Unlocking Lock-In: Accelerating Socio-Technical Transitions To Sustainability

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To Jonas & Jakob.

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English summary

Achieving global sustainability goals will require cleaner and cheaper technologies. While the technologies in use today can deliver significant sustainability improvements, they are insufficient on their own. Moreover, the technologies we do have are often unadapted or too costly for the consumers and users they aim to serve. The pace of change is too slow, and without a major acceleration of innovation, deployment, and social acceptance of sustainable technologies, these goals will not be reached. Public policy is central to achieving these goals and, in turn, ensuring a quicker pace of change. A major obstacle lies in the fact that technologies cannot be considered isolated entities: they are embedded in a powerful social context of cultural, organisational and institutional systems. This intertwining of different elements is referred to as a socio-technical system.

This thesis discusses how socio-technical systems have, over time, allowed locked-in configurations to emerge, referring to a combination of systematic forces that perpetuate unsustainable infrastructures embedded in society. Such lock-ins can inhibit innovation and competitiveness of low-carbon and sustainable technologies, and this thesis looks to concrete solutions for unlocking them.

Vital to this objective lies better understanding preferences, intentions, and behaviour of actors involved at each stage of technological development to improve public policy design. A discrete choice experiment – a quantitative non-market valuation method – was, therefore, a core method used to model preferences of key target groups when considering trade-offs between vital components of public policy. Target groups considered in the four major components of the thesis include i) industry players, ii) policymakers, iii) farmers, and iv) the general public in Belgium, France, Germany, Italy and Spain. Qualitative interviews complemented a segment of the research.

The thesis seeks to establish how both economic and regulatory instruments can be better leveraged to overcome lock-in, and several conclusions can be drawn from its findings. The inaugural chapter of the thesis looked to technological lock-in and market power: how regulation reinforced a patented monopoly by, as we argue - 'picking winners' to the advantage of a less sustainable option in the hydrofluorocarbon replacement industry. Governments require a more dynamic framing: it should be less about picking winners and more about forming contextually defined directions for policy.

A discussion on institutional lock-in follows the inaugural chapter by investigating European policymakers' preferences when allocating public resources through

research and development (R&D) technology funding. The results showed that policymakers that participated in the study were more likely to fund projects that resembled the incumbent rather than more innovative technologies. As policymakers can disproportionately influence the rate and direction of technological change, these insights are crucial to ensuring the success of innovation funding programmes and policies supporting early-stage technology development.

The third component of the thesis looks to behavioural lock-in resulting from French farmers' attitudes to agro-ecological practices. Results indicate that farmers are keen to switch to more sustainable practices but appear at a loss as to how they can do this. Semi-structured interviews illustrate that the farmers that took part feel an intense uncertainty for the future and a profound disconnect with authorities. As a result, farmers underlined the wish for concrete and local policy measures based on farmers' networks and peer support – as a crucial motivation for group-mediated action is uncertainty reduction. The research highlights the importance of taking behavioural and habitual considerations into account when considering farmers' decisions to adopting agro-ecological practices.

The final chapter comparatively assesses economic and regulatory instruments. The chapter does not seek to rank one over the other but rather how to increase the acceptability of such policies and what trade-offs people make. We quantitatively compare the acceptability of using a tax and a ban to phase out agricultural glyphosate use. One conclusion sees that implementing an efficient environmental tax regime – an economic instrument - requires balancing political feasibility and public acceptance considerations in line with tax and environmental policy. Results indicate that public acceptance of environmental taxation increases with earmarking.

The thesis provides important insights into how public policy may be unintentionally hindering processes of the innovation system through technological, institutional and behavioural lock-in mechanisms at the outset, and offers solutions to avoid these pitfalls. Overall, policy design should emphasise a more continuous and systemic approach to innovation and technology policy on the road to accelerating socio-technical transitions to sustainability.

Dutch summary

Het bereiken van wereldwijde duurzaamheidsdoelen vereist schonere en goedkopere technologieën. Hoewel de actueel aangewende technologieën aanzienlijke duurzaamheidsverbeteringen kunnen opleveren, zijn ze op zichzelf onvoldoende. Bovendien zijn de bestaande technologieën vaak niet aangepast of te duur voor de consumenten die ze willen gebruiken. De veranderingen gaan te traag, en zonder een aanzienlijke versnelling van innovatie, implementatie en een maatschappelijk draagvlak voor duurzame technologieën zullen deze doelstellingen niet worden bereikt. Het overheidsbeleid staat centraal bij het bereiken van deze doelstellingen en zorgt op zijn beurt voor een sneller tempo van de veranderingen. Het is een belangrijk obstakel dat technologieën niet als geïsoleerde entiteiten kunnen worden beschouwd: ze zijn ingebed in de sociale context van culturele, organisatorische en institutionele systemen. Deze verwevenheid van verschillende elementen wordt een sociotechnisch systeem genoemd.

In dit proefschrift wordt besproken hoe sociotechnische systemen in de loop van de tijd 'locked-in' configuraties hebben doen ontstaan, waarbij verwezen wordt naar een combinatie van systematische krachten die niet-duurzame infrastructuren in de samenleving in stand houden. Dergelijke lock-ins kunnen de innovatie en het concurrentievermogen van koolstofarme en duurzame technologieën belemmeren, en in dit proefschrift wordt gezocht naar concrete oplossingen om deze te ontsluiten.

Essentieel voor deze doelstelling is een beter begrip van de voorkeuren, bedoelingen en gedrag van actoren die bij elke fase van technologische ontwikkeling betrokken zijn om het ontwerp van het overheidsbeleid te verbeteren. Er werd gekozen voor een discrete keuze-experiment - een kwantitatieve 'non-market' waarderingsmethode - als methode om de voorkeuren van belangrijke doelgroepen te modelleren bij het overwegen van afwegingen tussen vitale componenten van openbaar beleid. De doelgroepen die in de vier belangrijkste componenten van het proefschrift worden overwogen, zijn onder meer i) spelers uit de industrie, ii) beleidsmakers, iii) boeren, en iv) het grote publiek in België, Frankrijk, Duitsland, Italië en Spanje. Een deel van het onderzoek werd aangevuld door kwalitatieve interviews.

Het proefschrift heeft tot doel vast te stellen hoe zowel economische als regelgevende middelen beter kunnen worden gebruikt om een lock-in te doorbreken, en uit de bevindingen kunnen verschillende conclusies worden getrokken. In het inleidende hoofdstuk van het proefschrift wordt gekeken naar technologische lock-ins en marktmacht: hoe regulering een gepatenteerd monopolie heeft versterkt door, zoals wij stellen, 'winnaars te kiezen' in het voordeel van een minder duurzame optie in de vervangingsindustrie voor fluorkoolwaterstoffen. Overheden hebben een meer

dynamische framing nodig: het moet minder gaan om het kiezen van winnaars, maar meer om het formuleren van contextueel gedefinieerde beleidsrichtingen.

Op het inleidende hoofdstuk volgt een discussie over institutionele lock-ins door de voorkeuren van Europese beleidsmakers te onderzoeken bij het toewijzen van openbare middelen via financiering van onderzoek en ontwikkeling (O&O). Uit de resultaten bleek dat aan het onderzoek deelnemende beleidsmakers eerder geneigd waren projecten te financieren die op de gevestigde technologieën gebaseerd waren dan meer innovatieve technologieën. Aangezien beleidsmakers de snelheid en richting van technologische veranderingen onevenredig kunnen beïnvloeden, zijn deze inzichten cruciaal voor het succes van financieringsprogramma's voor innovatie en beleid ter ondersteuning van technologische ontwikkeling in een vroeg stadium.

In het derde onderdeel van het proefschrift wordt gekeken naar gedragsmatige lock-ins als gevolg van de houding van Franse boeren tegenover agro-ecologische praktijken. Uit de resultaten blijkt dat landbouwers graag overschakelen op duurzamere praktijken, maar niet weten hoe ze dit kunnen doen. Semigestructureerde interviews illustreren dat de deelnemende boeren zich heel onzeker voelen over de toekomst en een diepe kloof ervaren met de autoriteiten. Als gevolg hiervan benadrukten de boeren de behoefte aan concrete en lokale beleidsmaatregelen op basis van boerennetwerken en collegiale ondersteuning, aangezien een cruciale motivatie voor groepsgewijze actie het verminderen van onzekerheid betekent. Het onderzoek benadrukt hoe belangrijk het is om rekening te houden met gedrags- en gebruikelijke overwegingen bij het selecteren van de beslissingen van boeren om agro-ecologische praktijken toe te passen.

In het laatste hoofdstuk wordt een vergelijking gemaakt tussen economische en regelgevende instrumenten. In dit hoofdstuk wordt niet getracht een rangorde aan te brengen tussen het ene en het andere, maar wordt eerder onderzocht hoe het draagvlak van dergelijk beleid kan worden vergroot en welke afwegingen mensen maken. We vergelijken kwantitatief de aanvaardbaarheid van een belasting en een verbod om het gebruik van glyfosaat in de landbouw geleidelijk af te schaffen. Een van de conclusies houdt in dat voor de implementatie van een efficiënte regeling voor milieubelasting - een economisch instrument - een evenwicht moet worden gevonden tussen politieke haalbaarheid en aanvaarding door het publiek in overeenstemming met het belasting- en milieubeleid. De resultaten geven aan dat het publiek draagvlak voor milieubelastingen toeneemt naarmate er meer middelen worden vrijgemaakt.

Het proefschrift biedt belangrijke inzichten in de wijze waarop overheidsbeleid processen van het innovatiesysteem onbedoeld kan belemmeren door technologische, institutionele en gedragsmatige lock-in mechanismen, en biedt oplossingen om deze valkuilen te vermijden. In het algemeen zou het beleidsontwerp de nadruk moeten leggen op een meer continue en systemische benadering van innovatie- en technologiebeleid op weg naar versnelling van sociotechnische transities naar duurzaamheid.

Contents

Chapter 1

Introduction

Ensuring a green and resilient recovery from the COVID-19 crisis requires major systemic changes. Encouragingly, pledges by governments have increased substantially in recent years, such as the Paris Agreement on climate change that sees that we need to limit the global temperature increase to well below 2°C to avoid major economic, social and environmental disruption and costs. Nonetheless, despite high-profile pledges, these ambitions do not always align with reality. While the technologies in use today can deliver significant emissions reductions, they are insufficient on their own. Moreover, the technologies we do have are often unadapted or too costly for the consumers and users which they aim to serve. The pace of change is too slow, and without a major acceleration of innovation, deployment, and social acceptance of sustainable technologies, these goals will not be reached.

The substantive changes required for a recovery require a transition from one socio-technical system to another. These changes are referred to as 'socio-technical', as they do not solely involve technological innovation or substitution, but also require complex and interconnected changes in the overall configuration of energy, transport and agri-food systems – involving alterations in technology, policy, infrastructure, markets, consumer practices, culture and habits (Geels, 2011; van den Bergh and Bruinsma, 2008). Essentially, what matters is not only the technologies themselves, but also the social and economic systems in which they are embedded (Upham et al., 2019). These ideas have been pioneered in the transitions literature (Rip et al., 1998; Geels, 2002; Rotmans et al., 2001; Smith et al., 2005) - an area of research that looks to understanding the radical social and economic changes required to re-order the current system in response to societal challenges.

A core concept in the transitions literature looks to the interdependencies of institutions, infrastructures and social systems, which have, over time, allowed locked-in configurations and systems to emerge that can stie innovation (Arthur, 1989). The concept of lock-in is rooted in evolutionary approaches to understanding technological change, broadly used to explain how technologies develop and endure, or why they simply disappear (Perkins, 2003). This condition arises through a combination of systematic forces that perpetuate unsustainable infrastructures: this can occur despite known environmental externalities and the existence of cost-neutral, or even cost-effective, alternatives. This condition can, in turn, inhibit innova-

tion and competitiveness of both low-carbon and sustainable alternatives (Unruh, 2000).

1.1 Research framework

Accelerating socio-technical transitions to sustainability requires escaping (Unruh, 2002), or indeed unlocking, unsustainable configurations. The concept of lock-in and its relation to sustainability challenges is an old problem that has been discussed in the literature and policy spheres for decades. Unfortunately, its prevalence still remains high. While we have been able to diagnose lock-in full and well, its treatment still needs to be better described and prescribed. This thesis takes the stance that, as a result of lock-in dynamics, existing socio-technical systems have had a restrictive influence on innovation dynamics, technological change and adaptation to sustainable societies, and that policies need to be designed and supported with this in mind.

As shown in Figure 1.1, three main types of lock-in can be identified, as distinguished by Fouquet (2016) and further illustrated by Seto et al. (2016). These three types of lock-in include i) institutional lock-in; governance and decision-making shape both production and consumption of technologies, thereby impacting energy supply and demand ii) technological lock-in; technologies and infrastructures directly or indirectly influence the energy supply and associated emissions iii) behavioural lock-in; behaviours, culture, habits and norms related to the demand for goods and services impact the uptake of sustainable technologies. Even though distinctive processes define each of these three types, they are highly interconnected, mutually reinforcing, and can create collective inertia concerning transitions to sustainability (ibid.). Efforts to escape one of these types of lock-in, whether institutional, technological or behavioural, can result in resistance to change in the other types.

In order to understand how we can unlock lock-in in practice, and, in turn, encourage innovation and the uptake of sustainable technologies, lock-in needs to addressed at the systemic level. Indeed, to capture the complex combinations of forces - including investments, policies and actors - involved across iterative innovation stages of sustainable technologies (and technologies in general), the energy technology innovation systems approach (ETIS) (Gallagher et al., 2012; Jordaan et al., 2017) is a useful application even though this thesis also looks to case studies that look beyond the unlocking of the energy technology sector, including the transition to agro-ecological practices in the agricultural sector. Nonetheless, the ETIS is helpful in the sense that it takes a systemic perspective on innovation comprising all stages of the technology development cycle, and all the major innovation processes, feedback, institutions and networks. Innovation processes begin with research and proceed to development, demonstration, market formation, and diffusion. Successful technologies diffuse throughout the economy, but all are either modified or eventually disappear. What the systemic approach comprises of,

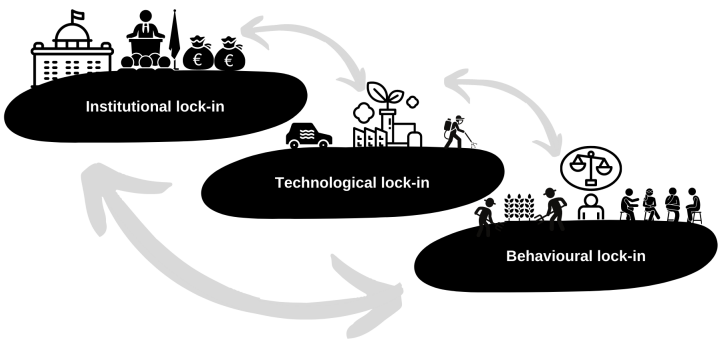

Figure 1.1: Interconnections of lock-in at the systemic level

then, is the notion that technological innovation is the product of "combinatorial evolution" (Arthur, 2009).

Even though considerations of the innovation systems and the ETIS framework naturally also involve the private sector - as illustrated in Figure 1.2, an overarching theme of this thesis lies on the role of the public sector in innovation processes (Mazzucato, 2011), and in unlocking lock-in to encourage faster *eco-innovation* processes. While Rennings (2000) first coined the term, Kemp and Pearson (2007) provide the most comprehensive definition of eco-innovation as "the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives."

As discussed by Costantini et al. (2017), the past research that has looked to what aspects drive eco-innovation highlights the major role that is played by public policies (environmental regulation, energy and technology policies) in achieving clean energy innovation, and increasing the development, deployment and diffusion of sustainable technologies (del Río González, 2009; Horbach et al., 2012; Johnstone et al., 2010; Mowery et al., 2010; Newell, 2010). Importantly, much previous research has focused on the significance of sound policy design and implementation in achieving such clean energy innovation (Abdmouleh et al., 2015; Romano et al., 2017; Kemp and Pontoglio, 2011; Polzin et al., 2019; Bergek et al., 2014; Costantini et al., 2017).

Limited research has, on the other hand, focused on the way in which public policy may, at the outset - from the regulatory push stages - be unintentionally hindering processes of the innovation system through institutional, technological and behavioural lock-in mechanisms. These processes range from the way in which

R&D funding, as well as loans and grants are spent: rooted in the choices and preferences of policymakers and decision-makers, to the ways in which policies to encourage sustainability transitions may be causing resistance in certain communities and groups due to distributional effects. This thesis seeks to address these gaps to ensure that these impacts can be minimised in policy design.

It is at the same time important to acknowledge the major role that the private sector plays in unlocking socio-technical transitions to sustainability, and one example is insurance companies. Climate change and unsustainable habits and practices increase the risk of natural disasters, biodiversity loss, and impacts on the environment at large, as well as health impacts - which in turn threaten society and companies. The insurance industry provides cover for these risks and their financial consequences and plays a vital role in contributing to sustainable finance as long-term investors. In the long-term, insurers will be critical to mobilising capital to build climate risk-resilient infrastructure. Moreover, by targeting their financing, what to invest in, and in which solutions they develop, financial institutions, on the other hand, can play a leading role in accelerating the necessary transition towards a sustainable economy (Tzankova, 2020). The required investment is beyond the capacity of the public sector alone.

Despite the importance the private sector can and will play in the transition to sustainability, the focus of this thesis lies in the role of the public sector. The two major public policy categories often discussed with regard to accelerating eco-innovation in regulatory pull processes of i) regulatory instruments and ii) economic instruments (Bergek et al., 2014; Horbach et al., 2012; Kemp and Pontoglio, 2011; Peters et al., 2012; Rennings, 2000), are here discussed against the backdrop of unlocking institutional, technological and behavioural lock-in. Economic instruments, such as taxes, seek to incentivise actors to adopt low-emission technologies through compensations corresponding to the avoided social cost of pollution, while they economically punish actors investing in polluting technologies (Bergek et al., 2014). Regulatory instruments, such as bans or standards (often referred to as 'command-and-control'), seek to control the use of certain technologies. Transitions research acknowledges that public policy must play a central role in shaping the directionality of transitions through environmental regulations, standards, taxes, subsidies and innovation policies (Köhler et al., 2019).

1.2 Research objective and approach

This thesis goes beyond diagnosing lock-in and looks to how economic and regulatory instruments can be leveraged to overcome lock-in. The research question underlying this thesis is the following: how does public policy contribute to systemic technological, institutional and behavioural lock-ins on the road to accelerating socio-technical transitions to sustainability, and how can economic and regulatory instruments be leveraged to overcome them? Naturally, any assessment of strategies to overcome lock-in needs to start from a clear understanding of the barriers

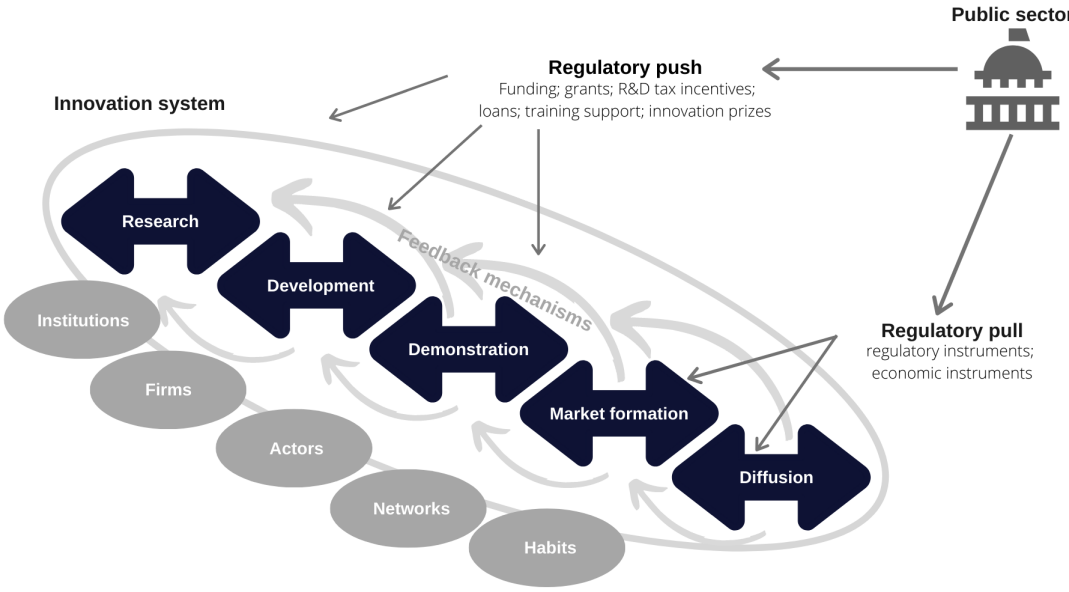

Figure 1.2: The role of the public sector in innovation systems: a systems approach. Figure adapted from Rennings (2000); Gallagher et al. (2012); Jordaan et al. (2017)

present in today's innovation markets. Fundamentally, there are three types of lock-in that can be approached from a systemic perspective i) technologically, ii) institutionally and iii) behaviourally, and the thesis looks at all of them. Specifically, within these three types, it focuses on public policy and its role (whether constructive or destructive) in steering technological development, and in turn, eco-innovation and transitions to sustainability.

Vital to this objective lies better understanding preferences, intentions and behaviour of actors involved at each stage of technology development. It is for this reason that the method used to investigate these questions in three out of the four principle chapters is a discrete choice experiment (DCE). A DCE is a quantitative stated preference-based method, a method often used for environmental valuation within the field of environmental economics, initially developed by Louviere and Hensher (1982) and Louviere and Woodworth (1983), that can measure the strength of preferences and trade-offs of respondents taking part in the study. The thesis relies heavily on interdisciplinary approaches to complement the use of DCEs with i) concepts from traditionally qualitative fields of study - from transitions research, sociology, cognitive and social psychology of decision-making, and political science, ii) and qualitative methods such as interviews with relevant actors to complement a segment of the research. If we are to democratise our current policy mix, modelling preferences of key target groups on issues at stake is criti-

cal. The thesis seeks to estimate and value individual components of policies to accelerate the socio-technical transition to sustainability, and understanding the trade-offs between policy components are important to ensure a quicker transition, and in this case, DCEs are a method of choice (OECD, 2018).

1.3 Research outline

1.3.1 Unlocking technological lock-in

The second chapter of the thesis introduces the concept of technological lock-in, which generally refers to the increasing returns to the adoption of a technology, where incumbent technologies have a distinct advantage over new entrants – not because they are necessarily better, but because they are more "widely used and diffused" (Arthur, 1989; Cowan, 1990b). The long life of physical infrastructure may lock societies into carbon-intensive emissions pathways that are difficult or costly to change, emphasising the importance of initial conditions and early decisions (Seto et al., 2016). The second chapter thus presents an inaugural understanding to how clean technology pathways are chosen through technological lock-in and the way these choices can get stuck through regulatory processes – temporarily, and sometimes even permanently - to the advantage of less sustainable and economically viable solutions (Bjørnåvold and Van Passel, 2017).

Using the case study of the phase-out of refrigerants called hydrofluorocarbons in the European Union (EU), we illustrate how market power, technological uncertainty and economic expectations have led to the uptake of inferior alternatives. As of 2017, the sale and use of hydrofluorocarbons were entirely banned in all new vehicles placed on the market in the EU, as they were recognised as potent greenhouse gases and, therefore, direct contributors to climate change. It is within this regulation-driven market that the technologies for a sustainable solution have been developed. However, this chapter argues that this market was 'locked-in' as a result of regulation reinforcing a patented monopoly in 'picking winners': to the advantage of a synthetic chemical, R-1234yf, as opposed to the main competitor and natural solution, which is CO_2. By developing a generic conceptual framework of path dependence and lock-in, the presented evidence seeks to show how a snowballing effect has led to the intensification of differences in market share. We also argue that the automotive industry is potentially promoting short-term fixes, rather than long-term, sustainable and economically viable solutions.

1.3.2 Unlocking institutional lock-in

The third chapter looks specifically to policymakers and their role in impacting institutional lock-in (Bjørnåvold et al., 2020). Can we trust that policymakers are steering innovation in the right direction? Mitigating climate change, and by

extension – decarbonising energy, requires governments and institutions to boost innovation – through investment in research and development, subsidies, as well as favourable tax or price regimes that can decrease the time-to-market of environmentally friendly technologies. However, institutions can inhibit the diffusion of carbon-saving technologies due to systemic relations and interdependencies where transitions result from joint development of technology and society (Foxon, 2002).

Through positive feedback mechanisms existing between policymakers, suppliers and infrastructure support, dominant technologies can be sustained in the face of potentially superior substitutes. Socio-technical transitions can thus be hindered by the resilience of existing infrastructures, as policymakers are reluctant to invest in novel products or services. Using the example of carbon capture and utilisation (CCU) based fuels, we set up a discrete choice experiment to assess whether European policymakers (working at European, national and regional levels) have a tendency to avoid investing in novel, and more disruptive technologies, and rather prefer to invest in technologies that resemble the incumbent.

1.3.3 Unlocking behavioural lock-in

The fourth chapter of the thesis looks to how sustainability transitions and policies imposed to target change may impact certain groups and livelihoods more than others, which may, in turn, induce a form of behavioural lock-in. The transition will affect nearly 1.5 billion workers across the world that the secretariat of the UN Framework Convention on Climate Change (UNFCCC) has identified: agriculture (1 billion), followed by manufacturing (200 million), buildings (110 million), transport (88 million) and energy (30 million) (UNFCCC, 2016). These sectors will in particular meet transitional challenges, and because of this, this third chapter focuses on the (French) agricultural sector in particular on the road to an agro-ecological transition.

Despite substantial policy efforts made by the French government to reduce dependence on pesticides, farming practices are only changing slowly. This paper analyses the socio-economic trade-offs that farmers are currently facing in the transition to agro-ecological practices, and how a kind of behavioural lock-in has occurred with regard to the uptake of sustainable farming practices and the way that institutional practices have reinforced this lock-in. A mixed-method approach - a discrete choice experiment that was complemented with semi-structured interviews - was set up to understand farmers' motivations, habits and perspectives, and how policy can accompany them on the road to low-pesticide agricultural systems, as a result out of this type of behavioural lock-in.

1.3.4 Unlocking lock-in: increasing acceptability of policy instruments to accelerate socio-technical transitions to sustainability

The fifth chapter of the thesis seeks to assess two of the main types of policies that are often considered when encouraging eco-innovation: economic instruments and regulatory instruments (Bergek et al., 2014; Horbach et al., 2012; Kemp and Pontoglio, 2011; Peters et al., 2012; Rennings, 2000). With this in mind, this chapter studies the relative acceptability of reducing the use of glyphosate by attaching a strong pesticide tax to it (an economic market-based instrument) with respect to a ban (a regulatory command-and-control based instrument), for the general population across several European countries. We consider the question: is an alternative to a ban, such as a tax, socially acceptable? The literature has established that environmental taxation is popular amongst economists for reasons of efficiency and environmental effectiveness, but very unpopular amongst the general public (Carattini et al., 2018). The aim of the research is not to establish whether one policy is better than the other, but to understand better how we can increase acceptability so that both instruments can be more widely used.

If we are to unlock lock-in processes and accelerate sustainability transitions, establishing how to increase effectiveness and acceptability of these policies is key. On the one hand, understanding how to implement an efficient pesticide tax regime to phase out the use of glyphosate, requires balancing political feasibility and public acceptance considerations in line with tax and environmental policy. While the rationale for a tax on glyphosate lies in the abatement incentives and reduction of pesticides that it might create among farmers, the question arises as to how the use of revenue from pesticide pricing affects its political feasibility – and specifically the preferences of the consumers of the agricultural products whose prices will likely be impacted. We compare this with the general population's preferences for an outright ban. To help answer this question, a discrete choice experiment (DCE) was conducted with a representative sample of the population in five European countries: Belgium, France, Germany, Italy and Spain.

1.4 Methodological discussion

1.4.1 Discrete Choice Experiments

Discrete choice experiments are a non-market valuation method based on repeated fictional choices made by respondents to elicit their preferences. Discrete choice experiments involve three inter-related components: (i) an experimental design used to implement a choice survey and generate choice data; (ii) quantitative statistical analysis to estimate preferences from choice data; and (iii) the use of the resulting model to either derive welfare measures or construct other policy

analyses. Monetary attributes and levels can also be incorporated into a DCE. Therefore, it is possible to determine a population's willingness to pay (WTP) for, or accept (WTA), an intervention.

The conceptual framework of a DCE assumes that respondents' utilities for a good, service or policy can be broken down into utilities derived from characteristics of that good, service or policy, as well as a stochastic and random element. Choices between alternatives thus reflect the utility of those alternatives, as derived from random utility theory (McFadden, 1973). The random utility framework depends upon the application of statistical design theory to construct choice cards. These choice cards describe different options - with each option is differentiated by a set of attributes and levels. Respondents will then choose their preferred option amongst a series of mutually exclusive alternatives (usually two to three). A baseline (i.e., a status quo alternative) or opt-out (a "do nothing" option) is often included to ensure that respondents are not forced to choose if they prefer not to and that they may consider worse than what they currently have. There are many strengths to using DCEs, but also certain weaknesses. Methodological challenges and related literature are further discussed in section 1.4.1.1 and section 1.4.2., but some of these strengths and weaknesses can be summarised as follows:

Strengths of discrete choice experiments

- DCEs can estimate values for changes in many public goods, including environmental services, human health effects, and other outcomes for which (direct or indirect) revealed preference data are not available. Hence, they can estimate non-use values, or use values associated with changes that fall outside the range of current markets or observed conditions (Johnston et al., 2017).
- DCEs are well suited to situations where a change is multi-dimensional, and the trade-offs between these dimensions are of interest: this strength is is based on the ability of DCEs to identify and value individual characteristics (i.e., the attributes and levels) of a good, service or policy (Holmes et al., 2017).[1] If policymakers are in need of measures of a change in individual characteristics of a policy, DCEs are helpful.
- The DCE presentation format makes it possible to customise choice sets such that they are realistic for respondents and reflecting the specific situation they may be facing in the future (Holmes et al., 2017).
- DCEs are highly informative given that respondents receive multiple chances to express their preferences for a valued good, service or policy, possibly over a range of payment amounts.

