakers, scientists, and the industry. The stances of these actors are therefore likely to also affect consumer decision-making. As a result, a deeper knowledge of how these factors affect consumer support or rejection can help improve our understanding of consumer acceptance of novel technologies more generally. This section will present key findings from the respective empirical studies and highlight their specific contributions and insights to the prevailing narrative about biotech acceptance, namely that the technology is generally rejected irrespective of the circumstances and that greater risk perception generally results in lower acceptance.

5.1.1. Consumer acceptance and risk perception

Some specific gaps in the current research on consumer acceptance of biotechnology were targeted by the following research questions as presented in Chapter 2:

RQ1.1: Are consumers more likely to accept green biotechnology used for the purpose of bioenergy production, i.e. compared to food production?

RQ1.2: Does consumer acceptance of biotechnology differ based on the overarching policy regime?

RQ1.3: Does risk perception differ across risk dimensions?

RQ1.4: What is the most important determinant of consumer risk perception?

Focusing on the most controversial application of biotechnology, namely GM food, has the potential to be misleading when talking about consumer acceptance of this technology more generally. While applications to food are mostly rejected in Germany and other major grain producers within the EU (Gaskell et al., 2010), acceptance is however likely to be higher for applications such as bioenergy (Verbeke, 2007). Indeed, results suggest that acceptance for the purpose of bioenergy production is typically higher, i.e. as associated risks are lower, which concurs with prior findings that non-foods are more acceptable than foods (e.g. Christoph et al., 2008). Moreover, the transition towards a bioeconomy that is less dependent on fossil-based products sparks the need for alternative sources of energy production, of which biorenewables will remain a major contributor until (at least) 2030 (IRENA, 2014). However, more technology-based innovation is currently needed to make bioenergy competitive vis-à-vis fossil-based versions (Davison et al., 2015). Crucially, this thesis provides first evidence on consumer perceptions of using biotechnology for the purpose of bioenergy production. Another advantage vis-à-vis previous research is that the specific end-use was investigated instead of just the broad area of application, i.e. “non-food”. Hence, it can be illustrated, e.g., how health risks are of great concern to consumers of GM food, whereas socioeconomic risks play a major role for use of biotechnology in bioenergy production. In both cases, environmental risks are of pivotal concern to consumers. These findings suggest that the use of biotechnology is not merely evaluated at the technology level, which would suggest that consumers would generally reject biotechnology. Instead, it is typically evaluated at the product level, which has important policy implications. Biotechnology might therefore find more public acceptance if it is related to a specific end-use which consumers are generally optimistic about such as bioenergy.

In this respect, the first study (Chapter 2) indicates that the policy regime plays the most important role for technology perceptions. So far, there is a lack of research on the influence of policy regime on public perception. As such, the positive relationship between a policy that permits full commercialization and high levels of acceptance in the related countries lent support to the belief that these factors are correlated (Gaskell et al., 2010). Evidence from this study thus reiterates this finding, while also doing so for Germany. Respondents therefore perceive R&D efforts for biotechnology as less risky when compared to the full commercialization. Similar to the end-use context, this suggests that the policy context affects consumer acceptance of biotechnology, as well. These findings suggest that the public is not generally rejective of green biotechnology, but rather differentiates with respect to the practical context. A complete ban of biotechnology for all end-uses and the restrictions for R&D-funding might not be an appropriate legislative response on public concerns. The underlying reasons for the varying perceptions in this regard are subject to further analysis in Chapter 3 when the interrelationships between perceived risk, self-control, and personal risk responsibility are investigated against the backdrop of the practical context.

With respect to the risk dimensions, prior research suggested that health risks would play the most important role to consumers of GM food (Martinez-Poveda et al., 2009). The results from Chapter 2 however show that an array of German consumers is also concerned about health risks, though the degree of concern is the greatest for environmental risks. The main advantage over prior research, however, is that risk was measured for all relevant dimensions simultaneously, thus allowing for direct comparison of various types (environmental, health, socioeconomic, ethical) both irrespective and regarding product end-use and policy regime.

After policy regime, the next-most important determinants of risk perceptions of green GE are risk dimensions and trust in industry, followed by the age of respondents. Extant research has discussed the direction and size of effects of (most of) these factors for consumer risk perceptions (e.g. Flynn et al., 1994). This study is the first, however, which is able to provide a ranking of these factors with regard to their importance. Given that the statistical importance is unable to provide much insight into the interrelationships between these factors, the aim of the following study is therefore to shed light on the interplay between key determinants of consumer acceptance and the practical context.

The lack of understanding the interplay between major determinants of consumer acceptance and the practical context gave reason to investigate in Chapter 3 the following research question more closely:

RQ2: How are the major determinants of biotechnology acceptance interconnected and related to the practical context?

Prior research mostly documented bivariate correlations or multivariable relationships between perceived risk, self-control, and personal risk responsibility (e.g. Leikas et al., 2009) which has not provided insights into the interrelationships between the key determinants of consumer acceptance of biotechnology. The use of multivariate serial multiple-mediator analysis with interaction terms could thus identify the underlying relationships between these variables and how they were affected by product end-use, policy regime, risk dimensions, and individual factors. Hence, the main insight from this study is how these interrelationships are directly affected by the practical context. Risk dimensions and trust were both identified as important determinants of the variables, and with effects in line with prior research (e.g. Siegrist, 2000). The established relationships between perceived risk, self-control, and personal risk responsibility were also generally consistent with findings in the literature (Walster, 1966; Frewer et al., 1994; Redmond and Griffith, 2004; Leikas et al., 2009). As a result it is shown, in contrast to the prevailing narrative, that acceptance can increase, in spite of higher risk perceptions, if individuals feel more capable of controlling these risks. Therefore, one broad strategy for promoting consumer acceptance would be to increase consumer perceptions about their capability of exercising control, which has strong implications for risk communication strategies. Thus, consumer support is not merely about whether perceived risks are as low as possible but rather it depends on the risk management and communication. Consumers accept higher risks if they feel that they can personally control for the risks, i.e. by taking measures to reduce or prevent their exposure to this risk. This, however, requires that there is no information asymmetry between producers and consumers which emphasizes the importance of risk communication through, e.g., labels and trust in supply-chain actors. To better understand how information can affect consumer acceptance in this regard, the empirical study in Chapter 4 investigated the influence the framing of risk messages as well as the role of trust in the industry actors and their decisions to support or reject biotechnology. Accordingly, the results are presented in the following section.

5.1.2. CONSUMER ACCEPTANCE AND DECISION-MAKING

Decision-making can be seen to be generally informed by consumer risk perceptions and the broader practical context as discussed in Chapter 2 and 3. As such, risk communication is broadly useful for consumer decisions about supporting or not supporting GM food as consumers have to rely on the information about such credence goods. As a result, individuals will therefore orient their decisions towards information they receive or seek. In this respect, the decisions of supply-chain stakeholders such as policymakers and industry actors play an important role also in relation to how they are trusted by the consumers. Moreover, there is also evidence to suggest that practical decision-making involves emotional aspects, but research in these domains is generally scarce. Moreover, little is known about the informational effect on consumer support and rejection with respect to GE bioenergy. The following research questions, as discussed in Chapter 4, were therefore aimed to close these gaps:

RQ3.1: Does information framing affect consumer decision-making with regard to the use of biotechnology for bioenergy production?

RQ3.2.1: To what extent are consumer decisions dependent on the stances of supply-chain actors?

RQ3.2.2: Does trust in supply-chain actors have the potential to increase levels of upstream support or rejection?