[1] This multi-dimensionality is contrasted to contingent valuation, which is considered the sister stated preference technique of DCEs. Contingent valuation techniques are used to uncover the value of total change in a multi-dimensional good, in which respondents are asked directly about their willingness-to-pay.

Weaknesses of discrete choice experiments

- DCEs rely on what respondents say they will do (as is the case for all stated preference data) rather than what they actually do - referred to as revealed preference data. The literature shows a healthy scepticism for relying on stated preference data compared with revealed preference data for this reason as we cannot be sure if these results can be replicated in real-world settings (Ryan et al., 2008).
- Relatedly, welfare estimates made with stated preference methods can sometimes fall prey to hypothetical bias: respondents are typically more price sensitive in real life than in hypothetical choice scenarios: the willingness-to-pay can therefore be overestimated in discrete choice experiments (Murphy et al., 2005).
- A major drawback of DCE lies in the cognitive burden placed on respondents relating to complex choices between alternatives, and attributes and levels. Respondents usually fare better when faced with a smaller number of easier trade-offs and such response bias can be avoided with careful design (Johnson et al., 2013). If too many attributes are included, respondents may experience response fatigue and rely on heuristics or rules of thumb to simplify the choice task.
- Research has shown that the status quo, baseline or opt-out option is often chosen disproportionately by respondents (Meyerhoff and Liebe, 2009; Scarpa et al., 2007). This can sometimes be attributed to status quo bias (Samuelson and Zeckhauser, 1988), rooted in inertia, biased perceptions, cognitive ability, uncertainty, distrust and doubts about the programmes proposed (Meyerhoff and Liebe, 2009).

1.4.1.1 State-of-the-art

As stated preference techniques reach maturity, most of the last decade's developments have been small improvements in statistical design, econometric analysis, and survey implementation (thanks to the proliferation of online survey techniques) (Mariel et al., 2021; Johnston et al., 2017). Discrete choice experiments are routinely discussed alongside the sometimes better-known contingent valuation method in state-of-the-art manuals discussing design, analysis and the use of stated preference studies. In recent years, DCEs have overtaken contingent valuation in the number of applications and citations (Mahieu et al., 2014) in environmental valuation. As discussed above, there are many reasons for their popularity, including the possibility of extracting extensive information from respondents. Also, statistical design, implementation and econometric analysis have been facilitated by developing statistical software and technology for online surveys, enabling ease-of-use for respondents. DCEs are useful when valuing complex multidimensional changes when valuing individual components of a policy and when the trade-offs between them are important.

DCE remains useful for non-market valuation, and when direct elicitation of preferences is not possible, but results should still be used with caution due to the potential for hypothetical bias and neglect of future, social and incommensurable values, and tests of reliability and validity should be more routinely integrated into DCE studies as a result (Rakotonarivo et al., 2016). Hypothetical bias is a well-known limitation of DCEs and something the field has sought to address to reduce (Jacquemet et al., 2013; Czajkowski et al., 2017; Liebe et al., 2019; Zawojska et al., 2019). Given the hypothetical nature of the method, respondents may overstate their WTP. Ways to reduce hypothetical bias, can, as Colombo et al. (2020) put forward, be divided into ex-ante and ex-post mitigation strategies. Ex-ante mitigation strategies seek to reduce hypothetical bias in the design stage of the survey by emphasising what can be referred to as consequentiality – i.e., the consequence of the respondent's choices. This can be addressed through additional payments and services, or reminders to respondents to behave as they normally would behave (such as 'cheap talk' scripts (Doyon et al., 2015)). Ex-post approaches to tackle hypothetical bias could include screening data for implausible responses based on post-experimental questions related to respondents' maximum WTP, for example, or respondents' stated certainty about a choice. Another option is to combine stated preferences data with revealed preference data (Colombo et al., 2020).

In addition to the potential for hypothetical bias, Lienhoop and Schröter-Schlaack (2018) discuss three important methodological challenges that can be directed to stated preference methods:

A first methodological challenge relates to preference formation. The assumption based on standard economic theory sees that respondents have stable and pre-defined preferences that can simply be drawn upon when responding to a survey. Psychologists, such as Kahneman et al. (1999) argue that people do *not* have such pre-defined preferences, and rather tend to have general attitudes towards a topic. This can particularly be of concern when valuing complex and unfamiliar goods and services, which can then mean that stated WTP does not necessarily reflect the true value of the good, service or policy studied (Tversky and Kahneman, 1974; Brouwer et al., 1999).

A second methodological challenge relates to the assumption of *homo oeconomicus* that preferences should be based only on personal needs. Preferences, and, in turn, WTP should then only maximise individual well-being, while respondents should disregard that of society at large. Disentangling the public from the private, however, is not as straight-forward as this, especially when considering issues of environmental valuation, which necessarily is a public good. A related criticism concerns the way in which preferences are elicited based on what the respondent chooses today, and not based on those of future generations. This disregard can lead to the underestimation of overall value (Niemeyer and Spash, 2001; Wilson and Howarth, 2002).

A third methodological challenge relates to the commensurability of stated preference methods, and therefore DCEs (Aldred, 2006). Commensurability refers to the way in which economic valuation derived from DCEs - usually expressed in

monetary units - is comparable when discussing costs and benefits for a project or policy. This commensurability assumes that we can keep impacts on the environment, health and biodiversity on par, which is unrealistic. This then raises the question as to whether these effects really can be comparable when reduced to the common metric of money.

An approach that can to some extent seek to address the above-mentioned issues is deliberative monetary valuation (DMV) - a term coined by Spash (2007). DMV is an approach that juxtaposes the quantitative with the qualitative by using concepts from political science, philosophy and sociology (specifically Habermas's ideal speech situation (Habermas, 1984), Rawls's Theory of Justice (Rawls, 1971) or more recently, Sen's approach to rationality (Sen, 2009)). By considering these concepts, DMV combines stated preference valuation with deliberative elements such as group discussions that include information provision, opportunity to discuss and time to think (Schaafsma et al., 2018). This approach seeks to improve and address issues of preference construction, lack of knowledge and understanding of complex environmental problems, for example (Spash, 2007). It further facilitates the development of a more complete view for respondents, including the needs of future generations, as well as social and incommensurable values. Specifically, DMV can allow respondents to discuss and consider public and other-regarding interests, as well as incommensurability issues, which can then enter respondents' thought and decision processes. By making decisions guided through concepts of Habermas, Rawls and Sen, respondents are encouraged to consider issues of fairness and how an issue may affect society at large, which can then be captured by the stated preference method (Lienhoop and Schröter-Schlaack, 2018). Previous studies comparing deliberative monetary valuation and conventional valuation surveys illustrate that preferences elicited in a deliberative setting are more accurate, and can be better explained and better informed (MacMillan et al., 2006; Lienhoop and Völker, 2016).

The need for complete accuracy of monetary valuation in DCEs depends on what they will be used for. When DCEs are used to inform policymakers on relevant policy features for future prioritisation, or for awareness raising, DCEs are still highly relevant and can provide important information for decision-makers or other target groups. Even though the monetary valuation may not be completely accurate, it can still provide useful information regarding the approximate magnitude of non-market values. Accuracy *is* needed to a greater extent, however, if the DCE is relevant for project and policy appraisal (Lienhoop et al., 2015; Lienhoop and Schröter-Schlaack, 2018).

1.4.2 Stability and change under risk and uncertainty

This thesis is grounded in the theoretical background of socio-technical transitions. A key component of transitions research lies in the contentious relationship between stability and change. First of all, despite increases in both supply and demand for sustainable innovations and practices in recent years – from e.g., alter-

native fuels, electric vehicles, urban and organic agriculture, to only name a few examples – these innovations are at the same time deeply entrenched in incumbent technological systems – from coal and gas power plants, to gasoline powered-vehicles, and other practices and sources of locked-in production and consumption patterns. These patterns create stable, path-dependent trajectories.

Because of its interest in radical systems change, transitions research aims to understand the interactions between radical change and the forces of stability and path dependence (Köhler et al., 2019). Technology does not exist in a vacuum – away from society, social behaviours and social institutions – it both shapes and is shaped by society (Bijker et al., 1989). In fact, socio-technical transitions do not just change the structures of existing systems, but they also affect related societal domains, such as culture, habits, housing and working, production, trade and planning. For reasons such as these, infrastructure systems are often regarded as inflexible, difficult to change, and vulnerable to path dependence and lock-in and can result in inertia (Markard et al., 2012). Transitions theory looks to ways in which it can be possible to break these patterns of path dependence and lock-in in an environment of risk and uncertainty.[2]

This contentious relationship between stability and change is also relevant to discrete choice experiments, the method used in three major chapters of this thesis. DCEs assume – to some extent – stable and well-formed preferences. As mentioned above, DCEs are a helpful tool to design policies and interventions that can, in turn, influence decisions, as this requires an understanding of how decisions are made, and the preferences underlying these decisions. Attempting to move people from their current set of choices to a new set of choices depends, according to standard economic theory, on understanding the changes in costs and benefits, and the trade-offs between these which DCEs can investigate. Economic theory also assumes that an attribute of a good or service presented to a respondent in a DCE is valued independently of context. Thus, respondents should make rational choices while choice tasks should generate attribute rankings that are consistent regardless of how they were elicited.

Random utility models underlying DCEs, as put forward since Lancaster (1966) and McFadden (1973), assumes that respondents' choices depend on compensatory heuristics. This implies that respondents can trade-off one attribute against another in order to determine their most preferred alternative. The use of non-compensatory decision rules can also be a fully rational process, however. As discussed by Araña and León (2009), Sen et al. (1999) sees that such non-compensatory behaviour "indicates the case for making room for departures from the usual requirements of 'rationality' in understanding actual behaviour." That decision rules chosen by respondents can be conditional on the DCE and provided choice task

[2]The definition of risk applied to transitions pathways by Song et al. (2020) and Agard et al. (2014) is relevant in this context: "[t]he potential, when the outcome is uncertain, for adverse consequences on lives, livelihoods, health, ecosystems, economic, social and cultural assets, services (including environmental services), and infrastructure." Risk to a low-carbon transition is framed as the deprioritisation of emerging technologies, thereby starving transitions processes of both attention and resources, or incumbents acting to limit innovations. Socio-technical transition to sustainability will as a consequence, be slowed.

raises challenges to the understanding of the use of the decision rules in DCEs, and to the measurement of their effects (Araña and León, 2009). This concern, and how to reduce it, is frequently discussed in the literature, as such 'rational' behaviour cannot always observed in practice, and cognitive anomalies and biases can indeed influence choices.

Prospect theory (Kahneman and Tversky, 2013) recognises that reference points influence choices, and movements away from the reference point are evaluated in terms of gains and losses relative to this point (Scott and Witt, 2020), and see that decisions can fall under two categories. A choice can be risky or riskless depending on the outcome of the choice (with risk referring to the probability of the uncertainty of the outcome of a choice), and the introduction of subjective probability weightings can lead to a respondent's risk-attitude varying with the subjective treatment of outcome probabilities (Kahneman and Tversky, 2013). For example, in an experimental setting, choice options can be manipulated such that one option represents a sure gain or loss, while the other represents a risky alternative with a numeric probability. A common finding in the literature is that people tend to take more risks when options highlight the avoidance of losses than when they highlight comparable gains (Levin et al., 1998). Such a risky choice framing effect calls into question the notion that people have stable and unmalleable preferences.

Status quo bias is also important to consider in this regard. As individuals weigh losses heavier than gains, they may also be reluctant to change and therefore biased towards the status quo alternative. Emotional commitment can also lead to preferences for the status quo - this can be due to the sunk costs invested in the status quo option or regret for making the wrong choice. Status quo bias is considered to be a cognitive shortcoming in the sense that the bias exists even when there is no evidence showing the status quo choice is better than the alternatives (Samuelson and Zeckhauser, 1988; Bekir and Doss, 2020). In some cases, however, the status quo bias can be the rational choice - making this choice might be due to transition costs, when the loss of switching to alternative choice is higher than the gains of sticking to the status quo, especially when valuing complex or unknown goods, services or policies.

Choice under risk and uncertainty is a central point of discussion both in the fields of sustainability transitions, as well as in DCEs when choosing between making a change or keeping things as they are. On the one hand, as transitions studies point out, uncertainty is prevalent in all domains of innovation pathways as it is impossible to predict which innovation will prevail. This uncertainty is rooted in the non-linear character of innovation pathways, political and socio-cultural processes that may hinder the success of a technology (Geels and Schot, 2007; Rosenbloom, 2017; Köhler et al., 2019). Further, regardless of the extent to which researchers seek to reduce uncertainty in DCEs, there will always be some inherent uncertainty in any choice made with regard to socio-technical transitions to sustainability, due to the unpredictable nature of natural environmental phenomena. As a result inherent uncertainty cannot always be controlled for (Torres et al., 2017).

1.4.3 Contributions of the thesis

This principle contribution of this thesis lies in bringing quantitative methods, and specifically in this case - discrete choice experiments - to transitions studies. According to a systematic review of peer-reviewed papers in the five most influential journals in the transitions field[3], over 80 % of research conducted since 2002 until recently has been of qualitative nature (Zolfagharian et al., 2019). Further investigation into the type of quantitative methods used in those remaining 20 % reviewed papers, as well as in the broader literature, reveal that DCEs have not been used in the field, at least to the best of the author's knowledge. Taking the economic value of environmental goods and services into account is becoming increasingly important for decision-making and policy assessment. If this is the case, DCEs have an important future role to play in transitions studies - by better understanding target groups' trade-offs and preferences related to policy avenues that can facilitate and accelerate change and socio-technical transitions. Stated preference methods have long been used to guide decision-makers in the health and transport domains (OECD, 2017), so the need for transitions studies to make use of the method should be increased to better understand determinants of behaviour to create policy interventions for effective transition pathways.

Moreover, by bringing DCEs to transitions studies, the importance of social acceptance in the field of transitions is emphasised - in this thesis through chapter 3 (policymakers' acceptance considerations) and chapter 5 (acceptance considerations of the general public). Social acceptance - especially with regard to the general public - has largely been disregarded in the transitions field, which has focused on elites, firms and niches, while somewhat simultaneously neglecting the role that citizens have to play in transitions processes (Markard et al., 2016a,b; Ingold et al., 2019). As Ingold et al. (2019) point out, "citizens are the target group of sustainability policies, and their acceptance and subsequent behavioural change are key in transition processes." Citizens are often the direct addressees of policy instruments and are expected to change their behaviour so as to achieve politically defined targets. Their reactions towards policy instruments (e.g., acceptance but also potential opposition) are crucial for the successful implementation of policy instruments, and for the success of larger sustainability transitions. Chapter 5 of this thesis specifically contributes to this gap by studying the public acceptance of the general public with regard to a tax or a ban of glyphosate, and in turn the agro-ecological transition and agro-food transitions to sustainability - two frequently discussed areas in the field (El Bilali, 2019, 2020; Grin, 2012; Levkoe, 2011; Smith and Jehlička, 2007; Meek, 2016). As mentioned previously, transitions research acknowledges the central role that policy will play in shaping the directionality of transitions through environmental regulations, standards, taxes, subsidies and innovation policies (Köhler et al., 2019).

On the other hand, the thesis contributes to the longer history of DCE literature bridging the traditionally quantitative method with the qualitative. For instance,

[3] *Energy Policy; Research Policy; Technological Forecasting and Social Change; Technology Analysis and Strategic Management; Environmental Innovation and Societal Transitions*

the fourth chapter of the thesis complements data acquired through a DCE with semi-structured interviews. The third chapter thus consists of a mixed-method study to understand farmers' decision criteria to accompany them on the road to changing their practices to more sustainably oriented agricultural methods. The semi-structured interviews did *not* validate the data acquired in the DCE - mostly due to the time taken between the distribution of the survey and the interviews which made this difficult, which means that the results of the interviews were in this way not directly related to the DCE data. What the information retrieved through the interviews *did* allow us to do was to gain a deeper understanding into views on the subject matter from a representative sample of the population that took part in the DCE. This approach of mixing DCEs with qualitative methods (through focus groups, group discussions or interviews for example) has previously been undertaken by e.g., Brouwer et al. (1999), Clark et al. (2000), Powe et al. (2005), Powe (2007), Spash (2007) Araña and León (2009) and Schaafsma et al. (2017), to only name a few.

The difference with regard to the aforementioned studies is that the decision to combine the DCE was not taken before the design of the DCE, but afterwards, due to the realisation of - what we argue to be - a certain rejection of the methodology by the respondents. DCEs are valuable to estimate preferences in a hypothetical setting. However, when considering such complex socio-technical transitions - and the highly uncertain, risky and controversial changes that are at stake (as with the case of agro-ecological transitions in France), we highlight how and why respondents needed a more open-ended discussion forum to complement the more rigid DCE format. A comparative review was conducted on former DCEs that have tackled similar topics, as these exist to falsify our methodological concerns. We argue that our study, in contrast to the others, took a broader view of the question at stake - to our loss. Through the semi-structured interviews, we were nonetheless able to gain a broader understanding of the respondents' views on transitioning to agro-ecological practices, and believe that this is a useful lesson for researchers tackling similar questions when discussing complex questions relating to socio-technical transitions into account.

The third chapter investigates policymakers' preferences through a DCE, which is uncommon. European policymakers' use of power through funding mechanisms (that, in turn, cause resistance to transitions to disruptive and innovative low-carbon transport systems) was explored. While it is not the first DCE to have investigated policymakers' preferences (see van Rijnsoever et al. (2013)), it is among the few in this area of research and the DCE literature generally, as these groups are known to be difficult to reach, as compared to the general population, students or other groups. This chapter therefore broadens the known target audience and highlights the importance of estimating policymakers' preferences and trade-offs of a group that impacts society as a whole. In addition to drawing from the transitions literature, it also draws from concepts in cognitive and social psychology to investigate policymakers' decision-making processes.

While the effect of introducing uncertainty in the analysis of preferences was not tested for - which requires comparing individuals' WTP for given environmental

outcomes in a certain versus uncertain setting (as briefly discussed above) - the author argues that it is possible to draw some insight into perceptions of risk and uncertainty from the DCEs conducted in chapter 3 and 5 of the thesis. In chapter 3, policymakers were asked about their preferences with regard to what was referred to as an incumbent and innovative fuel option - both directly (with no previous information) and again, through the DCE. Results illustrate that different mechanisms were at play when making a choice in a DCE and otherwise. When policymakers were provided with the associated information about each alternative presented to them in the choice sets (in this case regarding the fuel type), policymakers did not show a preference for either the incumbent nor innovative option and fully made their choice based on the attributes and characteristics presented to them. However, when they were simply asked - without any information provided - whether they would prefer to fund one of the fuel-types that was stated as being innovative, and the other as resembling the incumbent, the great majority of policymakers that took part chose the incumbent. This finding shows that the policymakers studied presented a healthy scepticism when information was lacking (and the choice was more uncertain), and were, in turn, more risk-averse.

In chapter 5, due to the difficulty of establishing and appropriate cost vector (the number of levels to use and their associated values for price), we decided to distribute a split-sample survey to consumers to investigate the choice we made and whether it impacted choices. This difficulty can be attributed to the uncertain nature of the question tackled. By distributing such a split-sample survey, we could gain some insights into the way in which the cost vector impacts behaviour and willingness-to-pay. Literature has illustrated that WTP tends to increase as the cost vector offered increases (Glenk et al., 2019). Our paper therefore contributes to the literature looking into the impact of cost vector design on WTP estimates (Ryan and Wordsworth, 2000; Hanley et al., 2005; Carlsson and Martinsson, 2008; Kragt, 2013; Su et al., 2017; Glenk et al., 2019). Glenk et al. (2019) reviews the literature on behavioural mechanisms that could be at play when differences in willingness-to-pay arise from different cost vectors. As discussed, an assumption underlying DCEs is that individuals have well-defined and stable preferences. However, criticisms of this assumption argue that preferences are actually malleable, and can change depending on the information received in the choice sets (Slovic, 2020; Bettman et al., 1998; Payne et al., 1999; Hoeffler and Ariely, 1999). A well-known criticism dates back to Tversky and Kahneman (1974): they found that prior cues or anchors affect subsequent valuations. Relating this to DCEs, respondents may have a range of acceptable values already in mind, and when respondents may be uncertain about a value provided or a question asked, the choices made by respondents might be affected by the framing of choice options, choice context and anchoring effects. We found that willingness-to-pay did change depending on the survey and associated levels - especially for one attribute. This chapter therefore contributes to the literature illustrating the challenges with regard to acquiring accurate WTP estimates, especially in a case where not all respondents were familiar with the topic in question.

Chapter 5 also demonstrates how reference scenarios can be established in the

challenging situation where the status quo is not a suitable baseline. This chapter made use of a DCE to establish consumers' preferences, with the aim to understand better how to balance political feasibility with the design of an effective pesticide reduction policy mix. In our DCE, respondents are asked to choose between two hypothetical alternatives and a status quo alternative, referring to the reference scenario. Including a status quo (i.e., the current situation) or an opt-out is useful to attain more realistic results: this avoids people being forced to make choices that they do not wish to make (Louviere et al., 2000a). However, in our case, the status quo had to present a future situation and was then the most probable or the business-as-usual future situation, which is not usually the case in DCEs. To determine the status quo, we had to decide the most probable policy outcome concerning the future of agricultural glyphosate use in 2022 when following the current political trend. Given the political context regarding glyphosate in the five countries we consider, we concluded that a ban on glyphosate was the most realistic business-as-usual option. (Adamowicz and Boxall, 2001; Lew et al., 2010; Pedersen and Gyrd-Hansen, 2013; Kontoleon and Yabe, 2003) state that choice cards can present a future situation, and the status quo is then the most probable or the business-as-usual future case. Our study contributes to this research area, and shows that it was indeed possible to inform respondents of the status quo alternatives as to the most likely outcome (and attain meaningful results as a result).

Overall, the this thesis contributes to the recent academic literature seeking to reconcile lock-in and sustainability transitions studies with considerations of policy, institutions and political decision-making processes through discrete choice experiments. Politics and power have been receiving increased attention in recent years in the transitions literature, due to criticism raised that they have been neglected within the field (Avelino et al., 2016; Kuzemko et al., 2016). After all, policy represents one of the core dimensions of the socio-technical regime, along with user practices, science, cultural meaning and infrastructure (Geels, 2014, 2018). Further, "transitions are inherently political processes in the sense that different individuals and groups will disagree about desirable directions of transitions, about appropriate ways to steer such processes and in the sense that transitions potentially lead to winners and losers" (Köhler et al., 2019).

Against this background, this thesis focuses on existing technology and innovation systems and the actors involved in the policies supporting them or hindering them. The specific contribution to the transitions literature is to consider regime stability, and in turn dependence on dominant technologies, as being a result of resistance, whether deliberate or not, by incumbent actors or institutions. In terms of lock-in as a configuration playing a major role in these transitions, this thesis takes a systemic stance, as opposed to one focusing on products or market forces, and seeks to illustrate the ways in which these processes are interlinked through technological, institutional and behavioural angles: policy design needs to take this into account if socio-technical transitions to sustainability are to be accelerated.

Chapter 2

The lock-in effect and the greening of automotive cooling systems in the European Union

This chapter is based on Bjørnåvold, A. and Van Passel, S. (2017). The lock-in effect and the greening of automotive cooling systems in the European Union. Journal of Environmental Management, 203:1199–1207.

2.1 Introduction

As we approach the 30th anniversary of the 1989 Montreal Protocol and its successful ban on the use of chlorofluorocarbons (CFCs) - the refrigerants blamed for depleting the ozone layer - the gases that were chosen to replace CFCs have, regrettably, been identified as significant contributors to climate change. Hydrofluorocarbons (HFCs), the synthetic refrigerants developed in the 1990s as ozone-friendly alternatives to CFCs, eventually emerged as potent greenhouse gases (GHGs), with thousands of times greater greenhouse potential than CO_2. HFCs are most commonly used in mobile air conditioning (MAC) - and thus in automotive cooling systems - and, along with a rapidly expanding market for cooling worldwide, the EU MAC Directive 2006/40/EC, has banned the use of all cooling agents in new passenger vehicles with a global warming potential (GWP) above 150 across the European Union (EU) as of 2017.

The EU MAC Directive is deemed 'technology-neutral'. This means that any substitute to HFC-134a - the refrigerant to be banned (whose GWP is 1430) e is accepted as long as the refrigerant has a GWP below 150. The MAC Directive gave producers five years to develop alternatives to the climate-damaging predecessor from the Directive's implementation in 2006, and through extensive research and testing by manufacturers and suppliers it eventually became clear that the synthetic refrigerant R-1234yf and natural option of CO_2 were the major contenders. The EU does not currently mandate the use of either, as long as the aforementioned guidelines are followed (Commission, 2014)

Although the market for automotive cooling systems in the EU has largely been driven by regulation in recent decades, research continues to remain focused on its technological development, often disregarding the socio-economic conditions driving (or limiting) their development or deployment. This paper seeks to address this gap, and argues that the regulatory framework of the EU has reinforced a patented monopoly held by the producers of R-1234yf - one of the two major contenders. At the time of writing, R-1234yf is widely known as the dominant replacement for HFC-134a MAC systems. It is already used in 18 million vehicles worldwide and all car manufacturers are shifting to R-1234yf, with the exception of Audi and Daimler, which plan to offer CO_2 systems as an option in some vehicles in 2017. In order to illustrate the way in which a patented monopoly has been reinforced through a regulatory framework, the objective of this paper is to highlight how the market for MAC systems has been 'locked-in'; this means that when two technologies are in competition with one another, operating under dynamic increasing returns, one (potentially inferior) technology, with a first-mover advantage, will eventually dominate the market.

2.2 Literature review: path dependence and lock-in revisited

The concepts of path dependence and lock-in are rooted in evolutionary approaches to understanding technological change. The concepts are broadly used to explain how technologies develop and endure, or why they simply disappear (Cairns, 2014). Central to these approaches is that certain 'choices' (although not necessarily conscious ones) lead to the way in which technologies and systems are designed. Different paths can be taken, which can lead to entirely different technological solutions and products entering the market (Foxon, 2011). Path dependence specifically, as (Margolis et al., 2009) put it, "is a condition in which economic outcomes exhibit inertia." As such, theories of path dependence argue that this evolutionary process of technological development can sometimes get stuck, temporarily and sometimes even permanently (North et al., 1990). Given that technological development in this sense is historically contingent, and not necessarily governed by optimality, a technology can base itself on inferior designs (Maréchal, 2009). This concept of path dependence, then, seeks to explain why sub-optimal solutions can sometimes prevail in the market.

David (1985) and Arthur (1989) are considered the pioneers behind technological lock-in, a concept used to understand the technological outcome of path dependence when markets are subject to inertia. The concept especially draws attention to the historically contingent nature of economic change (Maréchal, 2007). The idea of lock-in broadly sees that, in the event of two competing technologies being adopted in succession of one another, the market will tend to avoid experimentation, despite other alternatives potentially being superior or more efficient. Scholars of neoclassical economics argue that market processes would allow for a more efficient technology to be taken up by the market, given that manufacturers and

users should automatically seek out the most efficient alternative. However, in a world of uncertainty and bounded rationality, this does not necessarily hold with regard to the fast-changing nature of technological change. As such, technologies cannot be considered as isolated mechanisms, but instead belonging to technological systems that include natural, social and institutional elements (Unruh, 2000). Once historical conditions and the interrelation of characteristics have led to the emergence of such a system, their many components lead to the stabilisation and inertia of the system. Solving environmental or social issues through regulatory frameworks in an effective way requires a broader integration of social and natural sciences (Virapongse et al., 2016).

Specifically, through a series of self-reinforcing mechanisms of increasing returns (implying that the more a technology is adopted, the higher the likelihood that even more of the technology will be adopted), there are four classes that can lead to the first technology (out of two) dominating the market; these are (i) scale economies, (ii) learning effects, (iii) adaptive expectations and (iv) network effects (Arthur, 1989). From this, we can draw two central ideas from lock-in. The first is that technological systems can become deeply embedded into inert, durable, potentially sub-optimal and inferior patterns and designs. The second is that these systems are deeply entrenched in complex, interdependent technological and socio-economic systems that can be difficult to escape from. Thus, research into locked-in systems requires taking system-wide policy approaches into account in order to understand their full effect (Perkins, 2003). Understanding the principal causes of this inertia is crucial for enforcing system change (Marechal and Lazaric, 2010). As Carrillo-Hermosilla (2006) put it: "early superiority is no guarantee of long-term suitability."

2.2.1 Self-reinforcing mechanisms

When two technologies compete for the same market, a snowballing effect can lead to the intensification of minor differences in market share (Arthur, 1989). Choices, or decision-making processes, will then exhibit self-reinforcing mechanisms and feedback effects, where inferior and potentially inefficient technologies can become locked in (see Fig. 2.1). Thus, when increasing returns or feedback effects are present, designs that are inferior can be locked in to the market through a historically path-dependent process in which "circumstantial events determine the winning alternative" (Carrillo-Hermosilla, 2006).

Arthur referred to scale economies as one of four major issues that potentially lead to the lock-in of one new technology over another. Although new technologies are initially costly, these costs will decrease the more of the technology is produced (Arthur, 1989). However, significant barriers to entry exist from upfront investment costs, given that immediate cost savings cannot always be guaranteed. Furthermore, the fixed costs previously used to set up and place the dominant technology on the market (sunk costs) exist for technologies already in use, including early investments, which means that the incentives to invest or choose a new

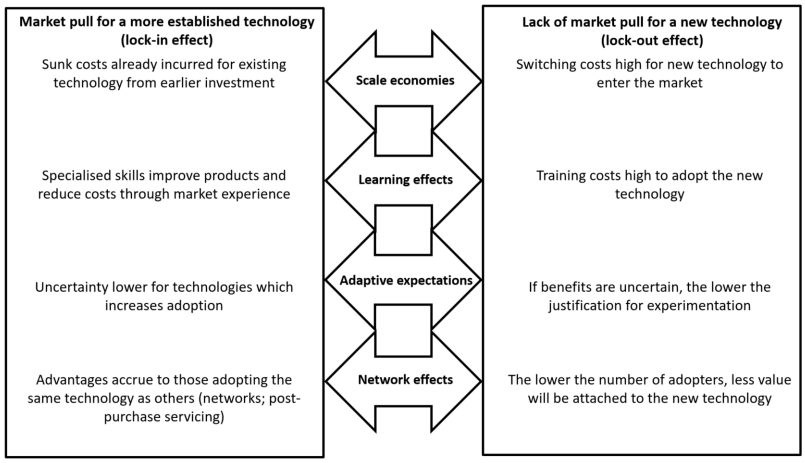

Figure 2.1: Self-reinforcing mechanisms leading to the lock-in or lock-out of competing technologies.

technology or alternative are reduced. This adds to the effect of scale economies, whereby cost advantages accrue to the producer that first entered the market. A superior alternative might not be chosen if the expected costs to switching to an alternative outweigh the efficiency gains of facilitating such a transition, which in turn engenders a barrier to adoption and entry (Woerdman, 2004)

Knowledge and experience accumulated over time generally lead to higher returns if you continue along the same production path as before (Kuokkanen et al., 2017). Thus, learning effects usually improve the quality of technologies, while reducing costs, which will in turn intensify the benefits of adopting one technology over another. This means that when two relatively young technologies are competing for the same market, the one that is initially leading in the market share will push it further all along the learning curve; this is because technicians and users will already have acquired skills to take it into use, which will make it more attractive to future adopters (Cowan and Gunby, 1996). In this sense, learning is path-dependent and the early success of lowering running costs contributes to the condition of lock-in (Woerdman, 2004).

An important indicator of lock-in mechanisms is the notion of adaptive expectations, and more generally, the effect that uncertainty plays on the expected uptake of technologies. Broadly speaking, the theory sees that adoption will increase as uncertainty decreases. This can be attributed to manufacturers or users that consider it too costly to experiment with alternative technologies, given that their expected benefits are not well known, and if some are recognised, they do not provide a decent enough justification for experimentation (Brekke, 2003). This means that the increased prevalence of a technology on the market in itself enhances beliefs of future prevalence on the market. In this sense, the expectation held by consumers and end-users that a product will hold a large share of the market redi-

rects demand and induces producers to place significant proportions of a product on the market. The fourth and final aspect present in locked-in markets is the advantages that benefit those adopting the same technologies as others: network effects (Katz and Shapiro, 1985). Network economies come to the fore given significant interdependencies between systems and users of technologies (Unruh, 2000). As Foxon (Foxon, 2002) explained, network effects emerge from systemic interrelations between "technologies, infrastructures, interdependent industries and users. These externalities reinforce the dominance of the system due to both physical and informational networks growing in value to users as they become larger and more interconnected." The more adopters exist in these technological networks, the higher the value users will derive and gain from taking part in them (Barnes et al., 2004).

2.2.2 Conditions for escaping lock-in

The lock-in and path dependence literature has thoroughly and consistently studied how these situations come about, but has devoted much less attention to what to actually do to escape it. This is problematic because the lock-in of a technology can manifest significant negative externalities. As seen by Cairns (2014), this effect is frequently noted as entrapment (Walker, 2000), or entrenchment (Collingridge, 1982). The lock-in of technologies has displayed significantly damaging effects on the environment and our health, which has led to an increasing number of scholars studying the link between technological lock-in and ecological change, especially with regard to pollution and the fossil fuel energy distribution system, widely referred to as 'carbon lock-in' (Unruh, 2000); and also within the nuclear industry (Cowan, 1990b), end-of-pipe solutions (Kline, 2001), and pest control strategies (Cowan and Gunby, 1996; Wilson and Tisdell, 2001). As seen through the Collingridge dilemma and the notion of societal control of technological development, in the early stages when a technology's applications are relatively simple to reverse, its impacts and effects are uncertain and unpredictable, but when these outcomes and effects are actually known, control and change of the technology is often difficult and even impossible due to the extent of its establishment in the economy. As Collingridge (1982) explains:

"When change is easy, the need for it cannot be foreseen; when the need for change is apparent, change has become expensive, difficult, and time-consuming."

Collingridge suggests that the only way around this is to improve anticipative and forecasting tools. One way to avoid this situation is to ensure that technological diversity, or flexibility, is maintained. However, as Huber (2004) argued, "lock-in is unavoidable, depending on the stage of structuration and diffusion. But there should always remain certain degrees of freedom." Therefore, it is necessary to distinguish the level of lock-in of a specific technology (Shackley and Green, 2007). It is the depth of the lock-in that can cause issues: the more the flexibility is reduced and 'error cost' increased, the more serious the problems will be, all of which are attributable to the reversibility of the technology.

Furthermore, it is important to highlight the importance of governments or central authorities in internalising externalities, in the sense that switching costs can be reversible, through incentives or taxes to encourage adoption of the alternative technology. This suggests that there is room for intervention when it comes to lock-in (van den Bergh et al., 2006). Moreover, encouraging flexibility - that is, incentivising the development of several alternatives - is crucial to responding to the lock-in (Kline, 2001). However, in order for this to occur, authorities must be willing to make these changes and switch from one technology to another in the first place. Unfortunately, breaking out of lock-in is most commonly considered to be achieved through 'external shock', exemplified through the action taken to ban CFCs after the depletion of the ozone layer became common knowledge (Unruh, 2002). Of course, there is no plausible way for policymakers to apply an algorithm that identifies ex ante with certainty which technologies are superior. However, what is sought is that in a climate of bounded rationality and imperfect markets, policymakers can seek vigilance with precautionary tools, rather than a predictive capacity in the face of competing technologies.

2.2.3 Research objective and aims

The remainder of this paper is divided into four main sections, with final implications, seeking to encourage potential for improved environmental conditions through the diffusion of clean technologies that already exist in the market for automotive cooling systems in the EU. The following section discusses the methods and materials and then presents the case study. The case study is subsequently placed within the conceptual framework of path dependence and lock-in by providing a detailed analysis of how relatively minor events have created a snowballing effect that has led to the synthetic alternative dominating the market for mobile air conditioning.We then discuss how these examples demonstrate how a lock-in effect is displayed in the automotive industry. The paper concludes with policy recommendations, holding significant implications for policymakers shaping the energy agenda and instigating technological innovation in the mobile air conditioning market.

2.3 Materials and methods

The research approach chosen for the study was a qualitative one, given that it characteristically enables an "exploratory, fluid, flexible, data-driven and context-sensitive analysis" (Mason, 2017). The paper in question is based on available literature on the scientific developments of CO_2 and R-1234yf systems, as well as legislative documents, at the European level, in order to construct a narrative of the market for automotive cooling systems in the EU in a comparative study of aggregated criteria. In particular, we have analysed these technologies with regard to wider socio-economic implications, described in relation to the socio-technical processes inflicting changes in the development of R-1234yf and CO_2 and their

subsequent market deployment, or indeed the lack thereof. These findings have then been applied to the conceptual framework described above of path dependence and lock-in. This has been done in order to understand the processes at play and to inspire further policy emphasis on the interplay of existing cause-and-effect chains of technological transition, regulatory change and market interests, in a complex chain of events where systems can be deeply entrenched in complex, interdependent technological and socio-economic systems.

2.4 Results and discussion

We argue that the technological development that has taken shape in the mobile air conditioning market in the past decade within the EU has emerged as an obstacle to the deployment of the 'best' or 'greenest' (most sustainable) technology. This development is attributable to the fact that it is the market, not the laboratory, that determines what the so-called best technology will be (Brand, 2005). In the case of mobile air conditioning, however, it can be argued that this market has also taken shape when producers and manufacturers have overestimated demand for it (Parkhurst and Parnaby, 2008). At the beginning of the 1990s, air conditioning systems were a rare luxury in the European automotive market. For instance, in Germany, in 1994 only 19 % of vehicles were fitted with MAC systems. By 2002, this figure had jumped to 87 % (Gilbert and Perl, 2010). Currently, over 95 % of the 13 million vehicles sold in Europe each year contain MAC systems (DUH, 2012). These changes have taken place in Southern and Northern Europe alike, where, at least in the latter, there was no particular consumer interest in owning an air-conditioned car (Wilhite, 2009). Thus, MAC systems have not exactly entered the European automobile market because of a technical solution resolving an urgent demand for comfort, but rather through what has been referred to as a 'conditioning of comfort' (Shove et al., 2008). Additionally, not only did manufacturers and suppliers perhaps over-estimate demand for air conditioning, but the environmental costs to this producer-driven demand have also been substantial (Parkhurst and Parnaby, 2008), while consumers' environmental concern and awareness have increased simultaneously (Nishijima, 2016).

The world is warming, incomes are rising and, despite this potential over-estimation of demand, so are comfort standards. It has been estimated that world consumption of energy for cooling will increase tenfold by 2050 (Isaac and Van Vuuren, 2009), with the demand for cooling expected to surpass the demand for heating by 2060 (Commission, 2016). It has been estimated that refrigerants accumulating in the atmosphere between now and 2050 (and notably HFCs) will contribute 27 % of the increased warming triggered by anthropogenic carbon dioxide emissions (Velders et al., 2009). Whereas HFCs only account for approximately 2 % of the EU's overall GHGs, HFC emissions have tripled since 1990 and more than doubled since 1995. This is in contrast to all other GHGs, which have been reduced significantly (Commission, 2014) and is closely related to the rising use of refrigeration systems. MAC systems on their own increase carbon emissions and other noxious

emissions that represent 10 % of car emissions, while also increasing the vehicles' fuel consumption by up to 2 L per 100 km; MAC emissions represent approximately 40 % of current global HFC emissions (DUH, 2012). As mentioned above, in an attempt to face this issue, the EU has banned the use of HFCs in automotive cooling systems as of 2017 and all other refrigerants with a higher GWP than 150. As shown in Table 2.1 below, several changes to refrigerants used have occurred in recent decades.

Table 2.1: Overview of refrigerants used in MAC and eventually banned in the past century.

Refrigerant	Ozone depleting?	Atmospheric lifetime	GWP	Years used
CFC-12	Yes	100 years	10,900	1920s - 1990s
HFC-134a	No	13.4 years	1,430	1990s - 2010s
R-1234yf	No	11 days	4	2010s - present
CO_2	No	Naturally occuring	1	2010s - present

Thanks to the 1989 Montreal Protocol phase-out of CFC-12, vehicle manufacturers worldwide transitioned to the use of HFC-134a. As a result of regulations in Japan, Europe, and North America, all passenger vehicle manufacturers are currently shifting to R-1234yf, with the exception of Daimler and the Volkswagen Group, which will be rolling out the use of CO_2 systems as an option on some vehicles in 2017 (UNEP, 2016). Organisational pressures to improve environmental management systems are not only attributable to regulatory bodies such as the Montreal Protocol, but also increased public awareness, media exposure on environmental issues, as well as organisations' willingness to improve efficiency through the reduction of environmental costs (Phan and Baird, 2015).

R-1234yf is certainly more environmentally friendly than its predecessors, given that it decomposes faster in the atmosphere (11 days compared to 13.4 years for HFC-134a and 100 years for CFC-12) and has a very low GWP of 4. As its manufacturers have pointed out; using R-1234yf globally would be the equivalent to removing over 30 million cars from the road permanently (Honeywell, 2013). Additionally, it is very simple to retrofit in existing systems due to its similarity to the former HFC-134. Further, as Ansari et al. (2013) note, "even though the values of the performance parameters for R-1234yf are smaller than that of HFC-134a, the difference is small, so is therefore a good alternative to HFC-134a because of its environmentally friendly properties."

However, it is becoming increasingly clear that, in terms of ozone depletion and the greenhouse effect, the problem with MAC refrigerants has been solved, but the ecosystem may be facing new challenges. The first measurements of the chemical show that R-1234yf breaks down into a new substance, trifluoroacetic acid (TFA), a stable molecule and strong acid that does not naturally decompose further and could potentially be toxic for certain plants and algae from large-scale usage (Smit et al., 2009; Vollmer et al., 2015). Even though TFA is a common by-product of other HFCs, R-1234yf has been shown to yield over 90 % TFA (4 - 5 times as much as HFC-134a) (Kauffeld, 2012). As Luecken et al. (2010) showed, "automobile

air conditioning R-1234yf emissions are predicted to produce concentrations of TFA in Eastern U.S. rainfall at least double the values currently observed from all sources, natural and man-made." Despite this, TFA is currently considered to present an insignificant risk to the environment and ourselves (UNEP, 2016). This is because it has shown to be of very low toxicity (Boutonnet et al., 1999), with peak TFA levels being at 1.26 - 1.70 mg/L, which is 60 - 80 times lower than the accepted safety level (KTH, 2015; Luecken et al., 2010). Nonetheless, these results are believed to be underestimations because they do not take into account the use of R-1234yf beyond the MAC sector, in addition to its variation in concentration depending on the seasonal precipitation patterns. Thus, the toxicity of TFA and its use in R-1234yf remains an open question (Kajihara et al., 2010; KTH, 2015). Moreover, it has also been reported that 20 % of the gases produced by the combustion of R-1234yf consist of the toxic chemical carbonyl fluoride, in addition to hydrogen fluoride, which can be released in a collision and ignite at high temperatures (it is known to ignite at 405 °C) and is both toxic and can be fatal in high doses (Feller et al., 2014). This is deemed to be extremely unlikely, however, but has despite these uncertainties paved its way into the industry.

At the same time, CO_2 MAC systems have also been developed to a stage where they have demonstrated their technical feasibility and comparable energy consumption. Although CO_2 is the largest contributor to anthropogenic climate change, its use in technical applications is normally considered to be sound given that CO_2 used in refrigeration and fire-fighting systems is a waste product that would otherwise have escaped into the atmosphere. Thus, waste CO_2 can become part of the solution to climate change, whereas competing chemical alternatives require manufacturing from scratch and are accompanied by the associated above-mentioned environmental uncertainties. It is both natural and safe, however, at the moment it is also somewhat more expensive and technically demanding given that these systems need to be developed and designed due to higher operating pressures and leakage detection problems.

Nonetheless, by recycling this industrial waste product into a natural refrigerant for cooling a car, it can become environmentally benign. Analyses of the emission and life cycle climate performance (LCCP) have shown that CO_2 components show significant advantages in terms of greenhouse gas emissions over time against R-134a and R1234yf under nearly all climatic conditions (Cavallini and Zilio, 2007; Hafner et al., 2004). Furthermore, research by SINTEF found that prototype CO_2 air-conditioning systems in railway passenger coaches had significantly lower energy demands (approximately 50 % less than the R-134a system). In this sense, this example shows that CO_2 can be more energy-efficient than HFC units (Haukås and Pachai, 2014). Moreover, a further reduction in energy consumption is expected as MAC systems are combined with heat pump modes for the compartment heating for cooler seasons. Additionally, the leakage detection and operating pressures can be improved through further research and design (Cavallini and Zilio, 2007). Further, as early as 2008, CO_2 systems had 30 % lower fuel consumption than similar ones using hydrofluorocarbons (Hafner, 2016). A prototype of a CO_2 air conditioning system that a heat pump in city buses has also been shown to save

up to 50 % of fuel for heating, with potential for further improvements (Nekså, 2004). To sum up, these examples demonstrate that the technology for use of CO_2 is already in place, but that the market pull for their widespread use may be lacking.

2.4.1 Self-reinforcing mechanisms: the lock-in of the European automotive cooling market

This section seeks to highlight the way in which the market for MAC in the EU is showing evidence of path dependence and lock-in through the existence of self-reinforcing feedback mechanisms; or, more generally, increasing returns. Given that the technological development and deployment of climate-friendly cooling agents is occurring at a rapid pace, and is largely driven by regulation, it is critical to recognise whether short-term fixes or long-term economically viable and sustainable solutions are being promoted in MAC systems. With R-1234yf entering the market as the dominant technology, we argue that, in the development of sustainable technologies in mobile air conditioning, we are seeing tendencies of the "technical fix approach" rather than more preventative approaches of technological diversification, despite the potential environmental effects of R-1234yf remaining inconclusive.

2.4.1.1 Scale economies

As described above, self-reinforcing mechanisms, or feedback effects, will favour and support the initial and dominant choice, while competitors, and perhaps more efficient alternatives, are left on the sidelines. When referring to scale economies and the lock-in effect, it is important to take into account the significant sunk cost that exists for technologies that are already on the market. This refers to early investments made in production, equipment, training and so on, which reduce incentives for manufacturers to opt for an alternative. In the case of R-1234yf and CO_2 , a majority of automotive manufacturers already consider the switching costs high enough to transition to R-1234yf, and even higher to take CO_2 on board. Informal discussions with industry stakeholders indicate that the present price of R-1234yf in the European market is approximately $80 per kg. This is at least five times the price of the predecessor, HFC-134a. On top of that, CO_2 MAC systems are expected to cost between $50 - 100 more per system than R-1234yf (DUH, 2012).

At first glance, the ideas of lock-in and scale economies seem to apply well to the case of R-1234yf. However, this is not merely a question of costs. R-1234yf was first developed by Honeywell International and DuPont, which has now shifted its flourochemical business to a new company entitled Chemours, and is also manufactured by competing French chemical company Arkema Chemicals. These multinational companies have not shown much interest in sharing the market for refrigerants with competing technologies: they hold all production patents for

the chemical and lobby heavily for the phasing out of the predecessor HFC-134a (which Honeywell and DuPont were the manufacturers of to begin with), and argue for the benefits of R-1234yf over competing, natural alternatives (Wodzisz, 2015). Nonetheless, Arkema and Honeywell have been rivals for years over their respective production of R-1234yf. In June 2017, Arkema made an official complaint to the European Commission against Honeywell for the abuse of its dominant position with respect to patents covering the use of R-1234yf - "preventing fair competition to the detriment of consumers, car manufacturers and the environment" (Arkema, 2017). This came after a series of Arkema's complaints - one of which prompted a 2011 EU antitrust investigation into Honeywell's practices. In contrast, due to the lack of patentability of natural refrigerants (as they are naturally occurring), natural refrigerants were initially perceived to be less valuable for businesses. Further, R-1234yf has very similar thermophysical properties to HFC-134a and can therefore can be used as a retrofit or 'drop-in replacement' to replace HFC-134a in MAC systems (Navarro-Esbrí et al., 2013). This means that it can be used with only minor equipment changes to existing vehicle AC systems and has led to close to 18 million vehicles using R-1234yf by the end of 2016 (Seidel et al., 2016). CO_2 only operates under very high operating pressures e almost 10 times more than R-1234yf e and therefore requires entirely new equipment. For this reason, almost every part of the system, from compressors to heat exchangers, requires redesigning in order to handle these higher pressures (Haukås and Pachai, 2014).

As Unruh (2002) maintains, when climate change and environmental degradation arises from a locked-in technological system, the first solutions that are sought are those that minimise changes to existing systems. Unruh (2002) further underlined that the least impactful solution will inevitably be to keep the existing infrastructure, with potential add-ons to those already in place, and leave the overall architecture unchanged. These often focus on intra-system innovations that keep costs to the minimum. As car companies already had to switch after the CFC phase-out in the 1990s, new equipment had to be replaced to start using HFC-134a, and the costs are considered too large to make changes once again.

In the case of R-1234yf and CO_2, however, it can be argued that EU regulation, through the MAC Directive, particularly incentivises the use of R-1234yf in the MAC sector on its own, whilst barring market entry for competitors. It was due to safety concerns of the potential flammability (ignition) and toxicity concerns in the event of a collision that the Volkswagen Group and Daimler chose to invest in developing CO_2 systems. However, in December 2015, Germany was referred to the European Court of Justice as the EU claimed that Daimler did not "make the necessary technical adaptations to ensure full compliance with the MAC Directive" (European Commission, 2015). In continuing to use HFC-134a, Daimler argued that it was simultaneously developing air conditioning systems for its vehicles that can use CO_2, given that Germany had given Daimler permission to keep using HFC-134a while developing alternative solutions in 2013. In a compromise reached in October 2015, Daimler agreed to use R-1234yf in the interim while continuing to manufacture systems capable of using CO_2. All other carmakers believe R-1234yf to be safe (Haukås and Pachai, 2014). Given the lack of flexibility on behalf

of the EU MAC Directive, regulation has reinforced this patented monopoly for refrigerants and led to the lock-in of R-1234yf in automotive cooling systems.

Furthermore, although it has been claimed that R-1234yf makes the transition to new cooling agents easier for the industry, in reality this transition may do the opposite, and the argument of lower switching costs does not hold if the question of long-term refrigerant supply is brought into the question. CO_2, as a gas, is released as an industrial waste product directly into the atmosphere: the constraining issue for CO_2 MAC will not be triggered by its availability and would allow for a greater variety of industry players to enter the market due to the refrigerant's lack of patentability. Contrastingly, R-1234yf requires manufacturing from scratch, while at the same time potentially decomposing into environmentally damaging substances. Additionally, the production capacity of R-1234yf is presently incapable of supplying for worldwide demand (Andersen et al., 2013), which means that costs are still high, despite similarities to the former refrigerant.

2.4.1.2 Learning effects

Knowledge and experience accumulated over time generally leads to higher returns if you continue along the same path as before (Kuokkanen et al., 2017). In this sense, learning effects usually improve the quality of technologies, at the same time as reducing costs, which will in turn intensify the benefits of adopting one technology over another. This means that when two relatively young technologies are competing for the same market, the one that is initially leading in market share will push it further all along the learning curve, rendering it even more attractive to future adopters (Cowan and Gunby, 1996). In this sense, learning is path-dependent, and the early success of lowering running costs contributes to the condition of lock-in (Woerdman, 2004). Thus, the transition to a low-carbon, high-efficiency economy represents a structural change in the labour market, which is not just about creating new jobs, but also about changing modes of production (Valente, 2015). What is needed is a 'topping up' of existing job-related skills in order to avoid disconnects between the demand and supply of skills. It is necessary to forecast future skills and occupational demands so that skilled employees are preconditions for further growth in the environmental protection sector. Stricter environmental management can also reduce the organisational flexibility of a company, given that substantial capital investments and changes in systems and methods of production enterprises are required (Lannelongue et al., 2017).

Mobile air conditioning is a knowledge-intensive industry that requires both training and experience. Furthermore, this is not the first time that vehicles' refrigerants have changed. Given the significant difference between CO_2, and with R-1234yf, and the heat exchangers and compressors being the same, it becomes easier to choose the latter as it is so similar to its predecessor, R-134a. Given that supplier industries will have an interest in keeping technologies they already know and have expertise in, this will have an effect on automakers' choices in choosing of technologies. In addition, repair and maintenance workers in local garages and car

workshops will have an incentive to learn how to repair the dominant refrigeration system. As only a few operators use CO_2 MAC systems, there are not yet any significant incentives to learn how to use unconventional MAC systems.

The number of technicians trained in the different alternative refrigerants as a percentage of the total number of technicians trained to handle replacement technologies for f-gases and HFCs is very low in the EU as a whole (0-2.3 %). As was recently been reported by the Commission (2016) on the "availability of training for service personnel regarding the safe handling of climate-friendly technologies replacing or reducing the use of fluorinated greenhouse gases", the uptake of alternative refrigerants is being held back by the lack of training and familiarity by service personnel and end-users. The European Commission further reports that if the appropriate training is not made available across the continent, the transition to alternative refrigerants may result in higher costs than necessary, with "the lack of trained service providers an important factor for abstaining from a conversion to alternative refrigerants, e.g., to the use of CO_2" (Commission, 2016).

Regulation (EU) No 517/2014 on fluorinated greenhouse gases requires technicians to acquire practical and theoretical training on the replacement and reduction of f-gases and alternative solutions, relating to product safety and risk such as flammability and high-pressure equipment. This means that it is currently illegal for employers to hire technicians who carry out installations, product designers, as well as maintenance and end-of-life decommissioning, without adequate risk mitigation training. As the Commission (2016) warned, training provided within the EU is currently insufficient to keep pace with the demand for alternative refrigerants and is slowing down potential market uptake. CO_2 can also be used in heat pumps, refrigerators and air conditioners. It is crucial to increase training in equipment use and risk management, given that CO_2 requires a specific skill-set due to certain drawbacks (described above) with CO_2 MAC systems, such as leak detection issues, which can only be solved with greater R&D investment. Specifically, in the case of mobile air conditioning, lock-in is increasingly becoming a problem given that automakers would rather choose the refrigerant that they know mechanics and local garages will know how to use. However, increased training on CO_2 refrigeration would be able to change this situation (Spletzer, 2016).

2.4.1.3 Adaptive expectations

Lock-in theory argues that adoption will increase as uncertainty decreases. There are significant uncertainties with regard to the safety of the two competing technologies in MAC systems. Phasing in new refrigerants is likely to take decades. Given the existence of a cyclical pattern of regulatory changes with regard to air conditioning systems, which is directly linked to growing awareness of environmental risk as well as technological development, and uncertainty involved in what the future in regulatory change might be, Unruh (2002) and Cowan and Gunby (1996) argued that it will take a "crisis" to break out of the lock-in. The automotive industry already had to change systems from CFCs to HFCs in the 1990s; this has

been followed by the current situation and it will take a lot of convincing before the rest of the industry players will change from R-1234yf to CO_2. The uncertainty with regard to changes in regulation and refrigeration may lead to inertia, which makes looking into new alternatives less attractive.

With regard to the bounded rationality of actors, a point can be made in reference to the difficulty of accessing and processing information needed to make economic decisions e for consumers, to firms, and governments e due to the uncertainty of future events (Foxon, 2011). What is particular in the case of path dependence and lock-in is that decision-makers do not allow for the development or use of a superior alternative; even though they know of its existence, they largely understand its characteristics and consider uncertainties inherent in its existence to be acceptable. There are significant uncertainties with regard to the safety of the two competing technologies in MAC systems. Whilst R-1234yf has been thoroughly tested to ensure its safety, and has met safety regulations, Daimler's tests show that it can ignite when it comes into contact with a hot engine, even though R-134a and CO_2 did not (Haukås and Pachai, 2014). As discussed above, research has also shown that it may significantly damage the ecosystem, and potentially users as well. Some tests have shown that R-1234yf is not dangerous, which has pushed manufacturers further into adopting the refrigerant. However, the more tests that show it is safe, the more opportunity R-1234yf has to promote its product. The most renowned of these is the SAE report, which legitimises its use and states that it is a safe alternative to R-134a. With Daimler and the Volkswagen Group switching over to CO_2 and the rest of the world using R-1234yf, we now have a split in the automotive air conditioning market. Given this high uncertainty, when applying the theory of lock-in, car manufacturers might in this case be under-supplying experimentation into alternative solutions. Thus, as seen above, the industry and policymakers consider the uncertainties inherent to its existence acceptable: a key condition to locked-in technologies.

2.4.1.4 Network effects

Network effects see that when more adopters exist in technological networks, users will derive and gain greater value from taking part in them. As an example, the provision of post-purchase services for durable goods displays the issues inherent in the way certain products provide a utility as a function of the amount of people using them. An example that is relevant to the case of R-1234yf is one illustrated by Katz and Shapiro (1985). They maintained that, in markets for vehicles, sales of foreign models of cars are relatively low compared to those of local cars, or at least not as rapid as with other markets, given that consumers often perceive networks of repair services for different models to be lower and less experienced. What this means is that using a lesser-known refrigerant entails a risk, given that it will be less likely to attain post-purchase services for the consumer.

In addition, product information is also more widely available for better-known brands and there may also be conformity or psychological bandwagon effects. How

the EU MAC Directive's regulatory framework allows for network effects to enhance the market dominance of R-1234yf largely relates to lobbying impact. Considerable sums are devoted to lobbying the European Parliament and EU decision makers by the refrigerant sector, and there are significant differences regarding the difference between synthetic and natural alternatives. In 2013, companies producing fluorinated gases (thus R-1234yf) spent almost 24 million euros, compared to the 900,000 euros spent by alternative industries looking for substitutes. Large multinationals, both by themselves and with the help of lobbyists such as European Partners for Energy and the Environment and the European Fluorocarbons Technical Committee, have invested significant time and money in heavy lobbying in the run-up to the implementation of EU Directive 2006/40/EC, and have therefore potentially prevented a leapfrogging or an easier market entry for other efficient and safe alternatives such as CO_2 (CEO, 2013). Moreover, the more suppliers sell the product, the more likely it is that others will adopt it as well. For instance, R-1234yf is widely available, whereas CO_2 is only being adopted gradually. SANDEN, a potential CO_2 MAC supplier that develops and supplies CO_2 refrigeration in commercial and industrial applications, stated that it has completed RD activities for CO_2 use in mobile air conditioning, but "did not reach commercialization development because of the direction taken by customers to go for R-1234yf" (Andersen et al., 2013). However, buses continue to rely on HFC-134a, with the trend towards hybrid electric buses allowing hermetic or semi-hermetic compressors, which renders the use of R-744 more likely (UNEP, 2016). Furthermore, the fact that Daimler and the Volkswagen Group are rolling out CO_2 MAC units for use will potentially, with the help of policy and incentives, enable other companies to take advantage of them, too.