RQ3.3: Do positive and negative information frames evoke an emotional response consonant to the valence of the framing?

The contribution of this study is thus threefold. First, the framing-effect was found to also exist for the bioenergy end-use. In contrast to GM food (Lusk et al., 2004), positive framing did not however affect consumer decision-making compared to use of balanced (risk and benefit) messages. Negative valence of the risk message was however shown to cause changes in consumer choices to support or reject biotechnology for bioenergy production, which corroborates findings in risk research for the non-food domain (Terpstra et al., 2014). Second, the impact of stances of the supply-chain actors on consumer decision-making has been neglected in past research. The results show that upstream decisions and underlying stances toward biotechnology play a major role for commercialization of GM bioenergy. Moreover, trust in responsible supply-chain stakeholders such as energy companies increases the effects of upstream decisions on support and rejection. In addition, labeling seems to work as a trust-enhancing mechanism, with major impact on consumer decisions. Notably, trust and labeling complement each other as they can account for their mutual absence such that, in terms of consumer support, e.g., low trust in industry actors can be compensated with mandatory labeling. Third, the findings suggest that, despite evidence for emotional aspects of practical decision-making (Roeser, 2012), cognitive processes are primarily utilized for decisions with regard to biotechnology in bioenergy production. One reason could be that risk and benefits are rather intangible to respondents, and thus evaluated via their long-term consequences (cognitive process) rather than product-liking (affective process) (Bredahl et al., 1998).

5.2. Main conclusion

The aim of this section is to provide an answer to the overarching research question by evaluating the theoretical and methodological contributions of the empirical studies with respect to the current narrative on consumer acceptance of biotechnology. As such, consumer acceptance is a prerequisite for market adoption of innovative technologies. For the case of biotechnology, consumer uncertainty about the merits and demerits of this technology is high and as a consequence German regulatory bodies decided to opt-out from the EU-wide approval for certain GMOs, and policymakers decided to restrict R&D spending. However, there is no evidence to suggest that this response is wanted by the public because research into the more practical context and features of consumer acceptance is scarce. The principal research question of this thesis was therefore:

To what extent does the practical context determine the level of public acceptance of green biotechnology?

The thesis used an integrated approach combining the theoretical model on consumer perception with the practical context. As such, consumer decision-making in the domain of biotechnology can be seen to be informed by perceived risks, more generally. The behavioral model thus investigated the interrelationship between risk perception and the closely related factors self-control and risk responsibility to better understand the underlying mechanism of consumer decision-making. The practical context entailed the contextual factors end-use, policy regime, and information framing which have an external effect on consumer perception as well as the existing socioeconomic environment where consumer decision-making takes place, namely consumers' interdependent decision-making in relation to the stances of relevant supply-chain actors. In addition, key individual factors and interaction effects with the key determinants of acceptance were included to control for individual differences in respondents' perceptions.

5.2.1. THEORETICAL CONTRIBUTION

The objective of this thesis was providing insight into the impact of the practical context on consumer acceptance. In this regard, the practical context has been identified as a plausible explanation for the heterogeneous consumer perception of biotechnology. The practical context referred to the main contextual factors that are relevant for consumer acceptance of biotechnology, i.e. product end-use, policy regime, and information framing, and consumer decision-making with respect to upstream acceptance. The analysis in Chapter 2 showed that in specific, product-related differences in consumer perceptions suggest that biotechnology is not generally rejected, but rather that this rejection depends on the product end-use. Given the importance of product end-use, the reasons that individuals do or do not accept might be more at the product than technological level. Supported by the fact that policy regime was identified as the most important factor of risk perceptions, moreover, it can be concluded that regulation specified at the technological level, i.e. by prohibiting all applications of biotechnology, is thus not the appropriate response to public concerns. Instead, potential commercialization strategies would benefit from a more product-oriented approach making decisions related to market adoption more dependent on specific consumer concerns. Communication strategies from science to public must therefore be reconsidered.

Considering that the key determinants of consumer acceptance are interrelated and susceptible to the practical context, Chapter 3 also provided further insights into the underlying mechanisms of acceptance. The analysis revealed that the higher the perceived risks, the less that consumers tended to accept biotechnology, signaling that a) consumers generally prefer both the use of GM crops for bioenergy purposes versus food and promotion of R&D-only versus full commercialization and b) that risk and acceptance tend to be inversely related to one another. In contrast to the prevailing narrative, one important exception to the last finding is that consumers do take more risk, and are more accepting, if risks are perceived to be personally controllable. The full commercialization of GM food – which has also been contemplated as the Achilles' heel of biotechnology acceptance – is therefore not generally rejected by German consumers but rather depends on the extent to which the individual feels capable of exercising control over, or the ability to cope with, the associated risks. This opens the door for a broad public debate about the necessity of biotechnology and the associated risks and benefits at both the national and global levels.

Risk communication from science to public (or "experts" to "lay" persons) requires a strategy tailored to the target audience. In contrast, current strategies for risk communication have not typically led to higher consumer acceptance, but rather fueled public uncertainty. As a result, the most effective way to promote acceptance, according to this thesis, is to increase perceptions of self-control. One approach in this regard is to provide consumers with information that is traceable and transparent through, for instance, labeling. Chapter 4 shows that the communication of risk messages about GM bioenergy requires balanced information that focuses on both the environmental and socioeconomic risks and benefits. Positive framing, in contrast, resulted in equal levels of support and rejection, while negative framing fueled rejection, clarifying the role of negative media coverage or negatively biased information campaigns. One common way to communicate product information is via labeling. In this regard, the results demonstrated that there is a positive effect of labeling on consumer support, in addition to that of upstream decisions in the supply chain. This therefore represents a potential challenge to industry resistance to label GM products, whether for reasons of cost-efficiency or a perceived harm to product perceptions. Of course, labeling is costly, but given that it is an effective way to promote consumers' perceptions of self-control, i.e. if production is traceable across the supply-chain from the development to raw materials to the final end-use, this would seem to dispel these concerns. Moreover, the fact that, after controlling for a range of supply-chain-related factors, the absence of a label increased likelihood of rejection (and diminished support) would seem to put pay to the idea that they are harmful to consumer trust. On a further note, higher trust in scientists at universities and consumer organizations can boost this labeling effect even more, highlighting how labeling intersects with a host of other factors. Independently, trust in the supply-chain actors related to energy production also affects consumer support and rejection. Thus, if energy companies are seen to be trustworthy, consumer support for GM bioenergy increased accordingly, whereas lower trust resulted in greater rejection. Moreover, even mere industry support affected consumer perceptions in the study. Higher levels of industry compliance thus increased consumer support and, conversely, more limited support by industry stakeholders induced higher consumer rejection. This effect is moreover amplified by both the labeling effect and levels of trust in industry which can therefore be seen as a type of support-building mechanisms. Notably, these factors are complementary for each other meaning that, in sum, they are mutually reinforcing and replaceable. Finally, the presumption that support and rejection tend to be inversely related to one another is partly supported by comparing effects on these two measures as dependent variables. Interestingly, however, there is no perfect inverse correlation between support and rejection suggesting, in this context, different underlying processes and determinants shaping those perceptions.

In response to the principal research question, it can be concluded that the practical context is crucial for assessing biotechnology acceptance. Not only the abandonment of R&D spending on biotechnology, but also putting greater emphasis on process-related instead of product-related regulation might be the wrong response on concerns of consumers. Section 5.3 is thus supposed to offer some practical recommendations for policy and industry that can help to orient the public debate about the need of biotechnology and how associated risks can be controlled by consumers.