2.5 Conclusion

Understanding technological change through an evolutionary framework of lock-in and path dependency means that the eventual outcome emerges through an uncertain and complex nature of complex interactions and dynamics. What is of concern is when a situation of lock-in occurs when actors and decision-makers do not allow for the development or use of a superior alternative, even though potential risks or costs of the dominant alternative are understood. It is important for policy-makers to abstain from 'picking winners' and to instead look to allow for the creation of conditions in evolutionary processes of technological transitions that can lead to the preferred outcome (Maréchal, 2009). In such a way, it is important to take facets of evolutionary economics into account so that policies focusing on technology development and deployment can promote the diversification of technologies and strategies, instead of maintaining static economic efficiency as the main objective (van den Bergh et al., 2006). In order for this to become a reality, it is firstly important that the limits to 'technical fixes' are recognised (Parkhurst and Parnaby, 2008), in the sense that there cannot be a single solution to any problem. Specifically, policy needs to allow for the support of alternative technologies, through training, incentives and subsidies.

This paper has argued that the market for mobile air conditioning in the EU is being locked-in, to the advantage of synthetic option R-1234yf, instead of natural solution CO_2. While it is not uncommon for one technology to take over the market to a greater extent than a competitor, what is particular in this case is the degree to which the uncertainty and risks inherent in the dominant solution are still widely accepted, with the degree of freedom of entry of alternatives significantly restricted - reinforced by the regulatory environment in which they are placed and potentially skewed lobbying influences in policy. As research is pointing to more damaging releases of chemicals into the atmosphere, we should be more cautious in committing ourselves (or allowing the automotive industry to commit itself) to the adoption of one technology without allowing alternatives to survive and develop.

Specifically, there was no lead-time to develop alternative solutions for the mobile air conditioning market and, as a result, the MAC Directive reinforced the market position of R-1234yf through an intensification of scale economies, learning effects, adaptive expectations and network effects. Further research and awareness into the issues at stake with regard to the potential lock-in of R-1234yf is crucial in order to ensure that technological diversity is maintained and that alternatives can survive and develop. Regulation needs to take costs and timing into account when determining how changes affect parties; these include administrative, legal and institutional contexts (O'Ryan et al., 2006). The more the flexibility is reduced and the extent to which the 'error cost' is increased, the greater the complications will be.

Policymakers worldwide are increasingly responding to rapidly evolving environmental risks. Against this background, we recommend that policy attach greater importance to market power when designing clean technology markets. If emerging markets for clean technology unnecessarily lock in patented technologies - as we argued to be the case for the EU MAC Directive, and effectively granting a monopoly to one firm - the monopolist is likely to reap most of the benefits of green technologies. In addition, as it is in many cases the state that funds the basic research enabling innovation (Mazzucato et al., 2015), it is important that consumers and taxpayers also reap the fruit of these innovations. To avoid the monopolisation of clean technology markets, policymakers therefore ought to ensure that their transition pathways leave sufficient time for the development of competing technologies and substitutes. As a consequence, we suggest placing a higher emphasis on the competitive benefits of substitutes for clean technologies, which can potentially be highlighted through regulatory impact assessments conducted by the European Commission for instance. While re-election concerns may sway policymakers to phase-out polluting technologies as quickly as possible, moving slowly may sometimes be superior in the long-term to ensure that short-term fixes are not promoted, but rather sustainable and economically viable solutions.

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Chapter 3

Eliciting policymakers' preferences for technologies to decarbonise transport: a discrete choice experiment

This chapter is based on Bjørnåvold, A., Lizin, S., Van Dael, M., Arnold, F., and Van Passel, S. (2020). Eliciting policymakers' preferences for technologies to decarbonise transport: A discrete choice experiment. Environmental Innovation and Societal Transitions, 35:21–34.

3.1 Introduction

While consumers ultimately determine which technology will be successful, policymakers influence the rate and direction of technological change. By governing innovative activity through subsidies, they also generate support for policies that send powerful signals to investors. Understanding what drives policymakers' preferences in the assessment of decarbonisation projects - referring to projects that reduce the amount of gaseous carbon compounds released in the atmosphere - is therefore crucial. Despite governmental initiatives to decarbonise energy systems, and action taken to steer away from current unsustainable technological systems, transition processes are often hindered by the resilience of existing infrastructures.

This paper addresses one particular system transition: decarbonising transport within the European Union. Decarbonising transport requires substantive system innovation; namely from one socio-technical system to another (Rip et al., 1998; Geels, 2004). The transition literature refers to these systemic changes as 'socio-technical', as they do not *solely* involve technological innovation or substitution, but also require complex and interconnected changes in the overall configuration of transport, energy, and agri-food systems - involving alterations in technology, policy, markets, consumer practices, infrastructure, culture and scientific knowledge (Geels, 2011; Elzen et al., 2004; van den Bergh and Bruinsma, 2008; Safarzyńska

et al., 2012). Essentially, what matters is not merely the technological innovation itself, but also the social and economic systems in which it is embedded (Upham et al., 2019). This paper seeks to shine a light on actors that play a complex role amid this social-economic-technological-institutional system: policymakers. Specifically, we investigate policymakers' funding preferences in the early iterative innovation stages, which may serve as input to any consequent debate on strategic public funding decisions, that may in turn affect the development of new products and services. The results provide indications as to whether policymakers may indirectly be contributing to technological and cognitive lock-ins that exist within established socio-technical regimes (Kemp et al., 2007; Avelino et al., 2016).

The research question underlying this paper is as follows: are policymakers more likely to fund technologies that resemble the incumbent system? In this regard, the paper assesses whether policymakers may be reinforcing dominant, incumbent systems, and notably whether they have a tendency to invest in technologies and energy systems resembling incumbents, or rather those that are novel, and more disruptive. In order to better understand whether this is the case, 129 European policymakers working at European, national, regional and local level participated in a discrete choice experiment (DCE) in which they were asked to allocate funding to their preferred decarbonisation project. The policymakers that were targeted worked with European funding programmes or advisory bodies related to realising Europe's transport infrastructure policy.

To find out whether decision-makers were more likely to favour more established technologies, and whether they are therefore more likely to invest in the technological systems they know best, the choice task in question involved allocating funding for the R&D of a project that would develop two types of carbon capture and utilisation (CCU) based fuels: liquid-based, and gas-based CCU. Policymakers also had the option to fund neither if they preferred to do so. These technologies were chosen as examples as they can either be compatible with current dominant incumbent engine systems (and these were representative of the conventional transport system), but CCU fuels can also require more of a change in design, products and processes - depending on the type (and these were representative of a more innovative choice). Before beginning the choice task, the policymakers were primed and told that it was liquid-based fuel that was compatible with current infrastructure (with attention being visually drawn to how fueling would occur). In addition, as these technologies have not reached the market at scale yet, they made for a realistic R&D funding option.

The choice model used in this paper, where policymakers make hypothetical funding decisions, allows us to predict both average and individual tastes and preferences in a hypothetical setting. This means we can in turn predict which alternative will be chosen in a similar scenario. If we assume that political power and choices are influenced by majoritarian principles, we can in this way reveal whether policymakers would be open to funding new technologies or not. While CCU powered passenger vehicles have been chosen as examples, this line of reasoning applies to decision-making on technological transitions where future gains

and losses of the technological system are unknown. DCEs are widely used to study how people make choices and to identify the elements that drive them. By analysing the trade-offs that European policymakers face when allocating a limited budget to the decarbonisation of fuels, we can provide indications as to whether decision-makers are prone to sustaining, and therefore - locking-in - the incumbent system. We suggest that DCEs have an important role to play in better understanding and improving policymakers' (deliberative and intuitive) decision-making processes in promoting sustainability systems transitions.

The remainder of the paper is structured as follows. In Section 3.2 we discuss the conceptual and theoretical frameworks underlying the study. This includes the examples studied, the concept of lock-in applied to this case, and the role of political decision-making in socio-technical transition narratives. Section 3.3 presents the DCE design and how it is applied to the study in question. The design of the questionnaire is elaborated upon, along with its respective attributes and levels for study and the distribution of the questionnaire. Section 3.4 discusses the results, and section 5 concludes with a discussion.

3.2 Conceptual framework

3.2.1 Techno-institutional lock-in in public R&D funding

Mitigating climate change, and by extension - decarbonising fuels, requires governments and institutions to boost innovation - through investment in research and development, subsidies, as well as favourable tax or price regimes that can decrease the time-to-market of environmentally friendly technologies (van der Vooren et al., 2012). However, institutions can inhibit the diffusion of carbon-saving technologies due to systemic relations and interdependencies where transitions result from joint development of technology and society (Van Bree et al., 2010; Foxon, 2002). This is often the case for infrastructure-dependent vehicle technologies, where sunk costs significantly influence their technological development (Klitkou et al., 2015). Investments in technology, to human resources, skills or physical assets, can bias policy towards the preservation of the status quo and the alternatives that are most familiar to decision-makers (Cecere et al., 2014).

Lock-in processes are generally referred to as increasing returns to the adoption of a technology, where incumbent technologies have a distinct advantage over new entrants - not because they are necessarily better, but because they are more "widely used and diffused" (Arthur, 1989; Unruh, 2002; Klitkou et al., 2015). Our discussion of lock-in mechanisms takes a broader view than traditional definitions, such as the textbook QWERTY case (David, 1985). An incumbent regime is the outcome of various lock-in processes, and such a regime favours incremental, as opposed to radical, innovation (Sandén and Azar, 2005). We focus on lock-in at the *system* level, as opposed to the product level. Our broader discussion of lock-in

mechanisms in this regard is applied to the role of policymakers in transitioning to a decarbonised transport system, where we argue that the existing socio-technical system has a restrictive influence on innovation dynamics and technological change. We specifically seek to investigate whether policymakers may be likely to avoid investing in a highly innovative idea, not because of any intrinsic flaw in the technology, but because the technology would require too much change from the incumbent system. This may in turn prevent the introduction of radically new technological trajectories, in this case on the road to decarbonising our transport system.

While market forces are the often deemed culprits behind the lock-in of certain technologies, Unruh (2002) argues that institutions could be perpetuating these barriers from the outset. Through positive feedback mechanisms existing between policymakers, suppliers and infrastructure support, dominant technologies can be sustained in the face of potentially superior substitutes: when a technology is dominant it is much more likely to receive support. Governments can influence the rate and direction of technological change through investment in the R&D for developing infrastructure. This occurs before technologies actually compete - both in the market for goods and services, but also to gain influence over institutional frameworks (Jacobsson and Lauber, 2006). This means that decision-makers can affect the success of novel, radical and disruptive innovations, and therefore reinforce the dominance of incumbent systems of energy technologies (Bjørnåvold and Van Passel, 2017). When innovation is mentioned in the remainder of this paper, it is disruptive innovation that is being referred to.

Understanding what drives funding decisions when allocating public funds for clean technologies is critical. While abundant literature exists on ex-post evaluation of R&D projects and programmes (Verbano and Nosella, 2010), research on what exactly determines strategic public funding decisions ex-ante is limited (Hirzel et al., 2018). This is an issue, among others, due to the potential impact funding has on the cognitive development of science (Braun, 1998), and the problem of 'conservatism bias' in R&D evaluation - that highly innovative projects run a higher risk of rejection. Brezis suggests focal randomisation can fix this - that the projects that are unanimously ranked at the top by all reviewers will be adopted (Brezis, 2007). Another study proposes that a decision support system for decision-makers evaluating R&D projects is needed (Ashrafi et al., 2012). While these studies do look into ex-ante public funding decision-making and point to issues, no study - to the best of our knowledge - investigates the preferences that drive these decisions.

If options that resemble the incumbent are consistently chosen to receive the most funding, innovation can become path-dependent from a systemic perspective. If technological change becomes path dependent, superior alternatives can be locked out, and the dominant, inferior solution locked-in which is difficult to change over time (Arthur, 1989; Cowan, 1990a). Novel and innovative technologies are rarely strong enough to enforce transitions alone. Incumbent firms, on the other hand, are familiar to decision-makers and have established and fixed routines, constrain-

ing them to respond appropriately to changing environments. Policymakers can thus be faced with deeply entrenched, path-dependent systems because of the unwillingness to change (Ettlie et al., 1984; Henderson, 1993). Consequently, systems can experience inertia that can prevent adaptation and innovation.

3.2.2 Reconciling political decision-making processes with transition narratives

This paper contributes to the recent literature seeking to reconcile sustainability transitions studies with considerations of policy and political decision-making processes. Politics and power have been receiving increased attention in recent years, due to criticism raised that they have been neglected within the field (Meadowcroft, 2011; Avelino et al., 2016; Kuzemko et al., 2016). After all, policy represents one of the core dimensions of the socio-technical regime, along with user practices, science, cultural meaning and infrastructure (Geels, 2014). Further, "transitions are inherently political processes in the sense that different individuals and groups will disagree about desirable directions of transitions, about appropriate ways to steer such processes and in the sense that transitions potentially lead to winners and losers" (Köhler et al., 2019).

One criticism directed towards transition studies, has been the skewed focus on green niche-innovations, while less attention has been given to the actions of existing regimes and incumbent actors behind the scenes that contribute to or prevent their deployment (Geels, 2014). In order to engender transitions and structural change to low-carbon systems, many of these regimes and incumbent actors may themselves be restricting these systems through various lock-in mechanisms. For instance, incumbent socio-technical regimes and actors might seek to resist innovation and restrict existing systems for reasons of institutional commitments, shared beliefs, vested interests, power relations, or convenience, making them resistant to change over time. New entrants will in turn seek to oppose this resistance in a power struggle of their own (Köhler et al., 2019; Unruh, 2002).

Against this background, this paper focuses on existing regimes and the actors involved in political decision-making processes. The specific contribution to the transitions literature is to consider regime stability, and in turn dependence on dominant technologies, as being a result of resistance, whether deliberate or not, by incumbent actors, and in this case: policymakers (Geels, 2014). We have in this regard chosen to investigate policymakers' use of power through funding mechanisms to resist transitions to disruptive and innovative low-carbon transport systems. As van Rijnsoever et al. (2013) did to estimate the preferences for alternative fuel vehicles by Dutch local governments, we also make use of a choice model to better understand trade-offs that policymakers face in the socio-technical transition to sustainability.

Technology does not exist in a vacuum - away from society, social behaviours and

social institutions – it both shapes and is shaped by society (Bijker et al., 1989). For instance, personal vehicles required infrastructures, supply and service systems, and norms of behaviour to develop alongside them. In fact, socio-technical transitions do not just change the structures of existing systems, such as transportation, but they also affect related societal domains, such as living, housing and working, production, trade and planning. For reasons such as this, infrastructure systems are often regarded as inflexible, difficult to change and vulnerable to path dependence and lock-in and can result in inertia for many transport systems (Markard, 2011).

We investigate the hypothesis that policymakers contribute to this inertia through a wish for consistency by investing in and funding technologies that resemble incumbent systems. Experimental evidence illustrates that individuals tend to prefer to purchase familiar goods and make familiar choices, and this has been particularly well documented in capital markets among investors. Investors have been over-documented to purchase stocks that are in culturally, geographically and linguistically proximate markets, while being reluctant to trade away from their existing ownership positions (Cao et al., 2009; Graham et al., 2009). Further, investors have been shown to be biased in favour of choice options made salient as default choices; and are prone to prefer past choices or investments that they currently hold (Cao et al., 2009). This experimental evidence has largely been applied to investors in capital markets, yet little attention has been leveled at policymakers'in this regard. This is of concern, as the choices decision-makers face when deciding how to allocate and invest public financial resources is complex and can have great significance on society at large (van der Vooren et al., 2012). Any decision-maker – be it in daily life or a policymaking context – interprets their surroundings through a lens of their own past and experiences; learning by combining heuristics and cognitive filters and known processes (Witting, 2017).

Samuelson and Zeckhauser (1988) maintain that various theories such as misperceived sunk costs and a wish for consistency can be reasons for a preference to remain within the current position. Nonetheless, innovation, especially breakthrough innovations, requires steering away from what you already know. Unsurprisingly, regulators as well as consumers generally value stability and predictability (Kiesling, 2008). Nonetheless, innovation generally brings with it change, and will for this reason often cause initial resistance. This can be caused by resistance to the behavioural change that is imposed as opposed to the actual innovation itself (Talke and Heidenreich, 2014). Understanding how decisions are made on a regulatory level is therefore crucial: decision-making depends on individual preferences and interests, which can contradict, most likely change over time, and develop based on experience with the issues at hand. Decision-makers have to consider uncertain outcomes, act in a political system, face novel and interconnected situations and problems, as well as the need to search for new ways to handle them (Goldthau, 2013). As a consequence there will always be uncertainty and risk about the eventual outcome and decisions taken, which therefore raises the importance of better understanding the trade-offs that policymakers face in the regulatory sphere.

3.2.3 Example used: carbon capture and utilisation based fuels

Transport represents close to a quarter of Europe's greenhouse gas emissions and is the foremost cause of urban air pollution. Transport has not shown the same gradual decline in emissions as other sectors, given that demand for transport only continues to rise. Road transport is the largest emitter, and accounts for up to 70 % of the sector's greenhouse gas emissions in the European Union (EU) (Commission, 2018b). Decarbonising transport fuels is therefore a priority, and the Renewable Energy Directive II will become the EU's binding policy framework for renewable fuels from 2021 to 2030. Early drafts of the Directive suggest that fuels derived from CCU will be included within the definition of renewable transport fuels. CCU is a process that finds end-use opportunities for captured and recycled carbon dioxide (CO_2)– from industrial outlets (i.e. factories and industry point sources) or the atmosphere – in order to produce commercially viable products such as construction materials, chemicals and fuels. It is considered a viable option to not only reduce CO_2 emissions, but also to shift some of the costs of decarbonisation onto willing consumers (Perdan et al., 2017). CCU-based fuels are currently not viable without high policy support, given their high cost of production. Brynolf and colleagues (Brynolf et al., 2018) suggest costs for different CCU-based fuels lie in the span of €17.4 – €152 per litre in 2015 and €14.5 – €62 per litre in 2030. However, the costs are still uncertain given that these fuels have not been demonstrated at scale yet, which in turn makes it difficult to attract significant investments.

The rate at which CO_2 will establish itself as a feedstock depends largely on the political framework to develop it further (Vreys et al., 2019). It is for this reason that the motivations behind policymakers' decisions to fund specific CCU-based alternatives is of interest. CCU-based fuel (also called power-to gas, power-to-liquids or synthetic fuels) can be used as a 'drop-in' fuel that can be used in existing engine types and infrastructure. This is mainly possible with liquid-based CCU (conversion of CO_2 into methanol (MeOH) using H_2 produced by electrolysis) – with drop-in meaning that they are compatible with current engines and vehicular systems (Blanco et al., 2018). The major hurdles for liquid-based CCU are more regulatory in nature (SETIS, 2016). The compatibility of gas-based CCU systems - which refers to the conversion of electrical energy into chemical energy in the form of hydrogen gas (H_2) or methane (CH_4) - is not impossible, but less so than with liquid-based CCU. The conversion pathways for power-to-gas are limited due to the lack of dedicated storage and distribution infrastructure (Eveloy and Gebreegziabher, 2018; Jarvis and Samsatli, 2018; CarbonNext, 2018).

Given that liquid-based fuels can be compatible with current dominant engine systems, we present these fuels as representative of the conventional transport system, and in turn incumbent systems. Given that gas-based fuels require more of a change in design, products and processes, in this paper, these fuels are representative of fuels that contribute to a transition, and in this sense a more inno-

vative option than the latter fuel. The study in question uses CCU based fuels as an example to provide theoretically driven insights and explanations into why some technologies receive funding for R&D and others don't, and whether it is an advantage for new technologies to display properties that mimic the current state of affairs (or not). If it is the case that policymakers consistently choose to fund technologies that most resemble the incumbent system, we argue that this could reinforce the lock-out of technologies that have yet to benefit from reinforcing mechanisms such as scale economies, network and learning effects, as well as adaptive expectations. In this regard, regimes, incumbent actors, and in this case, policymakers would have a restrictive influence on innovation dynamics and technological change, necessary to engender transitions and structural change to low-carbon systems.

3.3 Method

3.3.1 Discrete Choice Experiment

Discrete choice experiments (DCEs) are extensively used to model people's choices and to identify people's preferences (Louviere and Hensher, 1982; Louviere and Woodworth, 1983). Each respondent is presented with several alternatives, or choice sets, and asked to choose the alternative of their preference. The main goal of a DCE is to estimate the weight and sign of each attribute level coefficient from the repeated choices made (Cuervo et al., 2016). These weights can then be used to calculate ratios describing the trade-offs that respondents are willing to make among the available attributes (Louviere et al., 2000b).

Rational choice theory sees that the respondent chooses, based on the attributes that describe the choices available, an alternative that maximises utility. According to Lancaster's characteristics theory of value (Lancaster, 1966), a good or service can be defined by a set of characteristics, which means that the value of a good is the sum of the values of all its characteristics. Apart from the attributes and their levels no other factors should systematically influence peoples' choices. Combining this with McFadden's random utility theory (McFadden, 1973), as the discrete choice experiment modeling framework does, individuals make choices according to a deterministic part, which is visible to the modeller, but there will always be a stochastic element to people's choices. An unobservable component to people's choices should thus be taken into account: the modeller cannot know what is going on in people's minds, and the error term in McFadden's model captures this. In our discrete choice experiment, respondents are asked to choose between two alternatives and an opt-out. Including an opt-out is useful to attain more realistic results. This avoids people being forced to make choices that they do not wish to make (Lancsar and Louviere, 2006).

There have been few DCEs that focus on policymaker preferences in response to

the sustainability transition, and none, to the best of our knowledge, on how these choices might create a barrier for innovation through resource allocation of public funds of the European Union. The reason as to why a DCE is used to test this (based on coefficients), and not revealed preference data, is due to the need for a hypothetical market to be presented to the respondent as these technological options do not yet exist on the market. Further, by varying characteristics and policy options presented to the respondent, it is possible to estimate the tipping point that leads the decision-maker to allocate funding to one option over another. How funding is allocated to transport infrastructure technologies is also unclear, which makes a hypothetical discrete choice experiment such as this even more relevant. For instance, it is known that €70 billion is invested by the EU in the 2014 – 2020 timeframe on funding research and development of new transport technologies and services, €800 million on alternative fuels infrastructure, but not more specific than this (Niestadt and Bjørnåvold, 2019). This funding is spread across different projects and programmes for sustainable mobility – from ESIF, JASPERS, Horizon2020, Connecting Europe Facility (CEF)/TEN-T projects, European Energy Efficiency Fund, LIFE programme, to only name a few: these programmes do not explicitly state the amount of funding that goes to each platform, project or technology.

3.3.2 Study design

The participants faced a policy funding decision in the discrete choice experiment. Each respondent faced six choice sets, with each choice set consisting of two hypothetical funding options labelled 'Liquid-based CCU' and 'Gas-based CCU', as well as one opt-out option with which they could choose to fund neither. As mentioned above, these technologies were chosen as examples as they can either be compatible with current dominant incumbent engine systems (and these were representative of the conventional transport system), but CCU fuels can also require more of a change in design, products and processes - depending on the type. Choosing to opt-out of the funding decision would imply that the policymaker preferred to spend the available budget on other decarbonisation projects. Liquid-based fuel was illustrated to policymakers as the conventional fuel system type, given that engine types, service stations and compatibility with conventional gasoline remains the same. Rather than the technology of CCU, this liquid-based CCU seeks to represent a lock-in of a specific type of hybrid system that resembles the incumbent, while Gas-based CCU sought to represent a more innovative fuel system.

The first two options were characterised by five different attributes as shown in Table 3.1. These five attributes were i) the reduction in CO_2 emissions, ii) the required budget spent from 1 billion of EU Mobility Network funding, iii) the time until market commercialisation, iv) the market share and v) fuel cost (in 2040) compared to current (relative) levels. Fuel cost here refers to the amount the consumer will have to pay to purchase fuel for the given type (of either liquid-based or gas-based fuel). Each of these attributes could take on three different levels as summarised in Table 3.1.

The attributes and levels were chosen based on current literature, and fine-tuned in a pre-test conducted with seven policymakers all working in the European institutions in the field of energy transition (and familiar with CCU) in September 2018. The main goal of the pre-test was to further develop the questionnaire and the choice scenarios that were presented within the questionnaire, mainly to ensure the clarity and credibility of the information presented. Pre-tests are also helpful to develop a good design that can avoid respondent fatigue from the provision of unnecessary details. Specifically, we obtained a better insight into the survey response rate, item non-response rates, the suitability of the experimental design, and a preliminary investigations of hypotheses. When given choice between liquid and gas-based CCU fuel (and the option to opt-out), the overwhelming majority of pre-test participants (6 out of 7) opted for liquid-based CCU fuel, which confirmed the suggested hypothesis that policymakers do prefer the option that resembled the incumbent the most.

The authors thus sought to make the choice task as realistic as possible by testing the design on the target group before the final discrete choice experiment. As clarified above, modifications were made based on comments received from these individuals. Moreover, by associating attributes and levels in the design to actual EU policy targets and expectations, this realism was further embedded into the experiment.

3.3.2.1 Choice of attributes and levels: discrete choice experiment design

The budget to be allocated was chosen to be €1 billion for a 10-year timeframe. The monetary levels for the attribute 'Required budget spent from 1 billion of EU Mobility Network funding' are in this case €100 million, €200 million and €500 million. These amounts were set based on EU Connecting Europe Facility (CEF) for Transport funding: the funding instrument used to realise European transport infrastructure policy. While other funding mechanisms exist, CEF Transport concentrates on building and upgrading the trans-European transport and energy networks, and provided a total of €24 billion for transport between 2014 and 2020. Up to €800 million of these EU investments support alternative fuels infrastructure (Commission, 2018a, 2019a). Based on these amounts, and particularly the €800 million spent on alternative fuel infrastructure, a similar amount of €1 billion was chosen (while somewhat higher due to a higher timeframe of 10 years as opposed to 7 years) with a relative comparison of levels were chosen of €100, €200 and €500 million.

In this discrete choice experiment we define 'Market commercialisation' as manufacturers' attempt to profit from innovation by incorporating new technologies into products, processes, and services and selling them on the marketplace. Specifically, commercialisation implies the scale-up from prototype to volume manufacturing and committing greater resources to marketing and sales activities (Howard, 1993).

Table 3.1: Listing of levels considered for each of five attributes of the two fuels (liquid-based CCU and gas based CCU)

Attribute	**Attribute Levels**
Reduction in CO_2 emissions	20 %; 50 %; 80 %
Required budget spent from 1 billion of EU Mobility Network funding	€100M; €200M; €500M
Time until market commercialisation	2 years; 5 years; 10 years
Market share	15 %; 50 %; 80 %
Fuel cost compared to current (relative) levels	Lower; Same; Higher

The attribute 'Time until market commercialisation' implies that longer durations for the technology to reach market commercialisation correspond to higher transition costs. The levels 2, 5 and 10 years are chosen based on expected timeline of technological development of the Strategic Energy Technology Plan (SET-P) - the EU's platform with the aim to accelerate the development and deployment of low-carbon technologies. The SET-P's CCS and CCU implementation plan has been consulted, and years chosen based on their expected timeline for CCU transport fuels between 2018 and 2030 (Technology Readiness Level (TRL) 9 already expected 2020). As the Renewable Energy Directive II is the EU's binding policy framework for renewable fuels from 2021 to 2030, the timeline has been extended to last for 10 years.

The attribute 'Reduction in CO_2 emissions' is essential to capture the main motivation behind decarbonising fuel. This attribute has in previous discrete choice experiments been shown to have substantial effects on preferences for fuel technologies (Achtnicht, 2012). In this specific survey, reduction in CO_2 emissions is included as an attribute to represent the environmental component, as it is clearly considered in EU policy design on decarbonising fuels (Commission, 2018b). The three levels of 20, 50, and 80 % below 1990 levels were chosen. The varied levels were provided to present the respondent with a wide choice. A recent study commissioned by the European Commission stated that decarbonisation scenarios of 80% to 95% emissions reductions relying on a technology mix with CCU fuels are possible (Fleiter et al., 2019). Another study suggests a reduction potential of more than 70% is possible, making a CO_2-based fuel car comparable to an electric vehicle (SETIS, 2016). On the other hand, Fernández and colleagues argue that a system including power and CO_2-DME production has 2% higher emissions than business-as-usual (electricity plus diesel) (Fernández-Dacosta et al., 2019). Full emissions potential is therefore contested and uncertain, and the study sought to provide a large span to policymakers to encompass this variation.

The attribute 'Fuel cost' seeks to represent the extent to which the policymaker is willing to value the effort and monetary burden for the consumer, given that it is these costs that will be incurred by the end-user. The levels of lower, same, higher, and not quantitative levels, were chosen due to difficulty of predicting

realistic levels across the EU as a whole in such a time scale. We could not predict realistic numbers given that the technologies have not been produced at scale yet. Any price we could have provided would have been contested by the policymakers that took part. Overall, however, this attribute sought to represent the amount the consumer will have to pay to purchase a given fuel relative to current levels.

We seek to highlight the trade-offs that are made in policy funding decisions, and thus uncertainty costs need to be taken into account. In this experiment uncertainty costs are represented through the attribute 'Market share', which expresses the perception of risk associated with the new alternative being accepted on the marketplace. This attribute can be used to understand preferences of respondents on consumers' perceived risks and benefits of the respective technologies. While a technology may have reached market commercialisation, and a high TRL (and thus likelihood of positive net benefit), this does not necessarily mean that it is accepted by the public and reaches a high market share. An emerging technology, or any innovation for that matter, brings with it uncertainty when it comes to public acceptance and will take time before it reaches wider public acceptance (Huijts et al., 2007). This attribute seeks to gain some insight into the extent to which a higher uncertainty with respect to market acceptance, and in turn consumer acceptance, can make decision-makers apprehensive or not about funding a switch to a new alternative. Market share is a tangible way to present the degree to which the technology is used by consumers. The levels chosen for this attribute are also relative on a wide range, from 15 %, 50 %, up to 80 % were chosen due to the variation of predictions that have been made to date depending on the type of CCU fuel (Global CO_2 initiative, 2016).