5.2.2. Methodological contribution

By looking more closely at differences in not only the actual end-use of biotechnology applications but also the policy scenarios and relevant risk dimensions, this thesis was able to identify factors that can explain, and therefore facilitate the reduction of, the degree of variability in perceived risk. This feature has not been captured in previous studies. In specific, the use of a total of 16 subgroups in the samples for the empirical studies presented in Chapter 2 and 3 was able to decrease the standard deviation from the median levels of risk perception for each group, and leading to improved, less-biased estimation results overall. In this manner, the approach thereby adds further support to the findings of a recent meta-analysis on risk and benefit perceptions of biotechnology conducted by Bearth and Siegrist (2016), who emphasized that greater focus should be put on the (latent) factors causing variability in perceived risk.

Most research has focused on certain aspects of risk, e.g. health and environmental consequences (Bawa and Anilakumar, 2013). However, other aspects have also been shown to be relevant in the eyes of consumers, i.e. socioeconomic and ethical risks. Therefore, this thesis attempted to assess risk in a more comprehensive way by including risk statements for all of these four dimensions. Toward this end, risk statements used in Chapter 2 and 3 were deduced from the scientific literature based on evidence for actual (not perceived) risks. In specific, food-risk statements are developed from Hess et al. (2016). Accordingly, risk perception was assessed using a formative measure which is – by definition - not affected by measurements error, in contrast to the reflective scales that are commonly applied. Of course, in practice this is not necessarily the case but a validity check that was performed with the respondents suggests high validity of this comprehensive approach. As a result, the risk measurement in this thesis better assesses the actual and unbiased level of risk perception among individuals that exists.

Furthermore, the risk measure used in Chapter 2 and 3 was adapted from Rayner and Cantor (1987), who measured risk by means of likelihood of occurrence and severity of consequences. The amendment that was introduced to this measure assessed whether consumers agreed with the risk statements. Thus, statements only entered into the risk calculation if consumers agreed that the risk existed and was important for them. Accordingly, levels of agreements were used as weights, whereby it became possible to perform an implicit validity-check of science-based evidence for risk vis-à-vis consumer perceptions. Higher levels of agreement, meanwhile, can be seen to indicate greater overlap between the objective evidence of risk and consumer perceptions of risk. Agreement on the part of consumers is also therefore useful as a test of the validity of the risk measure.

Few studies have made use of a multivariate regression to identify interrelationships of behavioral variables (e.g. Costa-Font and Gil, 2009). Even among these few, however, none have considered the importance of the practical context. In this regard, the main advantage of serial multiple-mediator analysis, as presented in Chapter 3, is the resulting potential to explore and integrate interaction effects with product end-use, i.e., as so-called moderated mediations. As Preacher et al. (2007), p. 193, explain, “moderated mediation occurs when the strength of an indirect effect depends on the level of some variable, or in other words, when mediation relations are contingent on the level of a moderator”. In the context of this thesis, the ability to explore such effects allows to draw conclusions about “when” effects occur, i.e. when the product end-use is introduced. Moreover, the significance of these effects can be assessed using an index of moderated mediation that quantifies the association between the indirect effect (of policy regime on personal risk responsibility) and its moderator (end-use) (Hayes, 2015).

Finally, the introduction of interdependent consumer decisions in Chapter 4 to explore support and rejection of biotechnology in bioenergy production is novel, not only in terms of the application context, but also given how it relates consumer decision-making to stances of supply-chain stakeholders regarding support or rejection. Influence of opinion leaders has already been described by Sapp and Korsching (2004) for consumer acceptance of food irradiation and Pakseresht et al. (2017) for GM food. However, this thesis offers the first evidence for the biotechnology domain, and with regard to bioenergy end-use in Germany. Key interactions with levels of trust for various actors also suggest the importance of controlling for consumer confidence in stakeholders in future research, both in general and specifically when assessing the influence of upstream decisions on consumer decision-making.

5.3. Practical implications

The main global challenges that we face are food security, depletion of natural resources, climate change, and loss in biodiversity, all of which are exacerbated by expected growth in population up to 9 billion in 2050 (UN, 2015). Transition towards a more sustainable bioeconomy in Germany, and the EU more generally, therefore aims to tackle the sustainable development goals (SDGs) at a range of levels, many of which require more product and process innovations (European Commission, 2012; UN, 2015). Next to population growth, the change in consumption patterns in countries with a growing middle class, like China or Brazil, will also demand more food and energy supplies (Hoorens et al., 2013). For Europe, another challenge is to maintain jobs and remain competitive against the emerging economies that can offer cheaper products due to relatively low wages. Exploiting the benefits of innovative technologies can thus contribute to meeting those global challenges while maintaining European competitiveness. Biotechnology is one example of a technological innovation that could contribute to addressing such societal challenges, i.e. by improving the production of bioenergy (Davison et al., 2015). For this to be possible, however, it is necessary for the public to accept this technology. Nevertheless, public acceptance of biotechnology is generally low in Europe compared to North America (Zilberman et al., 2013). It should be noted, however, that the level of acceptance across EU member states is quite heterogeneous (Gaskell et al., 2010), leaving some uncertainty about the potential reasons.

Global demand for bioenergy is projected to grow considerably during the next decades, especially in the transportation sector (IRENA, 2014). Against the backdrop of the EU's emissions-reduction targets, and the specific requirement that 20 percent of final energy consumption (next to a 10 percent blending target for transport biofuels) must be from renewable sources by 2020, the high priority assigned to bioenergy production can be observed. Though bioenergy production is often argued to conflict with the *food first* principle of sustainable development, it is still widely accepted by the European public (Gaskell et al., 2010). Conversely, consumer acceptance of biotechnology is low, even if it has the potential to enhance bioenergy production by facilitating improvements in crop characteristics or production processes. Such innovations are therefore highlighted as a potential solution for land-use problems and to alleviate other conflicts (Lenk et al., 2007; Gamborg et al., 2012). Moreover, the existence of such conflicts is central to the subject and focus of both principles for resource allocation (SCAR, 2015) and legislative binding targets. Thus, the EU Renewable Energy Directive (RED) II for the period 2021-2030 seeks to reduce conventional biofuels and gradually increase the support for advanced (non-food-based) options. High requirements in advanced biofuel production thus make technological innovation at the level of biomass production and processing even more important for ensuring that biorenewables can keep up with increasing demand.

The potential of biotechnology, especially with regard to novel techniques such as genome editing, is also extremely high and will likely replace less-efficient and controllable methods of plant breeding, such as irradiation. First-generation (sugar- and oil-based) and second-generation (lignocellulosic- and residue-based) biofuel production is growing in Europe and would benefit from innovations improving, e.g.: the efficiency of raw materials (e.g. feedstock resistance to environmental stresses), logistical processes vis-à-vis land and water use (e.g. biomass stability to accommodate storage and water requirements), and processing (e.g. conversion technologies for residues) (Davison et al., 2015). Within the USDA's (2017), p. 3, annual report on EU biofuel production, it is noted that, given the higher "maximum blending rates for conventional and minimum blending rates for advanced biofuels in the RED II, the consumption of advanced biofuels must increase significantly from 2020", that is, even as biofuels production has increased by a magnitude of billions of liters. Consumer opposition to biotechnology (even if often for good reasons) is therefore in conflict with the efforts for a more sustainable bioeconomy, at least those undertaken in this direction.

If the argumentation of Dunwell (2014), p. 120, holds, i.e. that France, Poland, and Germany are "conflicted" countries with scientists, farmers, and industry supporting biotechnology and the governmental sector and public rejecting it, it is, moreover, probable that these results might even be applicable to France and Poland, which together with Germany accounted for 80 percent of total mixed grain production in the EU-28 in 2016 (USDA, 2016). As such, these countries would also qualify as major grain producers, possibly suggesting a wider impact of the thesis' implications at European Union level. If these "conflicted" countries must reconcile the diverging views of different stakeholder groups – i.e., on the one side, scientists, farmers, and the feed industry who are willing to adopt and, on the other, consumers and government officials in opposition – we can expect similar developments, such as decreased support and investment in biotech R&D, to put pressure on the EU's long-term, global competitiveness.

Accordingly, this chapter is used to discuss the practical implications for risk communication strategies and policy against the backdrop of the grand societal challenges, and specially the potential of biotechnology to contribute to achieving the related SDGs as described further above. On the basis of the results of this thesis, some further recommendations are offered for decision-makers.

5.3.1. Implications for policy

As indicated by the results from Chapter 2, the susceptibility of consumer acceptance to product characteristics and the specific policy context has important policy implications. Due to recent amendments to the EU Directives on the deliberate release and contained use of GMOs, Germany decided to opt-out from the GM maize variety MON-810, which is approved for cultivation within EU borders. As a result, this makes it less profitable, according to some actors, to engage in technological innovation in this direction which is suboptimal from an economic-growth perspective. Faria and Wieck (2015) provide empirical evidence of a negative impact of the asynchronous approval of GMO events on trade flows of cotton, maize and soybeans. Moreover, GMOs are also argued to be subject to higher burden of proof for derived products than, for example, food flavorings (Garnett and Parsons, 2017). Oftentimes, the brunt of this criticism is directed at the precautionary principle. In specific, emphasis on taking precautions with regard to biotechnology, especially if this takes the form of broad regulatory restrictions, is argued to paralyze innovation efforts (e.g. Sunstein, 2003). As a result, debates have often assumed the terms of a cost-benefit analysis between, e.g., the forsaken benefits from innovation and costs of potential consequences for health and environment and/or the diminished confidence of consumers (Todt and Lujan, 2014). Though it is certainly not wished to dismiss the potentially positive aspects of the precautionary principle, the results suggest that it is certainly likely to act as an impediment for green biotechnology. In fact, R&D efforts such as field trials have stopped in Germany since 2015, which could be a huge setback to the innovativeness of the economy if such efforts were not shifted to other technological innovation or moved abroad. The possibility granted to EU member states to opt-out from the approval of GM crops thus has consequences for international trade. Industry supply-chain actors could, for instance, work around the new regulations by shifting production to a member state that allows for the broad commercialization of approved GMOs. As a result, this would require that consumer acceptance is already high in the potential target markets such as, for instance, in Spain where Merck has expanded its biotech production capacity in 2016 – although not reportedly for these reasons (Merck, 2016). However, at the global level, future applications of biotechnology and related innovations in agricultural production are more likely to emerge from North America, Asia, and Africa (Parisi et al., 2016). If this comes to pass, one reason would certainly be that the national legislation in Germany failed to implement the European Commission's guidance and explore commercialization of biotechnology on a case-by-case basis (Garnett and Parsons, 2017).

Furthermore, emphasis on higher perceived self-control (Chapter 3) invests greater meaning to not only trust-enhancing mechanisms such as labeling but also the decisions and positions staked out by upstream actors in the supply chain (Chapter 4). The presumption that it is the consumers who have the power and ability to reject GMOs is thus challenged by the findings that industry actually has more influence than typically assumed. In this regard, the issues of how to promote acceptance is rather a matter of implementation by, for instance, the implementation of transparent and traceable labeling as required by the Regulation 2003/1830/EC on labeling and traceability. However, it is crucial to attain coherence among the stances of upstream actors, to avoid that consumers feel less certain because of conflicting messages. One potential strategy would therefore be to develop a labeling scheme that involves multiple stakeholders at the early stage, including consumers. One way to convey the coherent stances of supply-chain actors could be a label that allows consumers to trace the product from its beginning such that all involved actors are required to cooperate. Crucially and in contrast to the current approach as depicted in Regulation 2003/1829/EC – which is supposed to complement Regulation 2003/1830/EC such that it "ensure[s] that accurate information is available to operators and consumers to enable them to exercise their freedom of choice in an effective manner", article 4 - the results of the thesis suggest that, in order to enhance consumer support, the regulation could, for instance, be amended such that "traceability and labelling of genetically modified organisms and traceability of food and feed products produced from genetically modified organisms […] ensures that relevant information concerning any genetic modification is available [for the consumer] at each stage of the placing on the market of GMOs and food and feed produced therefrom and should thereby facilitate accurate labelling [which provides complete information about the whole production process and the use of genetically modified components in the end-product]" with components referring to ingredients in the current understanding of this regulation but in addition including enzymes such as Chymosin which is to a large part produced from GM microorganisms in today's industrial cheese production. Complete information contributes to a balanced message and moreover, traceability across the supply-chain has the ability to enhance consumer perceptions about controllability of the risk. According to the findings of this thesis, both measures can therefore be expected to reduce risk perception and increase consumer support of biotechnology. Offering this information via, for instance, labels and/or supplementary online information would also ensure consumers freedom of choice which is not sufficiently warranted at the moment due to examples such as GM Chymosin in cheese that is not labeled or also dairy and meat that has been produced from animals fed with GM crops.

Policymakers therefore have the responsibility: i) to initiate a public debate to elucidate the potential of biotechnological innovation, ii) to foster and provide incentives for R&D, iii) to promote the dialogue among industry stakeholders, iv) to incentivize labeling efforts and improve transparency in current regulation (e.g. in Regulation 2003/1830/EC as suggested above), and partly as a result of these measures, v) to promote freedom of choice. It may seem that there is little incentive for policymakers to do so given the high consumer concerns. The findings of this thesis, however, suggest that this policy response is the most feasible strategy to promote higher consumer acceptance.

5.3.2. Implications for risk communication

Beyond the use of the precautionary principle, the potential for broader public debate is inevitable. Indeed, the dialogue with the public demands an improved range of techniques for communication, given that novel technologies are always likely to emerge, and with them the risks and uncertainty that their use is likely to engender. For this reason, Pierce (2013), p. 876, stressed the bi-directionality of the relationship between science and society, finally emphasizing that it is science which has the “responsibility to seek societal resonance in innovation” so that a response might emerge which is “proportional to the significance of the influence or impact”. In line with this perspective, Chapter 2 of this thesis suggests a product-oriented approach could serve as a potential strategy for the commercialization of biotechnology, given the importance for consumers to be involved at an earlier stage of product development.

Therefore, dialogue and outreach from scientific actors to the public also demands upstream endorsement across the length of the supply chain, i.e. from regulatory actors to farmers, producers, and energy companies. Most importantly, consumers do not want to be *informed* but rather *involved* in the biotechnology debate, as described in Arnstein's (1969) ladder of citizen participation. The author highlighted the specific importance of higher personal controllability, leading to greater personal responsibility, as one often-overlooked factor conducive to consumer acceptance. In other words, if citizens desire to exert greater control over such processes, it is important to conceive of this control not in a general sense but rather as a personally felt aspect of decision-making. As a result of Chapter 3 of this thesis, this is also applicable to biotechnology. This shift holds substantial implications for, inter alia, the importance that is assigned to labeling that provides information that is objectively verifiable by the consumer, and thus conducive to perceived self-control.