3.3.2.2 Experimental design

The SAS-based software JMP was used to create the experimental choice design for both the pre-test and the actual study. A Bayesian D-optimal choice design algorithm has been integrated into the JMP software package (Kessels et al., 2009). Bayesian D-optimal designs – developed by Sandor and Wedel (Sandor and Wedel, 2001) are useful as they integrate available knowledge on the choice model's parameters into the choice design. They do so by introducing prior knowledge (which was attained through the pilot study conducted with policymakers working in the same field as the target group), and associated uncertainty about the parameters into the design - thus reducing the dependence of the design on unknown parameters (Kessels et al., 2011). There were no constraints imposed on the design. The design created two alternative profiles, with 12 different choice sets, which were then blocked into two groups of 6 choice sets to which respondents were randomly assigned. Thus, each participant answered six choice scenarios to limit their cognitive burden (Hensher et al., 2015).

3.3.2.3 Questionnaire

The policymakers targeted for the DCE included those involved in financing EU transport infrastructure programmes - at European, national, regional and local levels. All contact and questionnaire administration procedures were done electronically - by email directly to the policymaker (and in some cases their assistant(s) too). Participants' anonymity was guaranteed. Names and email addresses of all policymakers working in the European institutions - whether the European Parliament, the European Commission, the European Investment Bank or the European Investment Fund that were contacted are publically available in the Official Directory of the European Union.[1] Policymakers targeted in the European institutions worked on issues relating to the allocation of funds for transport, mobility and energy. Names and email addresses of national policymakers across Europe that were involved with the allocation and the financing of EU transport infrastructure programmes were acquired through publically available lists of i) members of EU advisory groups for CEF-Transport, as well as TEN-T ii) national contact points for EU innovation funds for transport iii) national contact points at Ministries across Europe and members of Polis - a network of European cities and regions working together to develop innovative technologies and policies for local transport, or iv) Ministerial national contact points and monitoring committees of Interreg - a key instruments of the EU supporting cooperation across borders through project funding, v) the policy advisory committee of Civitas - a network of cities for cities dedicated to cleaner, better transport in Europe. These contact points were chosen as policymakers responsible for the overview of the allocation of public European funds - at different levels, whether European, national, regional or local. The respondents that were approached were of senior official level, but respondents were asked to state their seniority (i.e., elected official; policy advisor) and age in the questionnaire.

All respondents received the exact same information on the purposes of the experiment: better understanding decision-makers' preferences in the area of funding decarbonisation projects. Our survey instrument included DCE questions and other questions regarding their work, attitudes, and socio-demographic characteristics of the participants. Survey distribution took place from mid-November 2018 to mid-January 2019.

In the valuation scenarios all subjects are asked to imagine that they are on the board of a fictitious transport infrastructure funding board called the 'European Mobility Network'. This is to avoid any preconceived ideas or opinions about any other funding platform that might already exist. Further, the fictitious nature of the network made it more likely that respondents followed their personal preferences, and not the vision of a body they might have already been affiliated with. The following text was provided to respondents in the online questionnaire developed on the survey platform Qualtrics:

[1] See https://op.europa.eu/en/web/who-is-who (retrieved 29 May 2021)

"Imagine you have been chosen to join the board of the European Mobility Network. The European Mobility Network brings together European policymakers to promote the transition to a decarbonised transport sector. The board is a group of elected representatives, responsible for contributing to the deployment of innovative solutions and projects. To achieve this goal, the board is currently assessing the allocation of €1 billion from the R&D budget for the next 10 years. ***As a member, you are required to choose your preferred projects for further developing (or improving) personal transportation infrastructure.*** *The set of questions provided to you on the next pages are hypothetical. First, you will receive a description of the 3 alternatives amongst which we ask you to make a choice, before we ask you to make that choice.* ***One of the decisions you will have to make is to choose the alternative fuel types for passenger vehicles you would allocate funding to. Two of the fuel types presented rely on a process called carbon capture and utilisation (CCU).*** *If you would not consider allocating part of the R&D funding to the alternative fuel options based on CCU, you also have the option to not do so. If so, the remainder of the budget would be spent on other options for decarbonising the transportation sector."*

	Liquid-based CCU	Gas-based CCU	Neither
Reduction in CO_2 emissions	20 %	50 %	The remaining budget will be spent on other options to decarbonise the transportation sector
Required budget spent from 1 billion of EU Mobility Network funding	€100 million	€200 million	
Time until market commercialisation	2 years	10 years	
Market share (in 2040)	50 %	15 %	
Fuel cost (in 2040) compared to current (relative) levels	Same	Same	
I would choose	☐	☐	☐

Figure 3.1: Example of a choice card

Simplified illustrations and descriptions on the process of producing both liquid-based and gas-based CCU are presented to the respondents. Respondents are then told that liquid-based fuels are compatible with existing infrastructures, such as service stations, while gas-based CCU has a compatibility that is limited to existing infrastructures. It is further clarified that the values presented to them are hypothetical, and only represent possible future technological options. They are asked to take the information presented to them as a given: features not presented cannot be taken into consideration when making a choice, and each choice should be made independently from the previous choice.

Data on background and socio-demographic characteristics of respondents are also gathered at the beginning of the survey, in addition to which level they represent

as a policymaker (local; regional; national or European), how they would describe their current role (policy advisor; legal advisor; political (elected)), which topics they dedicate most of their time to, and where they fall on the political spectrum. Once the respondents have chosen one option for each of the six choice sets, they are then asked the choice of which alternative – out of the liquid-based or the gas-based option, or neither at all – they would choose if they had to.

Finally, we present several statements to participants with the goal to identify participants' attitudes and beliefs on the contribution of policy to the decarbonisation of fuels. All respondents, irrespective of their preference for the decarbonised fuels in the choice sets, respond to the statements on a five-point scale (from strongly agree to strongly disagree). The different statements address attitudes towards innovation and alternative fuels, the decarbonisation of fuel as well as climate change. These statements are sought to reveal additional information that may not be captured by the discrete choice experiment, and possibly to investigate a link between participants' attitudes and the stated choices.

3.3.3 Statistical analysis

As discussed above, the analysis of respondents' choices is based on random utility theory, which states that a respondent's utility function is comprised of a deterministic, observable component X_{ij} and a random, unobservable component ε_{ij} (Hanemann, 1994). Thus, the utility U of an individual i choosing alternative j from choice set C is represented by

$$\mathrm{U_{ij}} = \mathrm{ASC} + \beta_{\mathrm{i}}\mathrm{X_{ij}} + \varepsilon_{\mathrm{ij}} \tag{3.1}$$

where X_{ij} is the M-dimensional column vector of observed variables for alternative j and respondent i; β_i is the M-dimensional vector of coefficients capturing generic marginal (dis)utilities of attributes; and ε_{ij} is the error term. The utility also includes the alternative-specific constant ASC that represents the opt-out option.

Eq. 1 can be estimated by different models, depending on assumptions made about the error terms. In the conditional logit model, the error terms are assumed to be independently and identically (Gumbel) distributed. Hence, the probability P_j of choosing alternative j is expressed as a function of a policymaker's expected utility from the choice of j relative to the expected utility of all alternatives J in the choice set:

$$\mathrm{P_{ij}} = \mathrm{e}^{\mathrm{U_{ij}}} / \sum_{\mathrm{k}\in\mathrm{J}} \mathrm{e}^{\mathrm{U_{ik}}} \tag{3.2}$$

In this model the preference parameters are fixed for all participants, assuming preference homogeneity in the sample (Hensher et al., 2015). Further models

were then tested in the next stages of analysis, including the random parameters logit model (RPL) and a modeling approach combining both Error Component and Random Parameters Logit model (EC-RPL). The assumption of homogeneity is relaxed in mixed logit models as it enables capturing unobserved preference heterogeneity by allowing the preference parameters to vary across participants. In RPL models one can also relax the traditional assumption of having no correlation between the random parameters (Train and Sonnier, 2003). The probability of participant i choosing alternative j is then computed as follows (McFadden, 1973):

$$P_{ij} = \int \frac{e^{X_{ij}\beta}}{\sum_{k \in J} e^{X_{ik}\beta}} f(\beta) d\beta \tag{3.3}$$

EC-RPL models also take correlation across alternatives into account and have been shown in the literature to produce higher model fit and robustness in contexts such as these - where choices between the hypothetical alternatives are more similar than those for the opt-out (Hess and Rose, 2009; Van Loo et al., 2014). We have introduced the error component by incorporating a zero-mean normally distributed random parameter, additional to the usual Gumbel-distributed error term in the non-status quo alternatives (Scarpa et al., 2007; Marre et al., 2015).

3.4 Results

3.4.1 Descriptive statistics

129 complete responses were obtained, and with 6 choice sets each, this represents 774 choice observations. With three options per choice set this results in a total of 2322 alternatives for analysis. The response rate was approximately 10%, which is the average response rate for discrete choice experiments (Johnstone et al., 2017). The small sample size is a common limitation for groups that are more difficult to reach as compared to the general public - and in this case policymakers working in a rather niche field. The duration of the survey was on average 10 minutes, and policymakers were incentivised to take part in the discrete choice experiment with the assurance that each completed survey would result in a small donation to the charity of their choice. With regard to choice shares, 40 % of respondents chose gas-based CCU, and 38 % chose liquid-based CCU. The remaining 22% chose to opt-out and fund different projects.

The 70.11 % of respondents were male and the average age of respondents was 46. The gender imbalance corresponds to the reported number of women working in political positions in the European institutions - especially related to political positions in areas of transport (Commission, 2019b). The nationality of respondents varied within the EU but the most represented countries were Belgium, Germany, the Netherlands, Greece, Poland and France. The majority of respondents work in the European Commission, European Parliament, National, Regional and Local

Government. Respondents remained anonymous - apart from providing their place of work - but as specified above, policymakers targeted worked on programmes providing funding for sustainable mobility – from advisory bodies of the Connecting Europe Facility (CEF), TEN-T projects, ESIF, JASPERS, Horizon2020, to name a few. Responses show that people working on these topics and responding to the survey were much more likely to be left-leaning (39.67 %) on the political spectrum than right-wing (11.89 %). A large proportion of respondents described themselves as liberal/central (23.80 %), while the rest preferred not to answer this question. Descriptive statistics of the questionnaire can be found in the annex.

Once the respondents had completed the choice task, all respondents were asked to choose, based on a multiple choice task, which of the alternatives from the discrete choice experiment – out of the liquid-based or the gas-based option, or neither at all – they would choose if they had to. In this question, it was specifically stated that the liquid-based fuel was closer to incumbent engine system, while the gas-based fuel was closer to the innovative engine system. Close to 50 % of respondents chose liquid-based fuel, 30 % chose gas-based fuel and the remaining 20 % preferred to fund neither at all.

3.4.2 Random Parameters Logit Model with an error component

The discrete choice experiment was labelled, meaning that all choice sets shown to policymakers included the option to fund liquid-based CCU, gas-based CCU, with the third option being none - where the remaining budget would be spent on other options to decarbonise the transport sector. Even though these three options remained consistent in each of the six choice scenarios presented to respondent, the levels - or characteristics - of the two aforementioned fuels varied in each of the six choice scenarios presented to the respondents (as is the case in all DCEs). The labels are represented as alternative specific constants, of either being liquid-based CCU and gas-based CCU (ConstantL and ConstantG presented in the results, respectively). We thus included alternative specific constants γ_j for each fuel alternative j in the random parameters logit model. These constants should reveal the general attitude of participants towards the two fuel types. Both constants were encoded as dummy variables, having a value of 1 if the respective fuel alternative was chosen and 0 otherwise. All attributes were treated as continuous variables, except for the attribute fuel costs which was modelled as a categorical variable (with values lower, same, higher) via a dummy encoding, with the base level being 'same'. All attributes were assumed to be normally distributed.

Given that it was a labelled discrete choice experiment, we sought to determine which preference parameters should be modelled as alternative specific (i.e., depending on the respective alternative j) and which as generic (i.e., independent of the respective alternative). In other words, we wanted to find out whether respondents chose fuel options based on the name of the label in the choice sets. We used likelihood ratio (LR) tests to establish this. For each attribute, the log-likelihoods

of the model in which the respective parameter is modelled as alternative specific is compared with the generic model (normally used for unlabelled discrete choice experiments), in which all parameters are assumed to be generic. The model fit of the generic random parameters logit model with an error component provided a better model fit than the alternative-specific random parameters logit model with an error component (log-likelihood test; $p < 0.001$). The results of a mainly generic specification estimated by the random parameters logit model with error components (while accounting for correlation between random parameters) are thus reported in Table 3.2.

The results were obtained using Nlogit, an econometric software specifically designed for the analysis of discrete choice experiments.

The constants for liquid and gas-based fuels were not significant, indicating that participants do not attach utility to the alternative-specific label. This finding appears counter-intuitive in view of the participants' responses to the post-experimental multiple choice question on whether they preferred liquid-based fuel (described to respondents as the "incumbent option") - which turned out to be 50 % of the time, as compared to gas-based fuel (described to respondents as the "innovative option") 30 % of the time. This means that different mechanisms are at play in making a simple choice or a choice in a discrete choice experiment as commonly found in the discrete choice literature (Johnstone et al., 2017).

Nonetheless, the attributes characterising each fuel option were significant - barring budget - which means that attributes selected for the experiment were relevant and important to the policymakers. Further, almost all associated standard deviations are significant, indicating preference heterogeneities within the target population. Policymakers generally had a strong preference for a larger reduction in emissions, a short time to market commercialisation, a high market share and significantly disliked a higher fuel cost. These observations held independent of the fuel type, and are in line with the hypothesised directions. Policymakers showed a tendency to support dominant technologies and those that held a higher technology readiness level: thus potentially supporting and reinforcing techno-institutional lock-in.

Interaction terms show that the preference for budget allocated to the transport system choice varied slightly between three groups – the older segment of the respondent population, policymakers from central Europe, and those that displayed an incumbency bias - compared to the group of respondents as a whole. The groups that had significant differences are presented in the results table. The older the respondent, the less likely they were to devote part of their budget to liquid and gas-based CCU. Further, gender did not have an impact on the results. Five regions were interacted with the results – Northern, Southern, Central, Western and Eastern Europe. Policymakers that stated they were from Central Europe – and in this case either from Germany, Poland, Czech Republic, Austria and Slovenia – preferred to spend less money on the CCU-fuel options, which was not the case for the other regions. Attitudinal responses that were collected from the post-experimental questions (see appendix A), including statements on preference for transport systems that are similar to those already in use were also

Table 3.2: RPL model with correlated error component (RPL-EC) estimates (n=129) using 1000 Halton draws. Alternative-specific parameters are marked with subscripts L for liquid-based fuel and G for gas-based fuel.

		Coefficients	St. Errors	p-Values
Main effects				
Non-random parameters				
Constant$_L$		0.649	0.717	0.364
Constant$_G$		-0.027	0.849	0.974
Standard deviation of Err. Comp.		2.63155***	0.508	<0.01
Random parameters				
Reduction in CO_2 emissions	Mean	1.016***	0.259	<0.01
	St. dev.	0.904***	0.227	<0.01
	Cholesky Diag. Val.[a]	0.904***	0.227	<0.01
Market share	Mean	0.591***	0.161	<0.01
	St. dev.	0.646***	0.166	<0.01
	Cholesky Diag. Val.	0.504***	0.152	<0.01
Time to market commercialisation	Mean	-.399***	0.100	<0.01
	St. dev.	0.379***	0.086	<0.01
	Cholesky Diag. Val.	0.227***	0.083	0.006
Budget	Mean	-0.219	0.153	0.152
	St. dev.	0.707***	0.186	<0.01
	Cholesky Diag. Val.	0.007	0.363	0.982
Lower fuel cost	Mean	-0.171	0.578	0.767
	St. dev.	2.568***	0.959	<0.01
	Cholesky Diag. Val.	0.709	1.607	0.658
Higher fuel cost	Mean	-1.766**	0.826	0.032
	St. dev.	2.538**	0.999	0.011
	Cholesky Diag. Val.	1.314	1.873	0.483
Subject effects				
Budget*Age	Mean	-0.00517**	0.00235	0.0275
	St. dev.	0.00439	0.00332	0.1861
Budget*Incumbency Bias	Mean	-0.09672**	0.04497	0.0315
	St. dev.	0.00079	0.184	0.996
Budget*Central Europe	Mean	-0.392*	0.200	0.050
	St. dev.	0.34968*	0.184	0.058
N observations				2322
Log likelihood				-525.39722
AIC				1110.8
AIC/N				1.435

Asterisks denote statistical significance at the *** p<0.01, ** p<0.05, * p <0.1 level. [a] These values are the diagonal elements of the random parameter model's Cholesky matrix.

interacted. This showed, that the higher the respondent's bias, and preference for incumbent technologies, the lower they wished the budget be spent on the new systems (presented as "Incumbency Bias" in the results). This was based on respondents' level of agreeing to statements such as "It is more effective to invest and improve existing fuel technologies, than in those that have not yet entered

the market", "If the choice of an alternative fuel choice were up to me, it would be compatible with current engines and infrastructure", "People are more likely to prefer vehicle technologies similar to those currently in use." For the remaining statements, no significant difference in results were found. Results for remaining groups also stayed the same regardless of the group the respondent might have fitted into, which points to the respondents being part of a rather homogeneous group, which is indeed the case and the point of the survey.

Correlation across alternatives was also verified given that the standard deviation of the error component was statistically significant. In addition to this, values of the Cholesky matrix were statistically significant which means that some of the random parameters were correlated (correlation matrix can be found in the appendix A). This is evidence for the appropriateness of using a random parameters logit model with correlated parameters (RPL-EC) and the estimates illustrate that respondents perceived the experimentally designed alternatives to be different from that of the opt-out. Upon further analysis of the results, certain policymakers that chose the opt-out verified this by clarifying their choice by anonymously stating comments such as the following: "producing fuels from CO_2 is too energy intensive. There are better and more sustainable options to reduce CO_2 emissions from transport"; "There is already too much attention to the decarbonization of fuel: budget must be used on research in particular how to manage the demand of transport and to improve the energy efficiency of the whole transport system"; "The market share in 2040 was not satisfying in combination with the CO_2 savings. I would prefer to allocate budget to alternatives transport modes instead of car fuels"; similarly another respondent stated that "I would not invest 1bn in any "technical fix" but instead in a radical change of (urban) infrastructure (esp. removing car lanes, boosting bike lanes) and supporting the systematic regionalisation of economic relationships".

3.5 Discussion and conclusions

This paper has analysed the trade-offs that European policymakers face when allocating a limited budget to foster the decarbonisation of transport fuels. The respondents represented a homogeneous target group working in the domain of EU funding programmes for transport and energy infrastructure. An example of this homogeneity is illustrated by the fact that a large majority of the respondents described themselves as left-leaning on the political spectrum, with a minority of respondents describing themselves as right-leaning. All respondents claimed to be rather well-informed on the topic in question and further held strong beliefs in the importance of policy in the sustainability transition. With this in mind, our main findings can be summarised as follows.

Firstly, the results illustrate that the participants showed to consistently opt for whichever transport decarbonisation fuel system provided the quickest fix to emissions reductions, regardless of whether the system chosen (as represented by the

labels) was closer to the incumbent or not. This was illustrated through the specific attributes investigated in the discrete choice experiment: policymakers preferred to fund technologies with the lowest time to market commercialisation, and the highest emissions reductions potential. In addition, the desire for dominant technologies was shown to prevail when choosing a fuel system for decarbonising transport. Technologies with a higher predicted market share and market penetration were much more likely to receive funding than those that had not; thus potentially showing how the lock-in of more dominant technological systems is reinforced.

Secondly, what can generally be concluded is that policymakers display a healthy scepticism when funding innovative technologies that require significant modifications. This was especially indicated in respondents' direct responses with regard to stating a preference for incumbent as opposed to innovative fuels, which was further documented in their attitude towards innovate fuel in the post-experimental questions. For the direct question, policymakers were not presented with exact information on the extent to which each fuel would reduce emissions, nor any information on the transition or uncertainty costs expected (as had been the case in the discrete choice experiment). Policymakers were only told that liquid-based fuel most resembled incumbent fuel types, while gas-based fuel was representative of the more innovative option requiring significant modifications. The policymakers were thus unable to make a fully informed choice, and it was in this case that they were instinctively less likely to allocate their budget to a more innovative and unfamiliar option, and thereby more risky option. As discussed above, when they *were* provided with the associated information to each fuel, however, policymakers did not show a preference for the incumbent or innovative option and fully made their choice based on the attributes and characteristics presented to them.

Thirdly, policymakers chose the alternatives based on the characteristics presented to them, while indicating that there was not always one dominant alternative in each choice set. Given that policymakers fully made their choice based on the attributes, it suggests that respondents either disregarded or did not care about the fact that the source of the fuel came from CCU. Nor did it matter whether the fuel came in a gaseous or liquid state. Additionally, the percentage of opt-out choices was fairly low, and only a few respondents chose to opt-out consistently, thereby clearly accepting CCU-based fuels. This illustrates that CCU does not have negative connotations and perception as a fuel source among policymakers. While ample research exists on the development and feasibility of CCU, there has been limited research into the social acceptance of CCU technologies (Jones et al., 2017; Arning et al., 2019). This paper thus contributes to this literature and points to the fact that the acceptance appears to be high among the policymakers that took part in this study.

In a worst-case scenario, skewed funding allocation in favour of incumbent technologies can reinforce the lock-out of the development of new technologies that have yet to benefit from feedback mechanisms such as economies of scale, learning effects, and network effects. In a best-case scenario, such biases are taken into account when decision-makers allocate funding to technologies to prevent such a

lock-out situation. Ways to encourage this would be, for example, to learn lessons from the world of unconscious bias training - traditionally geared towards discriminatory gender and racial biases (Williamson and Foley, 2018). Unconscious bias training involves programmes designed to expose people to their implicit biases, and can provide tools to adjust automatic patterns of thinking (Fiarman, 2016). Applying this concept to decision-makers, it is possible to raise awareness of both the need to invest in innovative technologies to reach worldwide emissions targets, and the potential for incumbency bias. Another solution would be to incorporate innovation targets and quotas, which would require decision-makers to allocate a certain proportion of the available budget to innovative technologies. It may also be useful to ensure representativity within groups allocating such budgets, in the sense that some may be rural while others may be urban-based, to provide an example. Representativity can reduce the risk of groupthink so that diverse preferences are taken into account. Better tracking of innovation progress (IEA, 2020) would also be helpful to avoid such a worst-case situation.

The interpretation of these results should be done carefully within the boundaries of the study's limitations. As discussed above, the relatively small sample size potentially limits the generalisability of the findings. We selected a rather homogeneous sample and the results cannot necessarily be applied to policymakers in general, but are rather restricted to those working in the area of funding transport infrastructure projects. The pre-tests and pilot undertaken before the distribution of the survey were small - a larger group could have improved the generalisability of the design. Further research on policymakers should take this into account, and attempt to reach a wider and more representative group of respondents. Moreover, a common limitation of discrete choice experiments is its hypothetical nature (Johnstone et al., 2017), and we cannot conclude whether the respondents would have chosen the same alternatives in real circumstances. However, hypothetical choices can be meaningful for improving real-world choices. Previous studies show that it is possible to elicit real world choices with fair precision when field or real-world data is unavailable (de Bekker-Grob et al., 2019; Haghani et al., 2016). Therefore, it is reasonable to assume that our conclusions will also ring true in real-world settings and not only hypothetical ones.

Overall, the results provide insights into the trade-offs of policymakers when allocating funding to clean technologies – they seek options that can ensure a quick solution to emissions reductions and stated an initial preference for the familiar and incumbent option. These findings have important implications for policy design and illustrates the importance of taking institutional actors' decisions into account in studies of transition. The experiment itself allows us to gain some evidence as to why incumbent technologies prevail in the market: even when the policymakers were provided with a hypothetical choice to allocate funding, they still chose the option that required the least amount of change and least amount of time to market. Policymakers may be likely to avoid investing in a more innovative idea, not because of any intrinsic flaw in the technological system, but because it would require too much change. These insights should be made available to and communicated among policymakers overseeing innovation funding programmes.

Acknowledgements

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Chapter 4

Why does France not reach its pesticide reduction targets? Farmers' socio-economic trade-offs when adopting agro-ecological practices

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4.1 Introduction

The past decades have seen a surge in studies implicating pesticides in environmental pollution, biodiversity loss and health problems (Wilson and Tisdell, 2001). In an effort to curb these effects and encourage a transition to more sustainable agricultural systems (an agro-ecological transition), there has been an increase in policy measures across France to reduce farmers' dependence on the use of pesticides. Research has shown that reducing pesticide use does not necessarily lead to lower agricultural yields or profits (Lechenet et al., 2017), and reducing pesticides may reduce farmers' costs, improve their health and living environment, and prevent pest resistance (Bourguet and Guillemaud, 2016).

Despite these trends, and rapidly rising consumer demand for organic products, pesticide applications remain high, and reduction targets are consistently not met. The French Ecophyto Plan aimed to reduce pesticide use by 50 % between 2007 and 2018. Nonetheless, recent figures show that, overall, pesticide use actually increased in France between 2008 and 2018 (Lapierre et al., 2019; Hossard et al., 2017). Further, the subsequent plan of Ecophyto 2 aims to reduce pesticide use by 50 % between 2018 and 2025, whereas pesticide use has increased between then

and now as well (French Ministry of Agriculture, 2020). Several policy instruments have been put in place to reach these goals, such as the creation of networks of local groups of farmers that are provided with technical support to reduce the use of pesticides (known as the DEPHY networks (Cerf et al., 2017)), pesticide reduction certificates, increased communication and information, as well as research and innovation on alternative solutions and integrated pest management, to financial support: €71 million are devoted annualy to the Ecophyto plan (French Ministry of Agriculture, 2021).

Why, then, does it appear that the transition to agro-ecological practices is so difficult to attain? More specifically, the research question underlying this study is the following: why are French farmers reluctant to reduce pesticide use despite strong policy support? We argue that, this reluctance largely mirrors a resilience of existing socio-cultural systems and patterns of behaviour. In essence, we suggest that better understanding socio-economic and behavioural factors lies at the heart of improving responses to pesticide reduction policies. Substantive system changes are required in the transition from one socio-technical system to another (Rip et al., 1998; Geels, 2005), and the transition literature refers to these systemic changes as 'socio-technical'. Socio-technical changes do not solely involve technological innovation or substitution, but also require complex and interconnected social changes in the overall configuration of culture, habits, work, markets, consumer practices, scientific knowledge and agri-food systems (Geels, 2011; Elzen et al., 2004; van den Bergh and Bruinsma, 2008; Safarzyńska et al., 2012; Bjørnåvold et al., 2020). What matters is not merely the technological innovation itself (and in this case, agro-ecological practices allowing alternatives to pesticides), but also the social and economic systems in which the existing technology is embedded (Upham et al., 2019).

A mixed-method study was conducted - a discrete choice experiment (DCE), which was eventually complemented with qualitative interviews - to understand farmers' decision criteria and to accompany them on the road to changing their practices. DCEs are a non-market valuation method based on repeated fictional choices made by respondents to elicit their preferences. While literature exists on the need for qualitative approaches in the DCE design phase (Jeanloz et al., 2016), this chapter contributes to the literature seeking to complement DCEs with interviews (Powe et al., 2005). DCEs are valuable to estimate preferences in a hypothetical setting. However, when considering such complex socio-technical transitions that may affect entire livelihoods, respondents may need discussion forums that complement the more rigid DCE format.

Our principal contribution to the literature is the use of two complementary methods to deepen our understanding of farmers' behavioural patterns on the reluctance of reducing the use of pesticides. First, our DCE explores decision factors - such as the transition time to adopt new agricultural practices. During this transition time, impact on income, health and environment are uncertain due to unknown effects on sales, costs, yields and development of the soil, while substantial learning and knowledge on novel practices are simultaneously required. We further included attributes taking the inclusion in a network of farmers into account, as

well as changes in the organisation of work - that are part of the social factors that may play a role in the transition. To the best of our knowledge, these attributes have not yet been studied in the DCE literature on farmers' behaviour regarding pesticide reduction measures (see among others Birol et al., 2006; Christensen et al., 2011; Blazy et al., 2011; Broch and Vedel, 2012; Villanueva et al., 2015; Peterson et al., 2015; Chèze et al., 2020). Second, we treat semantic data obtained through semi-structured interviews to complement the DCE analysis.

The remainder of the paper is structured as follows. Section 4.2 presents the mixed-method approach applied to the study, firstly detailing the DCE followed by the qualitative method of interviews. Section 4.3 discusses the results of both sections, while section 4.4 presents a discussion on both sections. Our conclusions are presented in section 4.5.

4.2 Method

4.2.1 Discrete Choice Experiment

Discrete choice experiments (DCE) have been extensively used to model people's choices and identify preferences (Louviere and Hensher, 1982; Louviere and Woodworth, 1983). Each respondent is presented choice cards with several alternatives - defined by various attributes (i.e., fundamental characteristics of the respondent's situation), each associated with a given level - and asked to choose the preferred alternative. The main goal of a DCE is to estimate the weight and sign of each attribute in respondents' decisions from the repeated choices made (Cuervo et al., 2016). One of the attributes is generally monetary, while the others can include either or both environmental and social implications of the issue. This paper seeks to estimate and value components of policies to accelerate agro-ecological transitions, and understanding the trade-offs between policy components are important to ensure a quicker transition, and in this case, DCEs are the method of choice. Moreover, DCEs are well suited to situations where a change is multi-dimensional, and the trade-offs between these dimensions are of interest.