Conversely, the mere provision of information on risks and benefits can make consumers insecure (e.g. Grunert et al., 2001). The results from Chapter 4 indicate that consumers tend to rely on cognitive processes during decision-making, that is, without direct interference from affective factors such as mood. According to Bredahl et al. (1998), cognitive processing of new information is necessary to bring about a persistent change in more enduring and resistant attitudes, and thus to ultimately affect behavior. In contrast, whether or not an individual's mood was positive or negative did not appear to influence decision-making or the uptake of new information during the experiment. Thus, balanced information is most likely to enable consumers to make an informed choice. Providing some reason for pause, however, mood had a significant influence on the decision to support or reject before the experiment began. That is, outside the controlled experimental context in which information was given, there is some reason to suspect that affective processes can often drive decision-making. This should be considered especially with regard to unbalanced risk messages, for instance, if used in negative media coverage.

5.4. LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

One major limitation of this research is that the findings are based on stated preferences rather than observed behavior. As a result, one possible shortcoming could be that acceptance could be different (higher or lower) in an actual market situation, where individuals are subject to binding (budget) constraints – in other words, the "intention-behavior gap". Nevertheless, Carson and Groves (2007) have demonstrated how stated preferences could still be more or less identical to *consequential* economic behavior, i.e. how people would behave if a market actually existed, if a few key conditions are met. In specific, they emphasize that individuals must be provided with sufficient information about the potential risks and benefits of the relevant activity and, as much as possible, it is crucial that there be actual consequences, whether in terms of potential enjoyment or foregone funds, for the decisions that individuals take. As such, this thesis helped to better understand consumers' intentions as it offered a specific context for the respondents, i.e. product, policy regime, and risk dimensions. If, for instance, participants are led to believe that their answers will be used as the basis for policy-making, then this could itself serve as motivation to respond as accurately as possible – that is, whether it is in addition to a lump-sum payment or even if there are no immediate monetary consequences.

Moreover, the measurement of risk, as used in Chapter 2 and 3, is not necessarily straightforward. Namely, the common use of likelihood and severity might be inappropriate for societal risk-management, whether owing to the diverging perceptions of likelihood or because it is difficult, according to utility theory, for aggregate preferences to be derived from individual choices (Rayner and Cantor, 1987). Our approach to measure risk, i.e. in terms of expected value including severity, may thus be misleading for decision-makers since extremely severe consequences such as the likelihood of a nuclear accident are often the product of objectively wrong perceptions with regard to the probability of occurrence (Aven and Cox, 2016). On the one hand, the thesis partly accounts for this shortcoming by basing results on relative comparisons between products and scenarios. On the other, it is generally advisable to take absolute levels of risk and support with caution.

In spite of these limitations, the strength and novelty of the findings rather speak for themselves. Chapter 2 demonstrated the influence and the importance of the contextual factors policy regime and product end-use. Against the backdrop of an emerging bioeconomy which is likely to make use of a range of novel products and processes, further research on other promising but controversial end-uses and technologies such as synthetic biology would contribute to the current understanding of consumer acceptance. With respect to the heterogeneity in approval of GMOs within the EU as well as at global level future research should consider the regulatory context and its influence on consumer perception in order to reiterate or complement these findings for other countries.

Resulting from the findings in Chapter 3, future research should therefore identify, for example, the underlying mechanism that consumers use to cope with the lack of self-control. One recommendation given in Chapter 4 in this regard is to improving current labeling schemes. However, the specific characteristics that enhance consumer's perception of self-control have not yet been identified.

Finally, and in line with, e.g., Sapp and Korsching (2004), the results from Chapter 4 suggest that low consumer acceptance could reflect the prevalence of negative information-frames with regard to biotechnology, particularly as a result of the influence of certain opinion leaders. Future research should therefore look more closely at framing effects and how they interact with decisions of upstream actors, potentially even in a more dynamic sense, in order to explore how consumer acceptance might evolve in response to information communication and stances of supply-chain stakeholders. In specific, future studies should account for the fact that support and rejection could be not the inverse of each other.

5.5. OUTLOOK

Against the backdrop of growing technological innovation in the domain of bio-based products and processes such as CRISPR-Cas9 and synthetic biology, lessons for consumer acceptance should be applied from the case of biotechnology, with a specific emphasis on the early involvement of the consumer in processes of technology developments as the current legislative response could turn out to be inappropriate for other novel technologies, thereby aggravating exiting problems such as restrictions of R&D efforts. Sprink et al. (2016) argue that, even though the Directive on deliberate release of GMOs 2001/18/EC is supposed to reflect a product-oriented approach that permits biotechnology for certain products, in practice it is rather a strictly process-based regulation. Given that a GMO is defined by whether the final product has its genetic material been altered, this has important implications for new breeding techniques with cisgenic approaches, such as genome editing, which only combine or alter genetic material from sexually compatible species. The final cisgenic product is therefore not fundamentally different to what might be produced using conventional breeding techniques and/or natural biological processes. Nevertheless, such products would still fall under the GMO legislation, that is, assuming that the introduction of this material could be traced by the regulatory authorities – a potential issue that is still in question. Yet, for genome editing, all this could be avoided through a product-oriented approach to GMO legislation. In general, losing track of developments in novel technologies that have an enormous potential shape out future in many regards would be an unfavorable option with respect to the greater societal challenges we are facing. Therefore, the appropriate response, according to this thesis, is to shape a political environment that fosters technological innovation through effectively responding to public concerns.

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APPENDICES

APPENDIX A

Risk statements for GM potatoes and maize for the respective policy scenario (R&D = Research & Development, FC = Full Commercialization) and risk dimension (Env = Environment, Hea = Health, Eco = Socioeconomic, Eth = Ehtical).

		GM Potato	GM Maize
1	R&D-Env1	Research on genetically modified organisms can lead to gene flow from field trials into the environment (the crop crosses with wild plants or non-GM crops), with potentially adverse effects on the functioning of agroecosystems.	Research on genetically modified organisms can lead to gene flow from field trials into the environment (the crop crosses with wild plants or non-GM crops), with potentially adverse effects on the functioning of agroecosystems.
1	R&D-Env2	Field trials can result in uncontrolled or unintended spread of new genes, which may cross into neighboring plants of the same or a sexually compatible species and lead to irreversible changes in the ecosystem.	Field trials can result in uncontrolled or unintended spreading of new genes, which may cross into neighboring plants of the same or a sexually compatible species and lead to irreversible changes in the ecosystem.
1	R&D-Env3	Cultivating GM crops may help farmers to reduce pesticide use in their farming. Hence, banning the cultivation of GM crops in Sweden might lead to continued use of pesticides that are harmful to the environment.	Cultivating GM crops may help farmers to reduce pesticide use in their farming. Hence, banning the cultivation of GM crops in Germany might lead to continued use of pesticides that are harmful to the environment.
2	R&D-Hea1	Research field trials can fail to prevent the introduction of the GM plants into the livestock feed and human food pathways, which may lead to adverse health effects, e.g. it can trigger allergies or it can lead to toxic reactions in the digestive tract.	Research field trials can fail to prevent the introduction of the GM plants into the livestock feed and human food supply chains, which may lead to adverse health effects, e.g. it can trigger allergies or it can lead to toxic reactions in the digestive tract.
2	R&D-Hea2	Some GM crops are designed to help human nutrient intake and digestion problems (e.g. GM potato with higher amylose content could be beneficial for diabetics and in diet food). Hence, banning GM technology means that consumers might be restricted in realizing these benefits.	GM crop cultivation has contributed to significantly reducing the release of greenhouse gas emissions from agricultural practices (for example herbicide-resistant GM maize requires less tillage and thus saves tractor fuel use) and thus helps mitigate climate change, which is blamed for an increase in natural catastrophes and thus losses of human lives. Therefore, totally banning GM technology might slow down or make it impossible to access such improvements.
2	R&D-Hea3	Genetic engineering has applications in producing foods with enhanced quality (for example foods derived from GM crops with lower levels of saturated fats), which is good for human health status. Therefore banning GM technology might slow down or make it impossible to access such food quality improvements.	Genetic engineering has applications in cultivation of energy crops that significantly reduce usage of pesticides (for example insect-resistant GM maize requires less insecticide spraying), which is good for the environment and thus for human health status. Hence, banning GM technology means that consumers might be restricted in realizing these benefits.
3	R&D-Eco1	By allowing GM crop cultivation only for R&D while banning it for other purposes, Swedish farmers might lose the opportunity to increase the profitability of their farm.	By allowing GM crop cultivation only for R&D while banning it for other purposes, German farmers might lose the opportunity to increase the profitability of their farm.

3	R&D-Eco2	By allowing GM crop cultivation only for R&D while banning it for other purposes, food industries might lose the advantage of GM food processing enhancement and market opportunities.	By allowing GM crop cultivation only for R&D while banning it for other purposes, energy industries might lose the advantage of GM maize processing enhancement and market opportunities.
3	R&D-Eco3	Cultivating GM crops for R&D purposes may lead to gene crosses between the GM crop and neighboring non-GM crops, which may inflict losses on farmers who are not growing GM crops.	Cultivating GM crops for R&D purposes may lead to gene crosses between the GM crop and neighboring non-GM crops, which may inflict losses on farmers who are not growing GM crops.
3	R&D-Eco4	Cultivating GM crops for R&D purposes might result in a situation where the GM plant crosses with wild relatives and becomes a weed, inflicting losses on neighboring farmers.	Cultivating GM crops for R&D purposes might result in a situation where the GM plant crosses with wild relatives and becomes a weed, inflicting losses on neighboring farmers.
4	R&D-Eth1	Gene technology alters genetic material in a way that does not occur naturally by mating and/or natural recombination and development of this type of technology (even for R&D purposes) might be interfering with nature.	Gene technology alters genetic material in a way that does not occur naturally by mating and/or natural recombination and development of this type of technology (even for R&D purposes) might be interfering with nature.
4	R&D-Eth2	GM technology can help increase the global production of staple foods, including maize, oilseed rape and soybean. However, Swedish society might lose its ability to help find a solution to the issue of global food security if GM technology is not permitted for use in Sweden.	GM technology can help solve land and water use problems arising from cultivation of renewable energy crops. However, German society might lose its ability to help find a solution to the issue of global waste of resources if GM technology is not permitted for use in Germany.
4	R&D-Eth3	Allowing GM crop cultivation only for R&D purposes while banning it for farming might restrict Swedish farmers in realizing an increase in crop yields; hence it might work to decrease farmers' income and welfare.	Allowing GM crop cultivation only for R&D purposes while banning it for farming might restrict German farmers in realizing an increase in crop yields; hence it might work to decrease farmers' income and welfare.
1	FC-Env1	Cultivation of GM crops may have a negative impact on the environment through transferring modified genes into native plant species and other agricultural crops.	Cultivation of GM crops may have a negative impact on the environment through transferring modified genes into native plant species and other agricultural crops.
1	FC-Env2	There might be some deficiencies in the ability of the current GM food regulatory framework to evaluate sufficiently the potential biosafety and environmental impacts of GM technology. Therefore, current regulatory frameworks may fail to detect potential adverse environmental effects of cultivating GM crops.	There might be some deficiencies in the ability of the current GM food regulatory framework to evaluate sufficiently the potential biosafety and environmental impacts of GM technology. Therefore, current regulatory frameworks may fail to detect potential adverse environmental effects of cultivating GM crops.
1	FC-Env3	Pesticide-resistant GM crops can protect themselves against unwanted insects, but there is a risk of this modified trait having unintended effects on non-target (neutral or even beneficial) species.	Pesticide-resistant GM crops can protect themselves against unwanted insects, but there is a risk of this modified trait having unintended effects on non-target (neutral or even beneficial) species.
1	FC-Env4	GM plants can out-compete native species or cross with them, which potentially threatens biodiversity.	GM plants can out-compete native species or cross with them, which potentially threatens biodiversity.

2	FC-Hea1	There might be uncertainties regarding the health effects of long-term consumption of GM foods.	By cultivating GM energy crops, the agricultural industry may fail to prevent the indirect introduction of genetic engineering into human food pathways (for example through meat consumption, since starch maize can be used for both bioenergy production and livestock feed and might use the same paths in the supply chains, e.g. during shipping, processing or storage), which could therefore lead to adverse health effects, e.g. trigger allergies or lead to toxic reactions in the digestive tract.
2	FC-Hea2	There may be a potential danger of gene transfer from consumed GM foods to the human body, which may adversely affect human health.	There may be a potential danger of gene transfer from energy crops to the human body (e.g. through GM non-food maize cross pollinating conventional food maize varieties), which may adversely affect human health.
2	FC-Hea3	There might be some deficiencies in the ability of the current GM food regulatory framework to evaluate adequately the potential health impacts of GM technology. Therefore, current regulatory frameworks may fail to detect potential adverse effects of consumption GM crops on the human health.	There might be some deficiencies in the ability of the current GM crop regulatory framework to evaluate adequately the potential health impacts of GM technology. Therefore, current regulatory frameworks may fail to detect potential adverse effects of using GM crops in bioenergy production on the human health.
3	FC-Eco1	Farmers not growing GM foods are concerned about how to preserve their identity as non-GM producers, since they have doubts about the ability of the agricultural industry to accurately segregate GM from non-GM crops. So allowing GM food cultivation may damage non-GM food business.	Farmers not growing GM energy crops are concerned about how to preserve their identity as non-GM producers, since they have doubts about the ability of the agricultural industry to accurately segregate GM from non-GM crops. So allowing GM energy crop cultivation may damage non-GM energy crop businesses.
3	FC-Eco2	Biotechnology companies may monopolize the GM technology market by way of patenting and licensing, which might restrict competition and make it difficult for rivals to gain access to new GM technologies on fair terms.	Biotechnology companies may monopolize the GM technology market by way of patenting and licensing, which might restrict competition and make it difficult for rivals to gain access to new GM technologies on fair terms.
3	FC-Eco3	GM seed fees and contractual issues put farmers at a disadvantage by restricting a potential economic benefit associated with GM crops. For instance, farmers are not allowed to use the harvested seed from their own GM crop fields to grow in the next period and they have to pay the seed companies. This means an increase in the cost of food production.	GM seed fees and contractual issues put farmers at a disadvantage by restricting a potential economic benefit associated with GM crops. For instance, farmers are not allowed to use the harvested seed from their own GM crop fields to grow in the next period and they have to pay the seed companies. This means an increase in the cost of bioenergy production.
3	FC-Eco4	Growing GM crops may eventually may lead to a reduced number of varieties and natural traits in crops (since they outcompete natural varieties), which means less consumer choice in the long-term.	Growing GM crops eventually may lead to a reduced number of varieties and natural traits in crops (since they outcompete natural varieties), which may have adverse effects on new product development.
4	FC-Eth1	Gene technology when applied to food may pose unknown risks for consumers as well as the environment; hence the technology may have adverse effects on the general well-being of the population.	Gene technology when applied to energy crops may pose unknown risks for consumers as well as the environment; hence the technology may have adverse effects on the general well-being of the population.