DCEs have until now been used to investigate various aspects of farmers' views on pesticide reduction measures. Birol et al. (2006) investigate the diversification of crop varieties in farmers' home gardens which contributes to understanding the potential role of home gardens in agri-environmental schemes (AES). Christensen et al. (2011) study the trade offs that farmers are willing to make between subsidy size and individual AES requirements and find that most farmers are willing to trade off the size of the subsidy for less restrictive scheme requirements and that the subsidy size depends on the specific scheme requirements. Moreover, Blazy et al. (2011) look to farmers reducing pesticide use by adopting agro-ecological innovations in view of receiving a subsidy, while Kouser and Qaim (2013) quantify the health and environmental benefits associated with cotton in Pakistan – and its associated reduced use of pesticides. They found that farmers themselves value

these positive effects at US $79 per acre, of which half is attributed to health and the other half to environmental improvements. Jaeck and Lifran (2014) investigate preferences for using alternative weed control technologies, based on a single payment scheme per hectare and Kuhfuss et al. (2016) study farmers' preferences for joining an AES scheme to reduce pesticide use, also based on a single payment scheme per hectare. Jin et al. (2017) investigate farmers' valuations for health risk changes associated with pesticide use in China and find that female farmers and those that are more educated are more likely to accept a compensation scheme if health risks increase. Danne et al. (2019) illustrate that farmers prefer the use of glyphosate to other alternatives to prevent weed infestation, while also saving work and labour costs, especially on large farms. Chèze et al. (2020) find that the risk of substantial losses in production as a result of pests reduces farmers' willingness to reduce their pesticide use.

In our case, respondents are farmers choosing between three alternatives of agricultural practices. Two alternatives are hypothetical situations implying a change of farming practices and a reduction in pesticide use, while the third one is an opt-out or status quo option, with the latter corresponding to the current situation of the farmer (i.e., nothing changes). Including an opt-out is known to attain more realistic results (Lancsar and Louviere, 2006; Kontoleon and Yabe, 2003; Adamowicz and Boxall, 2001), as opposed to 'referendum' type DCEs that would require the respondent to choose between two options provided by the researchers. We intentionally kept the change in agricultural practice in the two alternatives to the status quo general. With general alternatives, any modification in the farming practices leading to the reduction of pesticides could be envisioned by the farmers taking part. By not explicitly stating the exact nature of this change, we therefore sought to accommodate different types of farms and soil-climate conditions. At the same time, we provided examples of practice changes to farmers to make the decisions more realistic and concrete in the informative material provided to the farmers, which can be found in Appendix B.

4.2.1.1 Choice of the attributes and their levels

The first step in the design of a DCE study is choosing the attributes and their levels. As explained by Chèze et al. (2020), several factors influence farmers' choices in reducing or maintaining pesticide application such as reducing input costs, increasing the sales price, improving their public image, taking part in a network of farmers, improving quality of life and health, obtaining subsidies, routine behaviour, lack of technical knowledge, an aversion to uncertain outcomes, to only name a few. The attributes were chosen based on: i) the literature on farmers' use of pesticides and alternative practices ii) refinements based on pre-tests and two focus groups with three farmers each (one held at SOLAGRO, Toulouse, France and one held at AgroParisTech, Grignon, France) conducted with small groups of farmers to establish the elements of their greatest current and future concern; and, iii) online consultation with farmers who had previously converted to agro-ecological practices via the online OSAE (OSez l'Agro Écologie) platform. The

number of attributes was limited to five to minimise the risk of cognitive load and non-attendance bias. The selected attributes were: i) impact on income; ii) transition time of the change of agricultural practices; iii) impact on health and the environment; iv) impact on work schedule; and, v) potential agricultural support accompanying the change of practice (training, advice, network...). A detailed explanation of the attributes and the choice cards is given in Appendix B as was shown to respondents.

The first attribute is the monetary attribute represented by the impact on income. The associated levels are -10%, 0%, or + 10% of income compared to the current situation, and defined as the total revenue minus the total expenditure. Exact information provided to farmers on the income attribute can be found in Appendix B. Farmers' incomes are expected to vary - either positively or negatively - upon changing practices due to various reasons related to the impact on yield, spending on pesticides, governmental support, labour costs, investments and output prices of agricultural produce. The output prices of agricultural produce would change as produce that uses little pesticides can be sold at higher prices (i.e., organic products). Investments could include technologies needed to adapt to agro-ecological practices, such as a spike tooth harrow, to give an example. The choice of presenting income as a percentage change in 10% increments, and not precisely budgeted, was chosen after consultation with experts and farmers, and a review of the literature. A limited number of levels does not necessarily simplify the choice scenario and the cognitive burden imposed on respondents. However, these three levels were chosen to represent realistic income changes to farmers' income when transitioning to agro-ecological and low-pesticide agricultural systems, while at the same time presenting simple levels for calculation with regard to respondents' income.[1]

The second attribute represents the time taken to transition to new agricultural practices and the time expected to represent a period of uncertainty and adaptation in redefining a new cropping system. During this time, impact on income, health and environment are uncertain due to expected risk and unknown effects on sales, costs, yields and development of the soil, while substantial learning and knowledge on novel practices are simultaneously required. The selected levels are 2, 3, and 5 years, corresponding to a rapid transition for less complex changes to an upper average duration expected to transition to agro-ecological practices. For example, three years are necessary to produce enough carabids in direct drilling with cover crops in France (Petit et al., 2017).

[1]While the low number of levels sought to represent income changes that were realistic and simple to visualise, they at the same time caused a risk of attribute non-attendance. Cameron and DeShazo (2010) found that the greater difference in the range between alternatives of levels for an attribute is associated with a greater likelihood that an individual will take this attribute into account, *ceteris paribus*. WTP has also been illustrated to actually increase as the cost vector offered increases, which can be attributed to anchoring effects (Glenk et al., 2019). Moreover, empirical findings from 'bid acceptance curves' show continued demand despite a very high cost of alternatives - similar to the 'fat tail' problem found in contingent valuation studies - termed "choke price bias" by Mørkbak et al. (2010). If WTP values are too small, on the other hand, WTP values can become larger than the highest bid levels (Glenk et al., 2015).

The third attribute includes the impact on health and the environment upon changing agricultural practices. This attribute represents the expected decrease in the amount of pesticide residues used by the farmer, and as a result, found in the human body, food - and impacts both farmers' and consumers' health - as well as the various compartments of the environment. This attribute therefore represents both individual and public benefits, and both dimensions could be important - as for instance, studies have shown that farmers feel a responsibility to mitigate environmental effects (Mzoughi, 2011; Reimer et al., 2012; Vatn et al., 2020), but also about their reputation within their community and about what is considered "appropriate" (Villamayor-Tomas et al., 2019; Beedell and Rehman, 2000; Jaeck and Lifran, 2014). When designing this attribute, we considered having two separate attributes, given that the impacts of health and the environment present distinct components (Carvalho, 2017). However, research has shown that when discussing implications of pesticide use by farmers, they are highly correlated – one necessarily impacts the other (Juraske et al., 2007). Given that the complexity and imposed cognitive burden of DCEs generally also goes hand in hand with the number of attributes and levels chosen (Caussade et al., 2005; Hensher et al., 2015), we finally agreed to stick to one attribute combining the impacts of pesticides on health and the environment, in conjunction with discussions with farmers and experts. In a previous study, this attribute had not been significant on average (Chèze et al., 2020), but we chose to include it to corroborate or challenge this prior result. The levels selected for a decrease in pesticide residues were -20%, -50% and -95%. These levels were chosen to correspond to different levels of application of agro-ecological practices. The highest reduction of -95% approximates the amount needed to transition to organic farming practices, where the use of any pesticide is virtually prohibited, with some exceptions (in case there is an emergency pest attack, chemical pesticides may be authorised).

The fourth attribute corresponds to the change in the organisation of work - or work schedule - expected to accompany a change in agricultural practices. Specifically, this refers to the change in the distribution of time directed to the farming practices, with different options where workload would: i) become more condensed (with increasing alternating work peaks/rest times); ii) become more spread out, evenly, over time; or, iii) be unchanged. In consultations with farmers, the attribute of a potential change in work schedule frequently came out as an important aspect of concern with regard to changing practices. As also discussed by Vidogbéna et al. (2015), the change in the distribution of work can greatly impact farmers' preferences. We chose to stick to the attribute of 'work schedule', as opposed to workload, as we found that in the literature there is currently no consensus as to whether the use of pesticides increases or decreases farmers' workload (Lechenet et al., 2014; Paudel et al., 2020), while there is literature that highlights the modification of the organisation of work over time that the change in practices ensues (Daghagh Yazd et al., 2019). Given that we did not want to take a stance on this point, we chose to focus on the distribution of work as opposed to the workload in this fourth attribute.

The final attribute looks at farmers' preferences for support in transitioning to

low-pesticide agriculture and for inclusion in a network. Support was assumed to be optional and free and to be in addition to any current support. Types of support were: i) follow-up by an advisor; ii) membership within a peer network for an exchange of practices, knowledge and experience with neighbouring farmers; iii) target local training on new technologies and practices; and, iv) none of the aforementioned measures.

Table 4.1: Attributes and levels
SQ: level in the status quo (also possible in the other options); only SQ: level only in the status quo option

Attribute	Attribute Levels
Impact on income	-10 %; 0 % (SQ); +10 %
Transition time	2; 3; 5 years; no transition (only SQ)
Impact on health and the environment	-20%; -50%; -95% residues; no reduction (only SQ)
Work schedule	Condensed; Spread out; Unchanged (SQ)
Optional and free agricultural support	Advisor; Network; Training; None (SQ)

4.2.1.2 Experimental design of the DCE

With five attributes and three to four levels for each attribute, there are too many attribute-level combinations to present all of them to the respondents. NGene, a software tool created explicitly for the design of DCEs, was used to select the sub-set of these combinations that procures maximal information (see experimental design techniques in Louviere et al., 2000a; Street et al., 2005). We used an efficient Bayesian D-optimal design adapted to an econometric treatment with a random parameter logit and parameters following a normal distribution. Efficient designs have been consistently shown to be statistically superior to orthogonal designs (Rose et al., 2008). In comparison to orthogonal designs, they take preliminary information about the target group's preferences into account to maximise the information collected (Ngene, 2012). Efficient designs also allow for the attainment of lower standard errors in estimating the model for smaller respondent groups, which are characteristic of farmer DCEs. According to Greiner (2016), using a D-efficient experimental design, as we do, requires a much smaller sample size than a random orthogonal design. The design created 12 different choice cards, which were blocked into two groups of 6 choice cards to which respondents were randomly assigned (see one of the choice cards in Figure 4.1). Thus, each participant answered six choice cards to limit the cognitive burden (Hensher et al., 2015). The NGene code used for the experimental design is presented in Appendix B.

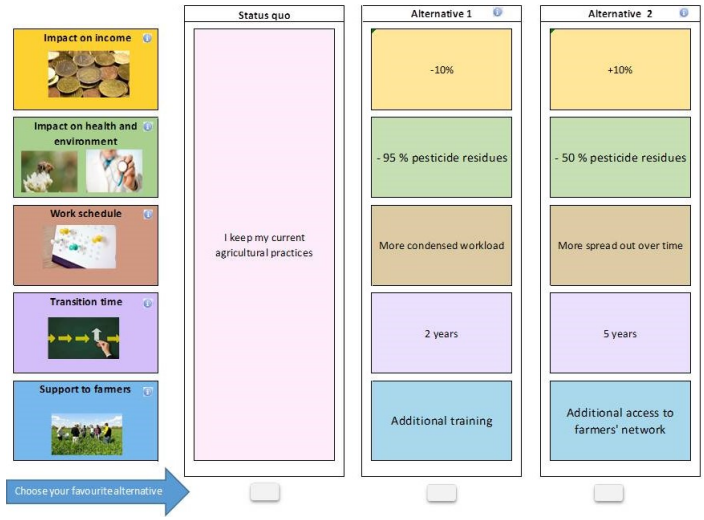

Figure 4.1: Example of a choice card translated from French

4.2.1.3 Questionnaire

The questionnaire was distributed between January and May 2019. It was sent to over 2000 French farmers - both conventional and organic - practicing various farming activities (see Appendix B). A significant proportion of the DCE distribution to farmers was done via the French agricultural network of SOLAGRO - which distributed the survey to farmers throughout France. Further contacts were attained through organisations providing agricultural training such as *CertiPhyto* (training on the use of pesticides which is mandatory for French farmers) and through meetings with agricultural stakeholders and networks, which allowed the authors to approach farmers. A Facebook page was also created with a link to the questionnaire that was only posted in private groups for farmers residing in France. The questionnaire's distribution was mostly by electronic means, except a dozen responses that were attained through in-person contact with farmers (using a hard-copy transcript of the electronic questionnaire).

There was a known risk to disseminating surveys electronically, including the potential for sampling bias, as those who choose to respond may have different preferences to those that choose to ignore it. Further, there may often be complexity attached to DCEs, and this complexity cannot be clarified to the respondent when the survey is disseminated electronically. Our survey instrument included the choice sets and other questions regarding respondents' work, farming practices, income, attitudes, and socio-demographic characteristics of the participants. Other sampling biases, such as particular groups being more interested than others, would be controlled for in the data analysis. In particular, distributing the survey through Facebook also opened up to potential biases, as the sample is then drawn from a population without regard to who that sample may be excluding.

Nonetheless, given Facebook's large user base, Facebook has in recent years become a popular tool in survey research as it enables swift and low-cost recruitment (Ramo and Prochaska, 2012; Zhang et al., 2020; Schneider and Harknett, 2019; Kalimeri et al., 2019; Grow et al., 2020). Given its large user-base, it also opens up the possibility of reaching traditionally hard-to-reach population groups (Schneider and Harknett, 2019). As discussed, farmers are part of those difficult-to-reach groups. In a study with 980 French farmers, 86 % stated that they were active on the internet on a daily basis, with 68 % of those active on social media, and Facebook was the most popular social media tool (Agricole, 2021). Based on these elements, we decided to supplement our sample with farmers recruited through Facebook.

The questionnaire was developed on the survey platform LimeSurvey and designed to last about 15-20 minutes.[2] The respondents were initially presented with an introduction to the organising actors – the French National Research Institute for Agriculture, Food and the Environment (INRAE) - emphasising the work of the institute and the respondents' likely role in influencing public decision-making through their participation. This latter statement is important to improve the consequentiality of the study, that is the fact that respondents believe there is a nonzero probability that their answers actually influence decisions, which improves their incentives to answer truthfully (Johnston et al., 2017). The objectives of the study were then outlined, while the anonymity of respondents was ensured. The respondents were given a series of questions on their farming activities. Their perception regarding the use of plant protection products was also queried, along with their perception of pesticide impacts on the environment and health, preferences for work schedule, and support measures and time of transition. Following this initial section, respondents were shown two explanatory videos explaining the issue, how to understand a choice card, the attributes and their levels[3], and the task at hand. A further statement that aimed to improve the survey's consequentiality was included at the end of the second video. This statement indicated that the respondents could be offered the opportunity to participate in a pilot programme to reduce pesticide use following the survey and that their answers would influence this programme. This statement sought to incentivise farmers to take part in the DCE with the assurance that their responses would have a consequential impact on public policy.[4]

Then came the six choice cards. As shown in the example in Figure 1, small informational icons were present in each choice card, providing - when clicked upon - a reminder of the attributes' definition and of how to complete the choice card. The order of the choice cards was randomised to prevent bias caused by either order or survey fatigue.

[2]The exact questionnaire that was sent to farmers (in French) is available following this link: https://catisae2.toulouse.inra.fr/limesurvey-206/index.php/325585?lang=fr

[3]Slides were used to explain in detail the choice cards and the meaning of each attribute (see Appendix B for a translation of theses slides).

[4]At the time of publishing this thesis, the pilot programmes with farmers have not been run but are still planned further down the line.

An additional question was asked to respondents selecting the status quo level in all the six choices to identify potential protest answers. Comprehension questions (degree of understanding and satisfaction), an open-ended question on the other factors that may influence their decisions and socio-demographic questions (income, age, education, gender, other sources of revenues, etc.) were also included after the choice cards. Socio-demographic answers are essential to better interpret the farmers' responses as they allow for interactions to be included in the econometric modelling.

4.2.2 Qualitative interviews

To better understand and to complement the results of the DCE, interviews were conducted with a sub-set of farmers that took part. Semi-structured interviews were thus conducted with a representative sample of the farmers who completed the DCE between August and October 2019: the farmers that had taken part in the DCE were asked - first by email (that was provided in the DCE questionnaire) if they were willing to be interviewed. The farmers were then asked to provide their telephone numbers and an appropriate time for an interview. The farmers were made aware that the interviews' objective was to understand farmers' preferences for agro-ecological practices (as was the case for the DCE), and complement the responses extracted from the choice cards by posing follow-up questions about these responses. The qualitative interviews allowed researchers to obtain information that was not accessible in a closed-form, formal questionnaire, such as the DCE. Participants were aware of the research goals (and that they would be asked to provide further information on the choices made), the research institution organising the survey - INRAE - as well as the researchers' characteristics (name, job position, research interest). The interviewer - a trainee working at INRAE under the supervision of the two lead authors of the study - did not know any of the participants prior to the study and there were no repeat interviews. The interviews were conducted over the telephone, given the France-wide distribution of the farmers. All interviews were audio-recorded and transcribed *ad verbatim* in the language in which interviews were conducted: French. These transcripts were then translated into English for semantic data analysis.

4.2.2.1 Interview set-up

Before the interview process began, an interview guide was developed based on comprehension questions, reasons for answers and views related to agricultural practices and policy changes. This interview guide can be found in Appendix B. The process and method of conducting the interviews followed an iterative process and informal structure. The interviews' main purpose was to delve further into the results of the DCE by allowing the farmers to speak freely and express their views on the topics at stake. Moreover, in-between interviews, the authors regularly discussed the semantic issued from the narratives in the interviews to identify the

main themes emerging from the farmers' responses. This identification of semantic and themes would later form the basis of the codes for data analysis (Chambliss and Schutt, 2018).

4.2.2.2 Data analysis of the qualitative survey

Data management and analysis were performed using the qualitative data software package NVivo. The transcripts were read and thematically coded by the authors to organise a pattern of convergence and divergence in the narratives of the responses of the farmers interviewed (Creswell and Poth, 2016; Patton, 2014). The qualitative content analysis thus included familiarisation with the data through slow reading, followed by a combination of deductive and inductive construction of codes classified into main categories and subcategories, depending on the main themes highlighted by the farmers, while remaining open to new main categories emerging from the semantic data. Coding discordance was discussed and re-coded as necessary. During the analysis, interviewees' statements were assigned to the themes to establish differences in the perspectives of the farmers involved. This process made it possible to identify relations as well as emerging patterns and ideas. If a statement was relevant for multiple topics or sub-topics, it was possible to assign the response multiple times.

We followed contemporary guidance in qualitative research methods when conducting the semi-structured interviews. While a large number of articles, book chapters and books recommend anywhere from 5 to 50 participants as adequate (Morse, 2000; Charmaz, 2006; Baker and Edwards, 2012), while Boddy (2016) considers a sample size "over 30 too unwieldy to administer and analyse," debates often respond that "it depends" (Baker and Edwards, 2012). Nonetheless, the general consensus is that new interviews should be conducted until data saturation is reached when "further interviews yield little new knowledge, until the law of diminishing returns applies" (Kvale, 1994). The concept of data saturation, which is the point at which no new information or themes are observed in the data from the completion of additional interviews or cases is a useful concept in terms of discussing sample size in qualitative research. Guest et al. (2006) found - in their example - that data saturation starts to become evident at six interviews and definitely evident at 12 interviews. Data saturation was therefore considered to have been reached when no more additional codes or novel data points were identified.

4.3 Results

4.3.1 Discrete Choice Experiment

4.3.1.1 Descriptive statistics

121 complete answers were received, and eleven of these were removed due to a lack of comprehension or protest answers. Tests were completed in order to clean up and understand the data sample (see Figure 4.2 for a summary of these tests). To examine the robustness of the results, respondents were sequentially removed based on their motivation or a lack of understanding. Such removals could be identified based on responses to the post-experimental questions. Concentration was also tested, evaluating an expectation of consistently opting for one alternative (on the left, either all six times or five out of six times) and short duration spent watching the explanatory video or completing the questionnaire. The authors also controlled for quality of the sample by doing background checks on those that had provided their email addresses (57 out of 121 farmers), as well as questions relating to farming activity and farm size, by making sure that the full sample were truly farmers. We found that 3 out of the 121 that took part were not currently farmers, and were therefore removed from the sample.

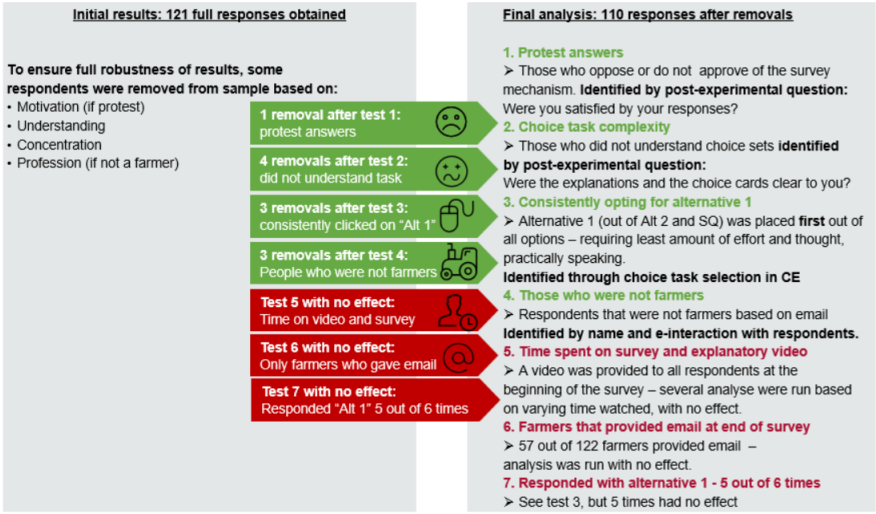

Figure 4.2: Final number of respondents to the DCE after sample removals

In the end, 110 full responses, and data from 5.5 % of farmers who received the questionnaire by email could be analysed. A major issue of online surveys is the participation rate, as response rates are generally very poor, as compared to in-person data collection (Nayak and Narayan, 2019). The small sample size is also an especially common limitation for groups that are more difficult to reach compared to the general population, such as farmers when discussing sensitive topics like

pesticides. This is clear from the many published DCEs conducted with farmers with similarly low sample sizes: to name a few: 90 French farmers in Chèze et al. (2020), 134 Swedish farmers in Franzén et al. (2016), 104 Australian farmers in Greiner (2016), 128 German farmers in Schulz et al. (2014), 104 French farmers in Jaeck and Lifran (2014), 49 U.S. farmers in Hudson and Lusk (2004).

While the survey was designed and distributed according to best practices on state-of-the-art DCE methodological considerations (Johnston et al., 2017), the pre-tests may have been ineffective due to small focus groups, but there may also have been a rejection of the study by farmers at the outset, leading to a non-response bias. Of the farmers that started the survey, 25.6 % of these completed it, with a great majority of the dropouts occurring at the very start of the survey. The survey was distributed at a time when topics surrounding the reduction of pesticides was a particularly sensitive topic (Kudsk and Mathiassen, 2020), which may also have contributed to the low response rate, and rejection by certain farmers. Notwithstanding this limitation, as discussed previously, the design used in this DCE is a D-efficient experimental design, which, as discussed by Greiner (2016), requires smaller sample sizes than random orthogonal designs, as illustrated by Rose et al. (2008) and Bliemer and Rose (2011). Furthermore, the time taken to complete the survey may have discouraged some farmers, leading to drop-offs: the average time taken to complete the survey was 15.9 minutes. Given this limitation of a small sample size, our results are not necessarily generalisable to all French farmers, but are still valuable given the little existing research on French farmers' reluctance to reduce pesticide use, and difficulty in reaching large samples at once.

While there is a diversity of farming systems used in the sample of respondents that took part, the great majority of the sample (72.56 %) are field crops farmers who use fungicides, insecticides and herbicides. Followed by this are mixed crop and livestock farmers (22.54 %), and a very low number of vineyards and market gardening farmers (both representing 1.96 % of the sample). About 6.4% of the sample are organic farmers. Organic farmers were included in the sample as their preferences could provide valuable insights into the way farmers in general should be accompanied in the transition to agro-ecological practices, as they have already gone through these processes. Furthermore, studies have shown that the insecticides organic farmers are authorised to use may have negative impact on pollination and pollinators, and certain organic farmers are seeking to transition to agro-ecological practices even further (AgenceBio, 2021).

Around half of the farmers taking part have additional external sources of revenue. Out of all respondents, 79% have already reduced pesticide use, and 89% have used alternative practices to pesticides. Upon questioning the impact of pesticides on the environment and health, many believe them to have a 'moderate' effect on both (50 %). Given that recent figures show, as mentioned above, that pesticide use has increased in later years (Lapierre et al., 2019; Hossard et al., 2017), this high number of farmers stating that they had already reduced pesticides may indicate that farmers that took part in this study are some of the more motivated and green front-runners of French farmers. However, we also need to acknowledge that these figures also depend on the way that pesticides are measured (whether

in kilogrammes, litres, through activation and other indicators), which means we need to interpret these figures with caution. Changes can and will also be linked to farm and crop type changes, as well as weather conditions. Nonetheless, even if this selection bias may exist in our sample, the obstacles to reducing pesticides may then be *even* stronger in the overall population of farmers that have not taken more extensive steps to reduce pesticides, as compared to those that have already taken steps to achieving a more sustainable agricultural system. The results obtained from this group therefore remain relevant, and perhaps even more so, to farmers in general that have not yet taken as many steps to reduce the use of pesticides.

The largest proportion of respondents were in the age group 40 - 49 (31.3 %), followed by age groups 30-39 and 50-59 (both at 26.3 % respectively), then 18-29 at (10.1 %) and lastly those over 60 (6 %). In terms of education, most of the farmers that took part had completed Bachelor's level degrees (47.06 %), followed by a high school diploma (22.55 %), a Master's degree or higher (14.71 %) and vocational training (11.76 %). The lowest proportion had not completed any formal secondary education (1.96 %). Most of the respondents worked as sole employees on their farm (55.35 %), some with one to two employees (31.68 %), and a minority worked with three or more employees (12.97 %).

Table 4.2 compares the descriptive characteristics of our DCE sample with the average French farmer, based on information from AgenceBio (2021) and Chèze et al. (2020). Our sample is rather representative of the population in terms of age and the proportion of respondents with high school diplomas. However, similar to the sample of Chèze et al. (2020), farmers with higher education diplomas are over-represented - which is typical for online surveys - and the mean size of farms is significantly larger than it is for the country as a whole, which is also common in online surveys with farmers. Our results should therefore be interpreted with caution, and are not necessarily directly applicable to the whole population of French farmers. Nonetheless, an imperfect sample is better than no sample, and we believe that insight from the farmers that did take part are still valuable input to the policy discussion.

Table 4.2: Comparison of socio-demographic characteristics between survey sample and French farmers in general

	Our sample	French farmers
Mean age	40-49	50.6
Farm size (hectares)	179	56
Proportion with a high school diploma	13.72 %	21 %
Proportion with a higher education diploma	84.32 %	17 %
Farmers with an outside revenue	58 %	51 %
Organic farmers	6.36 %	8.3 %
Farmers that frequently attend training (>every 2 years)	52.83 %	53 %

4.3.1.2 Econometric analysis

Attributes for impact on income, impact on health and the environment, and transition time were treated as quantitative continuous variables. Optional support and work schedule were modelled as qualitative categorical variables. The levels of the categories for the optional support were "advisor", "network", "training" and "none", with base level being "none" via a dummy encoding. The levels were "condensed", "spread out" and "unchanged" for the work schedule, with base level being "unchanged", also via a dummy encoding. The alternative specific constant (i.e. status quo, and nothing changes) is represented by no change in income, no time to transition, no reduction in the impact on health and environment as a result of a reduced use of pesticides, an unchanged level of work schedule, and none for the optional and free agricultural support. Econometric analysis was performed using Stata.

The conditional logit model (McFadden, 1973) was first run on our results, which is considered the workhorse model of discrete choice experiments. The conditional logit model is based on three assumptions: (1) independence of irrelevant alternatives (IIA): the probability ratio of individuals choosing between two alternatives does not depend on the presence or absence of any other alternative within the set of alternatives included within the model ; (2) that error terms are independent and identically distributed across observations; and (3) no preference heterogeneity (i.e. identical preferences across respondents) (Hensher et al., 2015). We ran the specification Hausman-test of the IIA assumption (Hausman and McFadden, 1984) on our conditional logit model, and our results confirmed that the IIA assumption could be rejected in our model ($p < 0.01$).

That the IIA assumption could be rejected suggests that the random parameters logit model is preferable to the conditional logit model given that it relaxes the IIA assumption. The assumption of homogeneity is also relaxed in random parameters logit models as it enables capturing unobserved preference heterogeneity by allowing the preference parameter to vary across participants, in addition to the traditional assumption of having no correlation between the random parameters (Train, 2009). Latent class models, on the other hand, are used to uncover possible different preference patterns among assumed respondent segments and also extends the conditional logit model. Segment membership, which is unknown to the analyst, is characterised by unobserved (latent) variables which can be related to a set of discrete observed measures such as general attitudes and perceptions, as well as socio-economic characteristics of the individuals (Amaya-Amaya et al., 2008). Based on the log likelihood values, we can also reject the conditional logit model in favour of either the random parameters logit model or latent class model.

To compare the model fit of the random parameters logit model and the latent class model the comparison on a likelihood ratio test is not appropriate as they are not nested. AIC and BIC values illustrated that the latent class model had the best model fit, and we therefore present the latent class model below. A latent class model was therefore also run on our results to uncover whether such

segments were present in our data-set. Determining the optimal number of classes (segments) in a latent class model is key as it is not predetermined. Generally, the literature sees that somewhere between two and five classes should suffice (Amaya-Amaya et al., 2008), and that the best segment retention criteria is a variation of the Akaike's information criteria (AIC) with a per-parameter penalty factor of 3 (Bozdogan, 1993; Andrews and Currim, 2003).[5] Nonetheless, it is recommended that several criteria are compared (including the Bayesian information criteria (BIC) and the Consistent Akaike information criteria (CAIC)). The results of the attempted number of classes and associated information criteria are presented in Table 4.3. They clearly indicate that the best model fit lies in the model with two classes.

Table 4.3: Model statistics for two to five segments (classes) of the latent class model

	Log-Likelihood	Parameters	BIC	CAIC	AIC	AIC3
2 classes	-555.0241	25	1227.56	1252.56	1160.0482	1185.0482
3 classes	-541.46	41	1275.64	1316.64	1164.92	1205.92
4 classes	-527.4194	57	1322.766	1379.766	1168.8388	1225.8388
5 classes	-515.0482	73	1373.231	1446.231	1176.0964	1249.0964

Results of the latent class model show that respondents in class 1 represent 76 % of respondents in the sample and are more likely to frequently attend training and be a mixed crop and livestock farmer than those in class 2. Results for class 1 revealed a significant, strong and negative value for the constant, indicating that there was a preference of this class of farmers to exit the status quo, i.e., to change their farming practices. They also show a significant preference to reduce impact on health and environment by reducing the use of pesticides.

Respondents in class 2 are the remaining 24 % of respondents in the sample. They show a highly significant dis-utility to reduce the impact on health and the environment through the reduction in the use of pesticides - in other words they do not want to change to alternative practices. This is confirmed by the insignificant coefficient associated to the constant, indicating these farmers do not particularly wish to exit the status quo and modify their farming practices. Farmers in class 2 positively value a spread out work schedule compared to a condensed one.

Nonetheless, the remaining attributes were not significant despite all attributes and levels being described as relevant and important in both focus groups and pre-tests. These insights required further testing, given that they did not conform with the information acquired in the pre-experimental stage, and further discussion was required with the farmers to better understand why the attributes seeking to represent 'Transition time', 'Work schedule' and 'Free and optional agricultural support' were disregarded. While the farmers that took part in the focus groups contributed to the design and the discussion on what attributes would be of most

[5]This information criteria is defined as AIC3 = 2LL – 3K where LL is the estimated log-likelihood of the model and K is the number of estimated parameters. As long as decreases on AIC3 are observed, adding segments (classes) is beneficial.

concern in the transition to agro-ecological practices - and followed best-practices of how to conduct focus groups - it is possible that these focus groups were somewhat ineffective. It is difficult to establish in hindsight, but it is possible the authors were subjects of 'yea-saying' (Blamey et al., 1999) or social desirability bias (Lusk and Norwood, 2009). These biases arise as a result of participants seeking to match the interviewer's expectations, rather than truthful answers. It is also possible that - given the small size of the groups - the farmers that took part were not representative of the rather heterogeneous group of farmers across France - also perhaps as they voluntarily chose to take part in the focus groups. The authors therefore decided to complement the discrete choice experiment with qualitative and semi-structured interviews with a sub-set of the farmers that took part in the DCE.

Table 4.4: Latent Class Model

	Class 1 (std. err)	**Class 2** (std. err)
Income	-0.025 (0.028)	0.062 (0.052)
Constant	-1.40*** (0.366)	0.791 (1.01)
Transition time	-0.006 (0.051)	-0.019 (0.162)
Health and environment	0.018* (0.018)	-0.047*** (0.015)
Condensed work schedule	0.063 (0.274)	1.062 (0.608)
Spread out work schedule	0.236 (0.267)	1.06* (0.548)
Advisor	0.263 (0.205)	-0.758 (0.682)
Training	0.175 (0.191)	-0.295 (0.544)
Network	0.039 (0.190)	-0.338 (0.523)
Class share	0.759	0.241
Log-likelihood	-561.53516	
AIC	1195.07	
BIC	1392.91	
N	1800	

Asterisks denote statistical significance at the *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ level.

4.3.2 Qualitative interviews

4.3.2.1 Descriptive statistics

All the farmers who provided their contact details at the end of the DCE questionnaire were contacted by email and 18 participated in an interview until data saturation was reached. They lasted from 30 minutes to 1 hour and a half. As suggested by guidance in qualitative research methods, data saturation was considered to have been reached when no additional codes or novel data points were identified: this point was thus reached when interviews on 16 % of the sample had been conducted, which was 18 interviews. The sample that took part in the qualitative interviews was representative of those that took part in the DCE with a slight over-representation of farmers frequently attending training (Table 4.5). Based on our comparison, we can assume that the results from the qualitative

interviews give indications for all the participants who took part in the DCE. The sample that took part in the interviews therefore hold the same limitations as those for the DCE: a selection bias could exist and a very high number of respondents in the sample had already reduced pesticides, with large farms and high levels of education, which is a common limitation for online surveys with farmers (Chèze et al., 2020).

Table 4.5: Descriptive statistics of qualitative interviews' sample compared to DCE sample

	DCE sample	Qual sample
Mean annual income	€18 566	€17,067
Size of farm (ha)	179 ha	190 ha
Farmers that have already reduced pesticide use	79.09 %	86.67 %
Farmers who have already used alternative practices	89.09 %	86.67 %
Farmers with neighbours that already reduced pesticides	44.34 %	40 %
Farmers that frequently attend training (>every 2 years)	52.83 %	86.67 %

4.3.2.2 Results

The qualitative results and semi-structured interviews showed that farmers are facing unprecedented challenges in how they undergo their professional activities. Given the nature of the changes at stake - to farmers' everyday lives - it was clear that the farmers that took part in the interviews appreciated an open forum to discuss their concerns. The interviewers discussed topics covered by all the attributes to deepen the understanding on the apparent rejection of the farmers of the DCE. These topics included income, transition time, income on health and the environment, work schedule, and optional and free agricultural support. The responses from the farmers indicated that there was no simple answer to these questions, requiring further discussion in an open format.

The methodological implications highlight the advantage of complementing the more rigid format of the DCE when approaching topics that may be of a controversial nature, and for certain expert groups, such as farmers. This may have led to the initial rejection of farmers to take part in a closed-form survey on this topic, and further disregard of several attributes in the DCE, as we noticed a strong preference of farmers that took part for personal interaction, to discuss the topic in a more flexible format, when approaching topics of how the reduction of pesticides already impact and would impact their lives. The findings of the qualitative interviews were key to understand farmers' motivations. What came through in the discussions, as through the DCE, was that most farmers were keen to make a change, but were at a loss as to how this could be done. From these discussions and data analysis, the main results could be sub-categorised into four major themes as listed below:

- technological uncertainty
- economic uncertainty
- social uncertainty
- governmental uncertainty

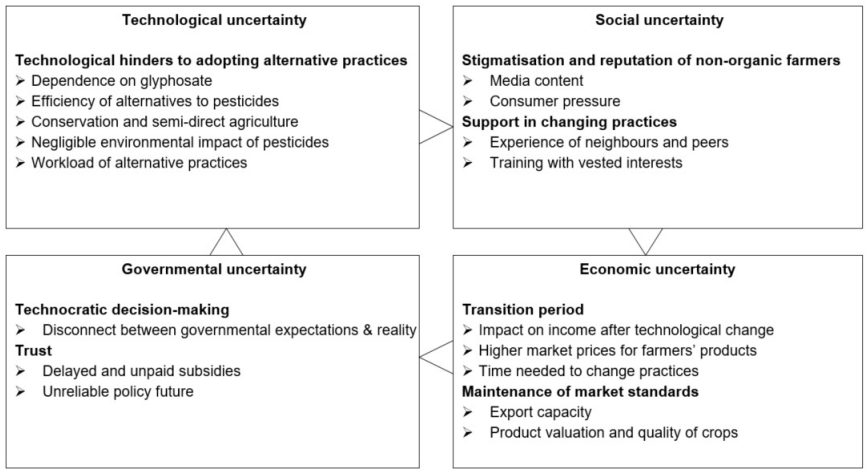

Figure 4.3: Summary of main themes emanating from qualitative interviews

These themes - that are all interconnected - are summarised in Figure 4.3. While NVivo is a useful tool to organise qualitative data, and word clouds in particular are useful to gain an overview of the main issues being discussed in the interviews, limitations exist to using these tools for analysis, however. Words are retrieved out of context as the technique omits the semantics of the words, and the phrases they comprise. This meant that, as described above, qualitative content analysis thus also included familiarisation with the data through slow reading of all transcripts, followed by a combination of deductive and inductive construction of codes, phrases and quotations classified into main categories and subcategories, depending on the main themes highlighted by the farmers.

A frequency table (Table 4.6) was developed and used to provide descriptive information on the interviews, to guide our descriptive language in the analysis below, referring to the share of farmers interviewed that vocalised a given issue: $> 50\%$ was considered "Most"; 30–49% "Many"; 10–29% "Some"; $< 10\%$ "Few" in the interviews, once the data had been classified into each category. A table of representative quotations for each category and sub-category can be found in Appendix B. The bold lines indicate the categories that were drawn from the sample's responses. The sub-categories are listed below the categories.

Table 4.6: Frequency of codes organised by themes, categories and sub-categories

Theme 1. Technological uncertainty		
Category and sub-categories	**Respondents (N)**	**Respondents (%)**
Technological hinders	**18**	**100 %**
Dependence on glyphosate	10	55.55 %
Efficiency of alternatives to pesticides	8	44.44 %
Uncertain environmental impact of pesticides	8	44.44 %
Workload of alternative practices	7	38.88 %
Conservation and non-tillage agriculture	5	27.77 %
Theme 2. Economic uncertainty		
Categories and sub-categories	**Respondents (N)**	**Respondents (%)**
Transition period	**16**	**88.88 %**
Impact on income after technological change	14	77.77 %
Time needed to change practices	5	27.77 %
Higher market prices for their products	3	16.66 %
Maintenance of market standards	**9**	**50 %**
Product valuation and quality of crops	5	27.77 %
Export capacity	4	22.22 %
Theme 3. Social uncertainty		
Categories and sub-categories	**Respondents (N)**	**Respondents (%)**
Stigmatisation of non-organic farmers	**15**	**83.33 %**
Media content	8	44.44 %
Consumer pressure	7	38.88 %
Support in changing practices	**14**	**77.77 %**
Experience of neighbours and peers	12	66.66 %
Training with vested interests	4	22.22 %
Theme 3. Governmental uncertainty		
Categories and sub-categories	**Respondents (N)**	**Respondents (%)**
Technocratic decision-making	**12**	**66.66 %**
Disconnect between expectations and reality	12	66.66 %
Trust	**15**	**83.33 %**
Delayed/unpaid subsidies	10	55.55 %
Unreliable policy future	5	27.77 %

Technological uncertainty

All farmers made clear that they felt they were being pushed into changing practices, despite a lack of clear and realistic alternatives being available to them. Most farmers pointed out that glyphosate dependence was synonymous with this hindrance; that for instance, "if glyphosate is banned, there is nothing I can do," while another stated that "the main problem, as is the case for all my colleagues, is glyphosate dependence". Glyphosate, one of the world's most widely used active substances in plant protection products, has, in recent years, become a subject of controversy over its safety and impact on the environment. Despite these controversies, the EU has renewed its approval of the substance until 2022, even though several member states, including France, call for its ban. The future of glyphosate is highly uncertain. With this in mind, some farmers vocalised their opposition to the ban, maintaining that there are no viable alternatives for the chemical. A quick transition to farming without the use of glyphosate is for many farmers too costly and challenging. Farmers working in conservation agriculture particularly highlighted this, whose method is based on non-tillage - causing dependencies on herbicides such as glyphosate. As one farmer clarified: "I want to stick to conservation agriculture using plant covers, but that can only be done with glyphosate." Many of the farmers interviewed stated that alternatives to pesticides were just not efficient enough and that "there is no alternative that will maintain the current level of production."

While many farmers did raise concerns about the impact of pesticides on the environment, with one stating that he wanted to stop exposing himself "to improve the quality of [his] life," many others felt that by using the right equipment and respecting good practices, changing practices was not necessary as they were already able to "minimise impact" by doing this. A further factor that added to apprehension was the additional workload and time needed to adjust: many interviewees mentioned this. This was especially true for those that had already made changes to their pesticide application routines: as one farmer mentioned, "since I switched to mechanical weeding, my workload has significantly increased. Chemical weeding used to take me 2 days, but now it takes me at least 15 days a year." Stress on day-to-day lives was also highlighted as a transition "involves more monitoring and more observation." At the same time, another underlined the "lack of knowledge and [the] experience required" to make a change. While some acknowledged that these technological uncertainties presented new opportunities, the hurdle they have to cross - from learning new practices to investment in new technologies - seemed insurmountable to most farmers due to the attendant risk of not ensuring a smooth transition.

Economic uncertainty

While income was noted as a major factor influencing decision-making, it was most of all a lack of certainty and predictability on income that elicited an aversion to switching to alternative practices. Incorporated into this uncertainty was the expected transition period and income instability during this period, a concern raised among most farmers interviewed. One questioned the interviewers: "How

am I going to make a living during this transition period when it is expected that we will be making less money [during this time]? It has to be possible to maintain the farmer's income during the transition period." Another highlighted that "if I have to invest in a big tractor and other machines [to make a transition], I will not have any income left." One pointed out that "if farmers are profitable in the system they are currently operating in, they will not change." A few noted the wish for improved valuation of their products: "my main concern is that the efforts made are not valued at the level of the product. I don't want any subsidies or help. I want a remunerative price to make a living from my job." Furthermore, some felt that too much time was needed to change practices, as it is expected that the transition period "lasts at least 5 years." Moreover, most farmers were concerned about maintaining market standards and the quality of their crops. One such concern was raised by some interviewees related to the expected export capacity, with a fear that there would be an "unfair competition with international products" and that if glyphosate were to be banned, they would "no longer be competitive." Some also pointed to a fear of maintaining yield and productivity, with one claiming that "I have the best yield in my area, so I do not need to change practices." This statement corresponds with the findings of Pedersen et al. (2012): that some farmers are more focused on optimising yield and pay less attention to expenditures and crop prices.

While most interviewees confirmed that farmers were open and willing to change practices, the economic uncertainty and unpredictability involved were of central importance to decision-making. As discussed above, several of the farmers highlighted the precariousness of their situation: from low incomes, to high costs of transitioning to alternative practices and difficulties maintaining competitiveness. This context likely contributes to farmers' perception that regulatory bodies constrain their ability to execute their role as producers effectively, as they put pressure on what farmers feel is an already strained line of work. As agriculture has increasingly become the focus of much environmental scrutiny, farmers may feel that their productive and profit-earning capacity is at risk in complying and reaching new standards (Burke and Running, 2019), on top of the precariousness of the agricultural profession that already exists.

Social uncertainty

In terms of social uncertainty, farmers that took part in the interviews felt intense pressure "from the government and consumers, but especially from the media." Most of the farmers interviewed felt stigmatised for not being organic. In turn, they felt a lack of understanding between farmers and non-farmers (out-group), leading to what felt like an attack on their identities. In almost all interviews, what came across was the intense social pressure they felt against their profession as farmers, and particularly from the media: "I'm worried on a daily basis that I'll be attacked in the media" as one farmer said. One mentioned that whenever he goes out with his protective gear on, "I feel like everyone is watching me." This sense of stigma has, in turn, led to them being defensive of their profession, with some arguing that "people on social media should stop taking themselves for agronomists." Moreover, "the pressure comes from people who do not know what

they are talking about – with the internet making things worse," as one noted. On the other hand, collaboration and cooperation between farmers is strong. Something that came across among most of the respondents was the wish for face-to-face interaction in finding solutions to changing practices, as exemplified by statements such as "the first advisor I listen to is my neighbour, and innovative peers: it is what is done in the fields that is proof of what works," to "when I changed practices, I did it together with friends and neighbours", and "you have to directly see what works for farmers." Furthermore, some of the farmers spoken to highlighted the need for regulatory bodies to converse personally with farmers to achieve results: "It is by talking to farmers that we can find solutions," while simultaneously "promoting greater visibility for those who are more efficient." Some further highlighted that particular training types had vested interests, stating that, for instance, "authorities should go directly to farmers that want to progress instead of going to chambers of agriculture or cooperatives, as these are often only looking to sell products even when treatment is not necessary." A consistent theme that emerged from the interviews was that policymakers, support-measures and consultants should have direct contact with farmers if results are to be achieved.

In times of uncertainty, norms within a group or community that a farmer belongs to may be more likely to influence behaviour than anyone else's. Identifying with reference groups and guiding behaviours based on what peers are doing can reduce uncertainty through knowledge and experience sharing (Smith et al., 2008). Furthermore, a main motivator for success is achieved in group contexts by positive in-group evaluations relative to other relevant out-groups, which suggests making examples of successful farmers in a given farming community could contribute to positive behaviour change. We, therefore, confirm the findings of Fielding et al. (2008); Bakker et al. (2021) that maintain that concrete recommendations emanating from other farmers may be more readily accepted than recommendations from others, such as governmental advisors. As has previously been illustrated by Sutherland et al. (2012), most of the farmers interviewed in our study underlined that they would be more inclined to change practices with the support of peers, through face-to-face interaction based on the sharing of experiences, rather than via external training by travelling technicians. This is a critical point for the future organisation of governmental support measures.

Governmental uncertainty

Finally, discussions with interviewees demonstrated what felt like a large disconnect between farmers and the government. As such, farmers interviewed saw that policies were out of touch with the agricultural reality and that incentives were not targeted appropriately at specific farmer groups. Policy is considered to be decided from Paris by 'technocrats' (in the sense of an office worker who does not know much about farming): "the government is out of touch with reality. (...) We need specific policies for each region". Another pointed out that "the government is completely disconnected from the reality of farmers because it is led by technocrats, not by people who know what farmers know: the government needs to listen to farmers," and "I have nothing against the government, but they do not know how to deal with people and professions different to them." In addi-

tion to an apparent disconnect between farmers and the government, a lack of trust was also highlighted in most interviews, with trust needing to be regained if policy targets are to be reached. This lack of trust often stemmed, from most farmers interviewed, from delayed and unpaid subsidies to those who had made shifts to a more sustainable agricultural system. One farmer underlined that "the government is lagging behind. I only received the payments and subsidies for 2017 today (two years later),", while another stated: "I am sceptical of any support from the government" in general for instance. This lack of trust also emanated from an unreliable policy future with some feeling that "the future of my farm is very unclear" for example. Therefore, what was highlighted was that communication between both groups should be encouraged, which could close the gap between what farmers consider the 'out-group', on the outside, and the 'in-group' of fellow farmers. A central argument that the farmers wanted to communicate to the authors was that they wanted to be listened to by the government, especially given that they felt that there is no current workable alternative to their farming practices. Many felt that their efforts to date had not been valued and that the government needed to "better support" alternative practices.

The interviews illustrate that social pressure from within farmer communities is often more likely to influence behaviour than pressure coming from outside pushes. Many reasons can be attributed to this. Past research has shown that when authorities or communities are trusted less (Tanis and Postmes, 2005), there will be less acceptance to engage in recommendations provided by that authority (Mackie et al., 2000). In addition to this, past research has shown that there may be a greater resistance to criticism that stems from out-group members (Hornsey and Esposo, 2009). Farmers in our study made clear that they yearned to be better listened to as they felt policies were out-of-touch with reality and that they, as a profession, were not taken seriously. It was clear that they felt their opinions and experience as farmers were unfairly undervalued and discredited in how the future of farming was planned. A way to bridge this gap in trust would be to integrate farmers' perspectives in policy approaches. Concrete possibilities to bridge the gap between farmers' perspectives and policy could include more field visits by policymakers, experts and agricultural advisors to farms to discuss individual cases and alternatives for change. On the other hand, farmers could be invited to seminars and training organised by authoritative research institutions and governmental organisations. Similarly, training could be organised for policymakers on the technical aspects related to agriculture, organised in collaboration with farmers.

4.4 Discussion

Bringing the results together, both the quantitative and qualitative results illustrate that most farmers wish to change practices but are at odds as to how this could be done. The results of the latent class model illustrated that the majority of the farmers that took part (>75 %) wished to change practices (through a

preference for an exit from the status quo) and showed a preference for reducing impact on health and the environment through a reduced use of pesticides, but disregarded the remaining attributes presented to them - including income, transition time, and optional and free agricultural support. The remaining farmers that took part in the discrete choice experiment showed a significant preference for *not* reducing impact on health and environment through the reduction of pesticides. Although there is a wealth of research on DCEs and environmental impacts, and also conducted with farmers, the authors question, given the disregard for many of the attributes presented to them, whether the DCE is an appropriate method and format to establish policy packages on the specific topic of pesticide use when impacting farmers' livelihoods, given: i) that farmers are both professionals and experts, making them less inclined to accept abstract and simplified approaches - such as DCEs - to mimic their decision-making process when attributes representative of their entire livelihoods are included (encompassing respondents' capabilities, assets, income and activities required to secure the necessities of life); ii) the political scrutiny currently aimed at the agricultural sector that may elicit resistance among the farmers (as evidenced by very high drop-off rates at the start of the survey) and, iii) the controversial pesticide issue which divides opinion, for example between communities such as farmers, ecologists and authorities.

As illustrated in Table 4.7, a comparative review was administered on DCEs that had successfully conducted surveys with farmers on the topic of pesticides, as these studies exist to falsify our methodological concerns (Birol et al., 2006; Christensen et al., 2011; Blazy et al., 2011; Kouser and Qaim, 2014; Jaeck and Lifran, 2014; Kuhfuss et al., 2016; Jin et al., 2017; Danne et al., 2019; Chèze et al., 2020). We compared these with our own study, and found that the major difference was the extent to which our study encompassed attributes referencing farmers' livelihoods and how the reduction of pesticides would, in turn, impact these livelihoods- in particular with regard to the monetary attribute used - whether through one-time subsidy payments, single payment schemes, an increase in price for pesticides, or an increase in cost of production per hectare, or a loss in profit per hectare.

What all of these studies have in common is that they only represent proportions of farmers' livelihoods - whether through diversifying crop varieties in farmers' home gardens (Birol et al., 2006); signing an AES contract in view of receiving a subsidy (Christensen et al., 2011); reducing pesticide use by adopting agro-ecological innovations in view of receiving a subsidy (Blazy et al., 2011); increase in health and environmental benefits associated with the reduced use of pesticides with Bt cotton in Pakistan, based on the price of a 400ml bottle of pesticides (Kouser and Qaim, 2014); preferences for using alternative weed control technologies, based on a single payment scheme per hectare (Jaeck and Lifran, 2014); preferences for joining an AES scheme to reduce pesticide use, also based on a single payment scheme per hectare (Kuhfuss et al., 2016), preferences for reducing pesticides and its associated health risk changes, based on production cost increase per year (Jin et al., 2017), preferences for cultivation strategies with and without glyphosate, based on cost per hectare (Danne et al., 2019), and risk preferences for reducing the use of pesticides based on associated variation in profit per hectare in Euro

per year (Chèze et al., 2020).

Our study, in contrast, sought to represent facets that would impact their income as a whole (with our monetary attribute of 'Income' with associated levels of -10 % decrease in income; 0 % change; and +10 % increase in income), as well as day-to-day life (such as our 'Work Schedule' and 'Transition Time' attributes), or indeed, their entire livelihoods. As Chèze et al. (2020) also highlighted, the topic of pesticides is sensitive among French farmers, and many refuse to be involved in surveys on this topic. The time the survey in question was distributed concerned one of great uncertainty for many farmers, especially with regard to the expected ban on glyphosate - which was discussed at length in the interviews, which represents inherent uncertainty for many farmers, divides opinion, is often discussed in the media, by authorities, civil society and elsewhere (Kudsk and Mathiassen, 2020; Clapp, 2021).

We therefore, with this in mind, argue that there may be a rejection from farmers regarding the use of abstract approaches to study their everyday lives and work, especially when presented in combination with the controversial topic of pesticides among French farmers, that presents an unprecedented change to their professional lives and ways of work, that is filled with uncertainty and no one-size-fits-all response. Our experience illustrates how farmers' narratives - including local and individual components- could not be fully tackled (in this particular case) through a rigid and closed-form approach as the DCE. We believe this experience can be of benefit to DCE researchers investigating similar topics in the future.

The semi-structured interviews provided indications that uncertainty and an apparent disconnect between farmers and outside pushes were central. A sub-categorisation of themes of the discussions revealed technological, economic, social and governmental uncertainty. As theories of socio-technical transitions put forward, these are all interconnected and need to be tackled individually and together to encourage a transition to a sustainable technological system. The interviews highlighted how farmers draw upon social relations and local knowledge in their reactions and resistance to contemporary agro-ecological policy. They further highlighted the importance of in-group influence, peer experience, and how social identification with other farmers affects willingness to change practices. Also, the farmers despised feeling incriminated by the general population, media pressure and felt a strong disconnect with the government. As mentioned by Smith and Louis (2009), uncertainties accentuate in-group influence. Moreover, the distrust felt by farmers regarding the French government (due, among other factors, to delayed payments) amplifies the rejection of out-group influence.

We make the conjecture that it is this uncertainty that led to farmers' rejection of the choices presented in the DCE. Farmers may have considered it too unrealistic to make choices on their professional future due to the uncertainty with regard to technological change - they do not see how they can make a change without the pesticides they are currently using, nor do they see how they can maintain their income. Further, the problem felt by many farmers is that current approaches tend to exclude the expert knowledge of farmers in the way that the future of farming

Table 4.7: Former DCEs conducted with farmers on the topic of reduction of pesticides

Reference	Topic	Scheme	Attributes*
Birol et al. (2006)	Estimate the private benefits farmers derive from agrobiodiversity found in Hungarian home gardens.	Technology adoption	Crop variety diversity; Landrace; Agro-diversity; Organic production; % of annual household food consumption expected from home garden
Christensen et al. (2011)	Analyse the motivations of Danish farmers in signing subsidy schemes for pesticide-free buffer zones.	Contract (AES scheme)	Contract length; contract release option; buffer zone width; changed agricultural practice; application method; **Subsidy size (DKK/ha/year)**
Blazy et al. (2011)	Analyse the willingness of banana planters to adopt agro-ecological innovations aimed at reducing pesticide use in the French West Indies.	Technology adoption	Innovation: intercrop; variety; fallow; Banana yield (ton/ha/year); Amount of pesticides active matter used (kg/ha/year); Amount of work needed for crop management; **Banana farm-gate price (EUR/box)**; **Subsidy for innovation adoption (EUR/ha/year)**
Kouser and Qaim (2014)	Quantify health and environmental benefits associated with the use of Bt cotton and its associated reduced use of pesticides in Pakistan.	Technology adoption	Human health effects; farmland biodiversity effects; soil and groundwater effects; **Pesticide price (PKR/400ml bottle)**
Jaeck and Lifran (2014)	Investigate preferences of French rice-growers to reduce their use of chemical inputs based on choice of weed control technologies.	Technology adoption	Weed control technology; crop management schedule; crop rotation; yield; yield variability risk; **Single payment scheme (EUR/ha)**
Kuhfuss et al. (2016)	Analyse preferences of French wine growers to sign an Agri-Environmental Scheme.	Contract (AES scheme)	Reduced herbicide use; localised use of herbicides; administrative and technical assistance; collective and final bonus; **Single payment scheme (ha/year)**
Jin et al. (2017)	Investigate farmers' valuations for health risk changes associated with pesticide use in China.	Technology adoption	Health consequence; baseline risk; risk change; **Production cost increase (CNY/year)**
Danne et al. (2019)	Analyse German farmers' preferences for cultivation strategies with or without glyphosate.	Technology adoption	Share of mechanical weed control in relation to the use of selective herbicides; expected yield impact; **Cost (EUR/ha)**
Chèze et al. (2020)	Investigate French farmers' willingness to reduce pesticide use associated with production risk (losses).	Technology adoption	Production risk; administrative commitment; health and environmental impact; **Variation in profit (EUR/ha/year)**

*Monetary attributes are highlighted in **bold**.

is being planned out through policy. As highlighted by Burke and Running (2019) in their discussions with farmers on pro-environmental behaviour, farmers often painted a picture of "us versus them," with the "them" portrayed as "well-meaning but silly city folks without intimate knowledge of the natural environment." In this sense, the farmers argue that agricultural policies and recommendations have little understanding of the technological difficulty of implementing the policies (Fielding et al., 2008). If farmers view that regulatory agencies compete with their interests, and threaten their credibility by not considering their expert knowledge, they will be less inclined to adopt the proposed technological change, which could lead to a sense of reactance. Given that the DCE was presented to them where a transition to farming with reduced pesticides was assumed, farmers who do not know how this is possible may have rejected the choices presented to them.

4.5 Conclusion

This paper has analysed the socio-economic trade-offs that French farmers are currently facing in the transition to agro-ecological practices. Despite substantial policy efforts, it is increasingly clear that the marked rise in the adoption of agro-ecological practices necessary to achieve sustainable agricultural systems is not happening fast enough. The respondents who took part in the study represented farmers residing in France, and our aim was to capture an overview of farmers facing these changes and challenges. Our principal findings are the following.