4	FC-Eth2	Gene technology when applied to food involves altering the genetic material in a way that does not occur naturally by mating and/or natural recombination. Hence, application of this type of technology may mean interfering with nature.	Gene technology when applied to energy crops involves altering the genetic material in a way that does not occur naturally by mating and/or natural recombination. Hence, application of this type of technology may mean interfering with nature.
4	FC-Eth3	Biotechnology companies might potentially monopolize the GM technology market by way of patenting and licensing, thus restricting competition and making it difficult for rivals to gain access to new GM technologies on fair terms.	Biotechnology companies might potentially monopolize the GM technology market by way of patenting and licensing, thus restricting competition and making it difficult for rivals to gain access to new GM technologies on fair terms.

Appendix B

Information material on technology, policy scenarios, and supply-chain actors.

Information that was provided to the respondents during the experiment was technology information (B1) and both descriptions of policy scenarios and supply-chain actors as well as the resulting behavior in the two policy scenarios (Figures B2 and B3). The information has been translated from the original German version into English.

B1: Genetic modification: when you purposefully alter the genome so that the crops obtain the intended characteristics.

B2:

The food chain

- **Decision makers**
  Parliament and the government policies and regulations that must be respected by all players in the food chain.
  Includes German and EU legislation concerning the production and sale of food, including food quality and safety.
- **German farmers**
  Responsible for the production of raw materials for companies in the food industry.
- **Food industry**
  Manufacturer of foods, including the processing of agricultural products.
- **Food retailers**
  Your grocery chain store. Aldi, Edeka, Lidl, Rewe etc.
- **Consumers (you)**
  Consume goods.

Scenario: Research and development

In this scenario the legislation allows for using GM technology for research and development (R&D) purposes, in for example laboratories or controlled farming areas within the borders of Germany.

	Policymakers	Only research on genetically modified food is permitted in Germany.
	Farmers	Are unable to grow GM crops.
	Food processing industry	Are unable to process GM products.
	Food retailers	Are unable to sell GM food.
	Consumers	Are unable to buy GM food.

Scenario: Full commercialization

In this scenario producing and selling genetically modified (GM) food is permitted, as long as the product complies with necessary requirements in food legislation.

	Policymakers	Allows commercialization and cultivation of genetically modified foods (GMO)
	Farmers	Farmers can grow GM crops.
	Food processing industry	Can process GMO products.
	Food retailers	Can sell GMO food.
	Consumers	Have the ability to buy GMO food.

B3:

The bio-energy chain

- **Decision makers**
  Parliament and the government policies and regulations that must be respected by all players in the bio-energy chain.
  Includes German and EU legislation concerning the production and sale of bio-energy, including bio-energy quality and safety.
- **German farmers**
  Responsible for the production of raw materials for the bio-energy producing industry (e.g. biogas producers).
- **Bio-energy producers**
  Producer of bio-energy, including the processing of agricultural products.
- **Energy supplier**
  Your energy provider, e.g. electricity (RWE, SWB, RheinEnergie etc.) or gas station (Aral, Shell, Esso etc.).
- **Consumers (you)**
  Consume goods.

Scenario: Research and development

In this scenario the legislation allows for using GM technology for research and development (R&D) purposes, in for example laboratories or controlled farming areas within the borders of Germany.

	Policymakers	Only research on genetically modified (GM) energy crops is permitted in Germany.
	Farmers	Are unable to grow GM energy crops.
	Bio-energy producers	Are unable to process GM energy crops to bio-energy.
	Energy companies (electricity, heating, gas)	Are unable to sell bio-energy made from GM energy crops.
	Consumers	Are unable to buy bio-energy made from GM energy crops.

Scenario: Full commercialization

In this scenario producing and selling bio-energy that is made from genetically modified (GM) energy crops is permitted, as long as the product complies with necessary safety requirements in legislation (e.g. guarantees security of energy supplies).

	Policymakers	Allows commercialization and cultivation of genetically modified energy crops.
	Farmers	Farmers can grow GM energy crops.
	Bio-energy producers	Can process GM energy crops to bio-energy.
	Energy companies (electricity, heating, gas)	Can sell bio-energy made from GM energy crops.
	Consumers	Have the ability to buy bio-energy made from GM energy crops.

APPENDIX C

Data collection system related to the decision-making task designed to elicit consumers' choices in response to decision by other actors. This image shows decision profile no. 1 in the FC scenario.

ID: 10011
Remaining pages: 20
Answered: 0

Decision information

In each section you will see the available option to each actor (policy makers, farmers, bioenergy producers, bioenergy companies) in relation to GM produced bioenergy. Please read the decided option by other actors thoroughly and then go to your section (consumer). Now select the option that you prefer considering the decisions other actors made. After you have made your choice please got to the evaluation section and follow the instructions.

Based on following options, policy makers decided to: ☒ GM bioenergy crops are allowed to be cultivated domestically or imported without mandatory labelling. It is both permissible to cultivate domestic GM bioenergy crops and importing. The product shall be subject to public patent and must meet mandatory labeling requirements.
And now due to new regulations, farmers had options as underneath to make their own decisions and you can see what they have decided as highlighted: ☒ Farmers support the regulation and are willing to grow GM bioenergy crops Farmers do not support the regulation and do not grow GM bioenergy crops
And among the following options, bioenergy producers decided to: ☒ Bioenergy producers support the regulation and process the GM bioenergy crops Bioenergy producer do not support the regulation and do not process GM bioenergy crops
And among following options, bioenergy companies decided to: ☒ Bioenergy companies support the regulation and sell domestically produced bioenergy that is made from GM crops Bioenergy companies do not support the regulation and do not sell bioenergy produced with GM bioenergy crops

As consumer what would be your choice regarding GM produced bioenergy considering information above and decision options below:

☒ I support the regulation and I am willing to use bioenergy produced with GM bioenergy crops
☐ I support the regulation, but I am not willing to use bioenergy produced with GM bioenergy crops
☐ I support the regulation and I am willing to use bioenergy produced with GM bioenergy crops, but I would prefer domestically grown GM bioenergy crops
☐ I do not support the regulation since I am against GM bioenergy crops, and I am not willing to use bioenergy produced with GM bioenergy crops

Appendix D

Product and technology information presented to respondents before the decision-making task. Pictures were presented throughout the experiment.

Positive

Genetically Modified Maize

German scientists argue that genetic modification is a way of facilitating natural mutation of organisms but in a much more controlled way.

They have developed a new GM non-food maize variety for bioenergy production with improved insect resistance which delivers yield gains from reduced pest damage of +10.4%. This could benefit German households as bioenergy (e.g. biogas or biofuel) could become cheaper.

High pesticide use is one of the main environmental problems caused by modern agriculture. The new GM energy maize requires 79% less insecticides and 11.8% less herbicides. Planting of this variety therefore provides environmental benefits to society.

Reduced insecticide use in agricultural practices helps saving bee populations and thus promotes biodiversity.

Moreover, less fuel use and additional soil carbon sequestration that results from less tillage contribute to reduced release of greenhouse gas emissions in agricultural practices.

Control

Genetically Modified Maize

Genetic engineering has been debated among societies, politicians and scientist for several years. German scientists do not agree upon a positive or negative direction of consequences for genetically modified crops. Some argue that this method might offer several benefits, e.g. in health research, and that widespread usage has already proven that genetically modified crops are safe. On the other hand, some scientists claim that genetic research is not sufficiently developed and that long-term consequences have not been investigated, yet.

However, a group of German scientists has developed a new GM starch maize variety that offers advantages in bioenergy production. Starch maize is a sustainable non-food crop that is widely used as input for biogas and biofuel production.
In biogas production, starch maize and agro-waste materials serve as energy source for electricity production. This method has been widely introduced in the late 1990's and now accounts for about 11% of renewable energies. It is not uncontroversial though.

Renewable energies are part of the Federal Ministry of Education and Research's strategy for a sustainable bio-based economy. The strategy aims to tackle worldwide challenges, such as food security, but also national challenges, such as supply security which has gained in importance due to Germany's exit strategy from nuclear energy. (Political/Environmental/Ethical/Socio-economic relevance)

Genetically modified (GM) starch maize helps to increase yields and decrease pesticide use and thus offers several economical and health benefits to society. However, long-term consequences of GM energy crops on human health and environment are heavily debated.

Negative

Genetically Modified Maize

German scientists have found that genetic modification of organisms entails uncontrollable risks for both society and nature.

They claim that a recently developed GM non-food maize variety for energy production only benefits large energy companies that aim to maximize their profits and strengthen their position at the market. This might lead to monopolistic behavior and thus to higher household energy prices.

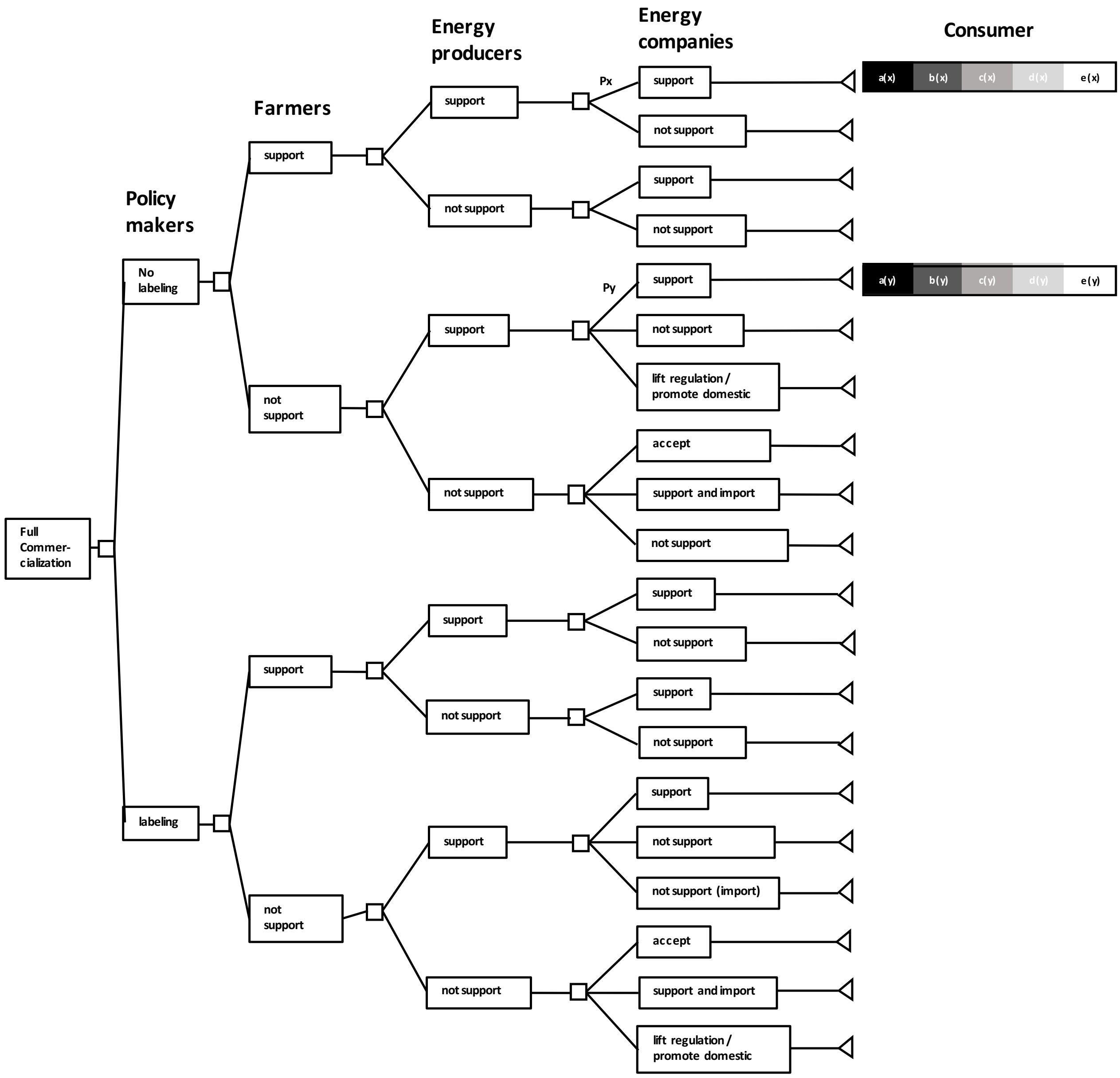
Cultivation of this variety may lead to extinction of other domestic varieties that have been cultivated for several centuries. This would then have drastic effects on biodiversity and would harm regional, national and worldwide ecosystems.

In addition, growing GMO crops could benefit development of resistant super bugs and weeds that can only be brought under control by using more fertilizers, pesticides and other chemicals. That, in turn, would make farmers dependent of large agri-input suppliers which is fatal for small-scale farmers in particular.

Moreover, it is impossible to control for genetic pollution of non-GM food maize crops. Thus consequences for human health are unforeseeable.

Appendix E

Decision-tree with consumer choice options at the end-nodes.



APPENDIX F

Stuart-Maxwell test results for consumer decision for each profile of the interdependent decision profiles without mandatory labelling (profiles 1-10) and with mandatory labelling and the patent being in public ownership (profiles 11-20).

Profiles	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1																			
2	NV	1																		
3	0.2426	NV	1																	
4	NV	0.001	NV	1																
5	0.3106	NV	0.5905	NV	1															
6	NV	0.0669	NV	0.0167	0.3173	1														
7	*.3189	NA	NA	NV	*.4130	NV	1													
8	NV	0.1517	NV	0.0651	NV	0.6621	NV	1												
9	0.0641	NV	0.2557	NV	0.8013	NV	*.1652	NV	1											
10	NV	0.0331	NV	0.0097	NV	0.2552	NV	0.1027	NV	1										
11	0	NV	0	NV	0	NV	*.0006	NV	0	NV	1									
12	NV	0	NV	0.0007	NV	0	NV	0.0007	NV	0.0027	NV	1								
13	0.004	NV	0.0003	NV	0.0001	NV	NA	NV	0	NV	NA	NV	1							
14	NV	0	NV	0.0119	NV	0	NV	0	0.3173	0	NV	0.2466	NV	1						
15	NA	NV	NA	NV	NV	NV	NA	NV	NA	NV	NA	NV	NA	NV	1					
16	NV	0	NV	0.0735	NV	0.0006	NV	0.0015	NA	0	NV	0.1893	NV	0.8165	NV	1				
17	*.0026	NV	0	NV	*.0000	NV	0.0069	NV	*.0000	NV	NA	NV	*.3550	NV	NA	NV	1			
18	NV	0	NV	0.042	NV	0.0006	NV	0.0027	NV	0.0011	NV	0.0429	NV	0.7055	NV	0.8948	NV	1		
19	0.0003	NV	0.0002	NV	0	NV	*.0075	NV	0	NV	0.0003	NV	0.5394	NV	NA	NV	0.1379	NV	1	
20	NV	0	NV	0.0536	NV	0.0002	NV	0.0008	NV	NA	NV	0.0923	NV	0.1797	NV	0.822	NV	NA	NV	1