The quantitative results showed that the majority of farmers that took part are keen to change the current state of affairs (i.e. the coefficient associated, in the model, to a change from the status quo was highly significant), while a minority did not wish to change practices through a reduced use of pesticides. However, the early drop-off rates were high and farmers that did take part disregarded many of the remaining attributes presented to them. We argue that farmers appear at a loss as to how to achieve transition in a one-size-fits-all approach and the results seemed to indicate a certain rejection of the DCE method - and disconnected policy approaches - by farmers. We argue that this rejection (and limitation to our quantitative research section) arose, in our case, as the choice sets sought to represent entire components of their livelihoods as a whole - such as work schedules, time (in years), and presenting the attribute of an *overall* impact on farmers' incomes based on given trade-offs. Moreover, this rejection is attributed to the fact that: i) farmers are professionals and thus experts on their everyday work topics, making them less inclined to accept abstract and simplified approaches made by researchers and people that are not fully immersed within their groups, their livelihoods and identities ii) political scrutiny is currently aimed at the agricultural sector which may elicit resistance among the farmers iii) the pesticide issue is controversial and strongly divides opinion between communities such as farmers and ecologists.

Most of the farmers interviewed highlighted the importance of peer and network

support in reducing pesticide use. The farmers that took part repeatedly mentioned the central importance of peer network and feedback from other farmers' experience, which indicates the role of in-group influence. The farmers also feel incriminated by the general population and experience media pressure and a strong disconnect with the government, which is amplified by several factors. First, the strong uncertainties that have been reported by farmers regarding technological change, the economy, society and the government. Second, the distrust felt by farmers regarding the French government (due, among other factors, to delayed payments) amplifies the rejection of governmental and policy influence. In sum, the interviews highlighted how farmers draw upon social relations and local knowledge in their reactions and resistance to contemporary agro-ecological policy. The problem felt by many farmers is that current approaches tend to exclude their expert knowledge, which forms an essential element in the identity of farmers. Our results further highlighted the importance of in-group influence, peer experience, and how social identification with other farmers affects willingness to change practices.

The qualitative interviews complemented the results of the DCE by illustrating that from our analysis, farmers were keen to openly discuss their personal experiences on the topic of pesticide reduction. The methodological implications highlight the importance of complementing the more rigid format of the DCE when approaching topics that may be of a controversial nature that impact livelihoods and individuals in specific and differentiated ways, and for certain individual expert groups, such as farmers. Overall, both the quantitative and qualitative results illustrate, however, that farmers wish to change practices but are at odds as to how this could be done. Several policy recommendations arise from our findings.

First, perceptions of peers may influence behaviour more efficiently than outside pushes, which is key to take note of when planning strategy and policy. Specifically, within-group comparison standards between farmers could potentially be made use of to encourage behavioural change and to attain more targeted approaches. The importance of peer support in implementing new strategies, and the need for working together with other farmers when decreasing pesticide use is not new, was also found by Brewer and Goodell (2012); Parsa et al. (2014) and Stallman and James Jr (2015). We further corroborate the recent findings of Bakker et al. (2021) which was based on Dutch farmers, on the importance of collective action - in the sense that future pesticide reduction strategies should rely on social interaction and shared experience. We therefore find that French farmers also look to successful examples of how to decrease pesticide use, either through exchange with peer farmers or knowledge provisioning on alternative pest control methods. Exchanges between farmers, through training and advisory mechanisms, should be increased. Our results further suggest that perceptions of peers may influence behaviour more efficiently than outside pushes.

Specifically, within-group comparison standards between farmers could potentially be made use of to encourage behavioural change and to attain more targeted approaches. Feedback relating to the environmental achievements or values attained by certain group members, potentially promoted by themselves, could serve as an

identifiable feature that could also encourage the reduction of pesticide use. One crucial motivation for group-mediated action is uncertainty reduction. Identifying with relevant reference groups and guiding your behaviour based on what your peers are doing can reduce uncertainty through knowledge and experience sharing (Smith and Louis, 2009; Cialdini and Goldstein, 2004). In times of uncertainty, norms within a group or community that a farmer belongs to may therefore be more likely to influence their behaviour than anyone else's. Furthermore, the use of peer networks is already used in practice, through for instance the DEPHY networks in France, first discussed above. Lead farmers schemes (Holden et al., 2018), as well as in the development of agricultural Payments for Ecosystems Services (PES) - agglomeration payments make use of farmers' networks (Kolinjivadi et al., 2019). We recommend further use of such schemes to encourage the reduction of pesticides by French farmers.

Second, bridges between farmers and policymakers should be encouraged. A deepened knowledge of the field by policymakers and immersion within the group of farmers, their livelihood and identity would be most welcome. Former experience as a farmer for certain decision-makers and/or increased face to face contact, locally, with farmers would be useful. Regulatory bodies that seek to encourage a transition to agro-ecological practices may therefore attain better results by recognising, valuing and shining a light on farmers' expert and local knowledge in policy development. Communication needs to be improved between authorities and farmers - going both ways - due to this major disconnect felt between the two groups. Overall, the research made evident that farmers were keen to discuss solutions to overcoming the transition openly, and both the DCE and the qualitative interviews made clear a wish for targeted, community-focused and personal policy measures to ease the transition.

Third, the extremely strong uncertainty felt by farmers in several fields needs to be reduced. Regarding technological uncertainty, research should be pursued on agro-ecological technological alternatives to pesticides and farmers should be regularly informed on the obtained improvements. Several interviewed farmers stated their wish to be informed on scientific advances on this topic. On economic uncertainty, as mentioned by Chèze et al. (2020), cheap and good quality insurance could be offered to farmers to reduce their income variability. Regarding social uncertainty, the general population should be sensitised - with the help of the media - on farmers' work, lives and concerns to reduce the stigma felt by the agricultural profession. As for governmental uncertainty, public authorities should certainly correct the problem of unpaid subsidies to farmers, simplify administrative procedures and implement reliable agri-environmental schemes to regain farmers' trust.

Our analysis presents several limitations. The relatively small sample size limits the generalisability of the findings, also as our study has focused on French farmers. Further, even though the DCE design was based on two focus groups with farmers, the question arises as to how effective they were, given that our results did not match our pre-experimental findings that formed the basis of the DCE. In addition, the farmers that did take part were over-represented by those that had higher education and had larger farms, which is a common finding in online sur-

veys with farmers, but means that our results should be interpreted with caution. In addition to this, our sample included a majority of farmers that had already taken steps to reduce their use of pesticides. Nonetheless, the obstacles to reducing pesticides may then be even stronger in the overall population of farmers that have not taken more extensive steps to reduce pesticides. The results obtained from our sample therefore remain relevant, and perhaps even more so, to farmers in general that have not yet taken as many steps to reduce the use of pesticides. Furthermore, a limitation in our DCE methodology remains, given many attributes that were not significant in the DCE relating to income, transition time, impact on health and the environment, work schedule and optional and free agricultural support were disregarded, and which we argue illustrates a rejection of our methodology on behalf of the farmers. It is also important to consider the focus groups - and the extent to which these were ineffective - in view of the results of the DCE. Future studies should ensure as full representativity as possible so that wide-ranging views are taken on board in the design of the DCE. However, our semi-structured interviews sought to make up for the lack of information acquired in the DCE. Lastly, the semi-structured interviews were partly subject to the authors' interpretation, although the information used for the semantic treatment was as neutral as possible as only the exact transcripts of the interviews were used. Further research should be done to corroborate our findings.

Chapter 5

To tax or to ban: public preferences for phasing out glyphosate use in agriculture

This chapter is based on joint work with Maia David, Vincent Martinet, Vincent Mermet-Bijon and Steven Van Passel.

5.1 Introduction

Glyphosate - one of the world's most widely used active substances in plant protection products - has in recent years become the subject of controversy over its safety and impact on the environment. A rising number of experts and agencies have warned of glyphosate's carcinogenicity, while others point to its threat to ecosystems and biodiversity (Clapp, 2021). Despite these controversies, the European Union (EU) renewed its approval of the substance from 2018 to 2022, against the backdrop of a European Citizens Initiative calling for its ban - garnering 1.3 million signatures.

At the same time, many farmers and farmers' unions are vigorously opposed to the ban, maintaining that there are no viable alternatives for the chemical, and that a quick transition to farming without the use of glyphosate is too costly and difficult. According to an IPSOS-AgriAvis study led in 2017, 81% of French farmers are against the ban - arguing that glyphosate is necessary for production, while 24% of farmers believe reducing glyphosate increases their production costs, and 57% believe that it would be more relevant to limit its use rather than to ban it (IPSOS, 2017).

Despite continuous policy efforts to reduce the use of glyphosate across the EU, its use has remained stagnant, and in some cases increased. The case for entirely phasing out the use of glyphosate across the EU demonstrates the need for a broader dialogue between regulators, farmers and consumers on the options, alternatives and regulatory directions available to us.

Is an alternative to a ban, such as a tax, socially acceptable? Imposing pesticide taxes at a high level allows fine-tuning at the farm level: in contrast to an outright ban, taxes allow regulators to influence application rates in a continuous (rather than all-or-nothing) manner.[1] With a tax, farmers have the choice to continue using pesticides for certain high value use cases, while discouraging low value applications where better alternatives exist. The main aim of pesticide taxes is thus to reduce their use cost-effectively. In the process, these taxes generate tax revenue. A pesticide tax would be able to compensate farmers for lower production and indirectly lead to price-driven shifts to sustainable agriculture (Berendse, 2017). However, just like in any other market, and irrespective of the environmental benefits resulting from the tax, the introduction of a tax imposes a burden on the consumers and producers in that market, and there is a net loss of consumer and producer benefits in using the substance in question.[2]

As we speak, pesticide taxes currently only exist at very low rates in Denmark, Sweden, Norway and France, and at least in the latter three, these taxes are so low that they have a negligible impact on the use of pesticides. Earmarking tax revenue for further environmental uses or rebating it to the affected population has currently been done with the Danish pesticide tax where revenues from the pesticide tax are reimbursed to the agricultural sector and helped reduce resistance to the tax among farmers. Norway also earmarks pesticide taxes to specific programmes (Finger et al., 2017; Möhring et al., 2020; UNEP, 2016). Despite their high potential to contribute to better policies, economic instruments such as pesticide taxes are rarely used in the current policy mix. Pesticide taxes are more allocatively efficient than other policy instruments that are frequently used, such as bans or regulation, but even though this is the case, little progress has been made to overcome stakeholders' preconceptions, preferences and concerns with regard to pesticide taxes (Zilberman and Millock, 1997; Finger et al., 2017). While many studies have shown that high tax rates should be applied to attain desirable reductions in the use of pesticides (Nam et al., 2007; Falconer, 1998; Finger et al., 2017), understanding public opinion of such a policy measure among consumers has yet to be studied to ensure social acceptance of pesticide policy measures.

The literature has established that environmental taxation is popular amongst economists for reasons of efficiency and environmental effectiveness, but very unpopular amongst the general public (Carattini et al., 2018). The unpopularity of environmental taxation such as fuel taxes has hindered their full implementation in France as they have been considered unfair - sparking the recent uprising referred to as the Yellow Vest Movement (Carattini et al., 2019). Fear of competitiveness effects of carbon taxes led to exemptions in Scandinavian countries, decreasing the potential for any considerable environmental effect (Baranzini and Carattini, 2017).

[1] A tax is also more flexible than possible exemptions to a ban, which could lead to endless debates and lawsuits (or even active lobbying) to determine who should and who should not use glyphosate. A tax solves this on economic grounds.

[2] In theory, for a Pigouvian tax aiming to reduce an externality to its optimal level, the losses for producers and consumers are more than compensated for by gains to citizens due to the reduction in the environmental and health externalities of pollution.

It has been argued that the general public underestimates the effectiveness of environmental taxes. Schuitema et al. (2010) maintain that subsidies are more likely to drive a voluntary change in behaviour than taxes are, as people believe the latter are felt as coercive, which in turn causes resistance. Using tax revenues to reduce income tax has also been seen to be relatively unpopular, while reductions in value-added tax perform similarly inadequately in terms of acceptability (Carattini et al., 2019). However, a common finding in the literature is that people are most willing to accept them if tax revenues are used to strengthen their environmental effectiveness (Maestre-Andrés et al., 2019; Beiser-McGrath and Bernauer, 2019). To explain this phenomenon, Rivlin (1989) suggests that earmarking is popular, as taxpayers would otherwise not know what the money is spent on, and might believe it is spent "wastefully or even fraudulently, or that a substantial part of it goes for a services of which they disapprove of." Dresner et al. (2006) identified "lack of trust that the government would not do what it promised" as a fundamental problem facing ecological tax reform.

This paper aims to assess the relative acceptability of reducing the use of glyphosate by attaching a strong pesticide tax to it with respect to a ban, for the general population across several European countries. Understanding how to implement an efficient pesticide tax regime to phase out the use of glyphosate, requires balancing political feasibility and public acceptance considerations in line with tax and environmental policy. While the rationale for a tax on glyphosate lies in the abatement incentives and reduction of pesticides that it might create among farmers, the question arises as to how the use of revenue from pesticide pricing affects its political feasibility – and specifically the preferences of the consumers of the agricultural products whose prices will likely be impacted. To help answer this question, a discrete choice experiment (DCE) was conducted with a representative sample of the population in five European countries: Belgium, France, Germany, Italy and Spain.

The remainder of the paper is structured as follows. Section 5.2 presents the method approach applied to the study, firstly detailing the method of the DCE and the steps taken to develop and distribute the questionnaire. Section 5.3 discusses the results of our study, while section 5.4 presents our policy recommendations and conclusions.

5.2 Method

5.2.1 Discrete Choice Experiment

Discrete choice experiments (DCE) have gained considerable attention since their first developments (see Louviere et al. (2000a) for a review). DCEs involve presenting a set of hypothetical choice tasks to respondents, each task consisting of several alternatives; the respondent is then asked to pick their favourite alternative within each choice task. Often, three alternatives are presented: a reference alternative

which is the same in all choice cards (i.e., the status quo or an opt-out), and two other alternatives that vary. Alternatives are made up of different attributes (i.e., fundamental characteristics of the respondent's situation), and each attribute can take different levels. When one of the attributes included in the alternatives is either a price or a cost, the method allows researchers to elicit the willingness-to-pay for changes in the other attributes' levels. This feature makes DCEs a useful method to estimate preferences for goods or amenities which do not have a market price, such as health or the environment (Adamowicz et al., 1994).

DCEs have until now been used to investigate various aspects of farmers' and consumers' views on pesticide reduction measures. Travisi and Nijkamp (2008) used a DCE to investigate Italian consumers' attitudes towards pesticide risk. They were able to demonstrate that respondents had a significant willingness-to-pay for agricultural goods that were produced in an environmentally friendly way. Chalak et al. (2008) consider consumers' willingness-to-pay for the reduction of pesticides in cereal production – mostly impacting environmental quality, and for fruit and vegetables – that mostly impact human health. Kouser and Qaim (2013) quantify the health and environmental benefits associated with cotton in Pakistan – and its associated reduced use of pesticides. They found that farmers themselves value these positive effects at US $79 per acre, of which half is attributed to health and the other half to environmental improvements. Among other results, Chakir et al. (2016) also find that respondents have a significant willingness-to-pay for a reduction in pesticide use. Jin et al. (2017) investigate farmers' valuations for health risk changes associated with pesticide use in China and find that female farmers and those that are more educated are more likely to accept a compensation scheme if health risks increase. Danne et al. (2019) illustrate that farmers prefer the use of glyphosate to other alternatives to prevent weed infestation, while also saving work and labour costs, especially on large farms. Chèze et al. (2020) find that the risk of substantial losses in production as a result of pests reduces farmers' willingness to reduce their pesticide use.

In this DCE we investigate the acceptability and preferences of policy instruments aiming to reduce the use of glyphosate in agriculture of the general population in five European countries: Belgium, France, Germany, Italy and Spain. These countries were chosen as they include four of the most populated countries in the EU and represent over 50% of the EU population (Eurostat, 2021). Moreover, France is one of the main European producers of agricultural products and users of pesticides, and the five main countries to which France exports these products are Germany, Belgium, Italy, the United Kingdom (UK) and Spain (Agreste, 2018). The UK was excluded from the study due to a different currency and uncertainties with regard to the scheduled withdrawal of the UK from the European Union ("Brexit"). Spain, Italy, Germany and Belgium are also France's main terrestrial neighbours. As France is one of Europe's biggest consumers and users of pesticides, the countries in its proximity have an interest in the policies put in place to restrict the use of glyphosate for environmental purposes.

In our DCE, respondents are asked to choose between two hypothetical alternatives and a status quo alternative, referring to the reference scenario. In the DCE

literature, the status quo option is not necessarily always the current situation or opt-out situation: choice cards can present a future situation and the status quo is then the most probable or the business-as-usual future situation (Adamowicz and Boxall, 2001; Lew et al., 2010; Pedersen and Gyrd-Hansen, 2013; Kontoleon and Yabe, 2003). In order to determine the status quo, we therefore had to decide what the most probable policy outcome with regard to the future of agricultural glyphosate use would be in 2022, when following the current political trend. Given the political context regarding glyphosate in the five countries we consider, we concluded that a ban on glyphosate was the most realistic business-as-usual option.

In November 2019, the French government announced that glyphosate would be banned from July 2021 onwards. In Germany, a ban is planned for 2023 - whatever happens regarding the EU vote on the glyphosate renewal. Even the Spanish government - which had voted in favour of a glyphosate renewal in 2017 - announced in May 2019 that it was considering a glyphosate ban. Moreover, in 2017 when the approval for glyphosate was renewed at the EU level for the period 2018-2022, the vote was very close, and Italy, Belgium and France were among the nine countries opposed to this renewal. The German agricultural minister changed his stance at the last minute, from abstaining to supporting the proposal of extension, against the advice of the government. This sparked an uproar, and given the recent German announcement, it can be assumed that Germany will not be among the bloc of countries voting for a renewal in 2022. Additionally, the UK - together with the Netherlands - led the coalition in favour of the authorisation of glyphosate. Now that the UK is no longer a member of the EU, the balance of power between countries voting for and against an authorisation will be significantly altered.

In 2017, the glyphosate re-authorisation process took a different turn to what had previously been the case for pesticide re-licensing procedures, where decision-makers generally voted quietly in EU-committee meetings, without much public attention. In 2017, however, policymakers were faced with backlash from both the general public as well as civil society towards the renewal of glyphosate. Public concern had in particular been sparked as the World Health Organization had declared that glyphosate was a substance that "probably causes cancer in humans" (WHO, 2015). Nonetheless, farmers' associations and interest groups representing the agro-chemical industry simultaneously downplayed risks and stressed benefits of the substance. We can expect a similar turn of events in the upcoming vote in 2022, and quite possibly a strengthened public interest, also perhaps to due a pronounced focus on public health as a result of the COVID-19 pandemic. While this is conjecture, another factor to consider was the finding that EU regulators had based their decision to re-license glyphosate on an assessment that had been plagiarised from industry reports (Parliament, 2017). These factors will most likely influence policymakers' decision-making and the likelihood of an imposed ban on glyphosate.

It is impossible to be entirely certain that an EU-wide glyphosate ban will happen in 2022 - and we therefore make an assumption - but what we can be certain of is a public and political willingness within the five countries chosen to reduce the use of glyphosate. The aim of our work is to test the acceptability of various policies

if we assume governments wish to drastically reduce the use of glyphosate, and a ban is therefore a relevant baseline.

5.2.2 Choice of the attributes and their levels

The first step to developing a DCE involves deciding upon the number of alternatives, and the respective attributes that compose each alternative, as well as their possible values (levels). As discussed above, the reference point for all respondents (the status quo) in this DCE was presented as a total ban of glyphosate in 2022, while the two policy alternatives presented to respondents were denoted as a tax.

The attributes and levels chosen are shown in Table 5.1. The first attribute refers to the reduction of farmers' use of glyphosate in agriculture. The second attribute refers to the increase in price of a respondent's weekly grocery basket of food and the third attribute focuses on the use of the revenue of a possible tax on glyphosate - the latter naturally only being relevant to the two policy alternatives of a tax, and not the status quo alternative of a ban. These attributes and levels simulating a purchasing decision were refined from discussions with experts (scientists, agronomists, researchers, policymakers and farmers), several pre-tests with the authors' colleagues and acquaintances, and finally a pilot survey with the target population of the survey, tested via Amazon Mechanical Turk (M-Turk) in May 2020 - a crowd-sourcing website used to hire individuals to perform discrete on-demand tasks. Forty-five individuals (unknown to the authors) from the general population in Belgium, France, Germany, Italy and Spain completed the pre-test in their respective languages (nine from each country). Changes to the survey were iteratively made based on all comments and feedback received in each step of the testing process. Pre-tests and pilots are necessary in order to test the appropriateness of the attributes, select appropriate choice vehicles and to refine the draft questionnaire.

In the end, we chose to stick to three attributes, as the complexity of DCEs generally increases with the number of attributes and levels chosen (Caussade et al., 2005). As explained by Hanley et al. (2002), the number of attributes should be small to limit the cognitive burden imposed on respondents. Nonetheless, a limitation to the choice of attributes and levels, and as a result a limitation to this study, lies in the lack of an additional attribute that looks to the potential benefits of the reduction in glyphosate use. While a limited number of attributes has been shown to reduce the cognitive burden imposed on respondents, including such an additional attribute may have simplified the choice at hand - especially for respondents that had never heard of glyphosate before. The authors discussed the potential for including such an attribute, but because of the widely contested nature of the topic at stake - with regard to whether or not glyphosate actually *is* harmful to the environment and to public health, we chose not to. These contested views often arise, at least in Western Europe, between people that live in rural areas and those that do not. To avoid the potential for protest answers, we chose to stick to the purely necessary attributes when discussing such a policy, and

sought to inform the respondents on the benefits (and costs) of reducing the use of glyphosate reduction as best as possible before beginning the survey.

Table 5.1: Attributes and levels

Attribute	Attribute Levels
Reduction in farmers' use of glyphosate (in %)	75%; 85 % ; 95 % ; 100 % (SQ)
Increase in price of weekly shopping basket of food	€1; €2; €3; €4 (SQ)
How the government spends the revenue from the tax on glyphosate	Environmental programmes; Health programmes; Additional support for farmers; Revenue flown into the government's general budget

SQ: level only possible in the status quo

The first attribute related to the reduction in glyphosate use by farmers and the second attribute relating to the increase in price of a respondent's weekly shopping basket of food were necessarily linked and constraints were imposed in the design to ensure this link. The higher the reduction in glyphosate - and in our case a ban when there would be a 100 % reduction in farmers' use of glyphosate - consumer prices would increase the most. Due the higher cost of banning glyphosate for farmers (INRAE, 2020) (at least in the short term; i.e. the Porter hypothesis (Porter and Van der Linde, 1995)) - the price hike for consumers would necessarily be higher in the status quo case of a ban, than by attaching a tax to its use. We chose glyphosate reduction levels from 75 % and above, given that current policies look to reductions up to 50% (Fogliatto et al., 2020). Our study looks to policy options that go further than what is currently the case, and if taxes were put in place we make an assumption that this would go beyond a reduction of 75 %.

While it is impossible to attach certainty to the prices chosen, they seek to provide as realistic a possible scenario for consumers if a glyphosate ban or a tax were to be put in place. In 2019, the French Minister of Agriculture and Food, Didier Guillaume, pointed to the increase in the price of consumers' weekly baskets of food (as a result of policies in place to increase sustainability of the agricultural sector and a reduction in the use of glyphosate) to approach an increase of 4 to 10 % (FranceInfo, 2019). A report by the Crop Protection Association (CPA) estimates that, in the absence of plant protection products, a family grocery bill in the UK would rise by almost £11 a week – an increase of more than 17 % (CPA, 2019). Given that we only consider glyphosate, and not all pesticides, these prices would be lower. Moreover, the CPA is funded by industry players such as Bayer, therefore we consider this should be the upper bound of a potential price hike, as the producers of glyphosate naturally have vested interests in highlighting the high costs of a potential ban on their product. For these two aforementioned reasons, as well as the aforementioned study being applied to the UK, the numbers projected by Didier Guillaume are more relevant. Taking these numbers into account, we consider the average weekly household expenditure of food in Belgium, France,

Germany, Italy and Spain. For a single-earner household, the average spending on food (across all five countries) is €65, and a two-earner household spends on average €144 per week (Eurostat, 2020b). If we increase a single-earner's household weekly food spending by 4 to 10 % this would amount to €2.6 to €6.5, and a for a two-earner household €5.76 to €14.4. While it is contradictory, these estimates were based on French agriculture, and these effects may be lower in the other countries studied, due to France's agricultural sector being the biggest consumers and users of pesticides as discussed above. We chose to base our levels of a potential increase in price of a weekly basket of food to a lower, and straightforward €1, €2, €3 and €4 increase.

Due to the difficulty of establishing an appropriate cost vector (the number of levels to use and their associated values), we decided to distribute a split-sample survey to French consumers to investigate the choice we made and whether a changed value would have an impact on preferences and behaviour. The first sample of 500 consumers to be compared would receive the standard choice experiment (with a status quo level of an increase in price of food due to a ban on glyphosate of €4: this group would be part of the cross-country study with the four other countries. However, another 500 French consumers (also representative of the general population) received a survey with a different experimental design: in this second survey, 500 French consumers would receive a choice experiment where the status quo (ban on glyphosate) and increase in price of food would always be representative of €3. By distributing such a split-sample survey, we could gain some insights into the way in which the cost vector impacts behaviour and willingness-to-pay. As was discussed in chapter 4, literature has illustrated that WTP tends to increase as the cost vector offered increases (Glenk et al., 2019). Our paper therefore contributes to the literature looking into the impact of cost vector design on WTP estimates (Ryan and Wordsworth, 2000; Hanley et al., 2005; Carlsson and Martinsson, 2008; Kragt, 2013; Su et al., 2017; Glenk et al., 2019).[3] While it would be ideal to make such a comparison in each of the countries studied, the available budget did not permit this. We therefore had to make a choice with regard to which country to study. Given France's principal role in reducing the use of glyphosate in the coming years, we chose to make a comparison between French consumers.

The third attribute sought to give respondents a choice on how the revenue from a hypothetical tax on glyphosate would be spent. The levels were chosen based on the main issues relevant to a full or partial reduction of glyphosate use by farmers: the residual effect on public health, the residual effect on the environment

[3]Glenk et al. (2019) reviews the literature on behavioural mechanisms that could be at play when differences in willingness-to-pay arise from different cost vectors. An assumption underlying DCEs is that individuals have well-defined and stable preferences. However, criticisms of this assumption argue that preferences are actually malleable, and can change depending on the information received in the choice sets (Slovic, 2020; Bettman et al., 1998; Payne et al., 1999; Hoeffler and Ariely, 1999). A well-known criticism dates back to Tversky and Kahneman (1974): they found that prior cues or anchors affect subsequent valuations. Relating this to DCEs, respondents may have a range of acceptable values already in mind, and when respondents may be uncertain about a value provided, the choices made by respondents might be affected by the framing of choice options, choice context and anchoring effects.

and finally, the likely loss of revenue for farmers on their way to transitioning to more sustainable forms of agriculture and how revenue could be used to effectivise the tax based on these (Beckie et al., 2020; Kudsk and Mathiassen, 2020; Danne et al., 2019). In terms of the effect of glyphosate reduction on public health, the revenue would be spent on monitoring food contamination of pesticides, financing research on the impact of pesticides on our health and limiting pesticide-related harm on public health. To effectivise the tax on its environmental impact, the revenue could be spent on reducing water and soil pollution and contamination, and biodiversity loss caused by glyphosate and pesticide use. A third level of this attribute referred to additional support to farmers. It was important to highlight the *additional* support, given that the governments studied allocate a given budget to any glyphosate-exit programme that is finally selected. This additional support would be spent on supporting farmers in their transition to a sustainable farming sector, through training, advisors, low-cost loans, insurance programmes, and so on. Finally, these earmarked programmes could be selected relative to an unspecified use of government spending. Respondents were informed that in this way, tax revenue could be spent by government on priority areas, that could be on pension programmes, public health, education, defence, transport, industry and employment. This revenue could also be spent to decrease another tax so as not to raise another tax such as income taxes (i.e. environmental fiscal reform (Bach et al., 2002).

5.2.3 Experimental design

The software programme NGene was used to develop the experimental design of the DCE. Several designs were tested beforehand, such as 'referendum' type designs with no status quo, but to keep it as realistic as possible, the final design contained a status quo and two alternatives for respondents to choose from. Through analysis with NGene, using prior means established based on the aforementioned literature and discussions, the final combinations provided the researchers with choice sets that would give them the maximum information based on the attributes and levels chosen (see experimental design techniques in Louviere et al., 2000a; Street et al., 2005).

An efficient Bayesian D-optimal design that was to be adapted to econometric analysis with a random parameters logit model in a willingness-to-pay space, following a normal distribution was used. Efficient designs are often illustrated to show statistical superiority compared to orthogonal designs (Rose et al., 2008), as they maximise information available by taking preliminary data into account on the preferences of the target group (Ngene, 2012). Constraints were imposed on the experimental design such that the status quo would always be presented by a 100 % reduction in glyphosate use and a €4 increase in the respondent's price of food. As for the two tax alternatives, a €3 increase in the respondent's weekly basket of food could only be represented by a 95 % reduction in glyphosate use, whereas a 75 and 85 % reduction in glyphosate use could be represented by both a €1 and a €2 increase in the respondent's weekly basket of food. In the end, the

design chosen contained twelve choice sets blocked into two groups - meaning that each respondent would be presented with six choice sets of which the order would be randomised.

5.2.4 Questionnaire

All contact and questionnaire administration procedures were done electronically and participants' anonymity was guaranteed. The survey took on average a total of 10 minutes to complete. These 10 minutes included questions concerning the respondents' personal situation and opinions regarding environmental sensitivity - further detailed below, the (mandatory) presentation of two videos, a slide, a ranking question, the six choice sets, and post-experimental questions relating to how clear the survey was. All respondents received the same information before beginning the DCE, and the surveys were translated into Dutch, French, German, Italian and Spanish. As research has shown that language and grammatical tense can impact economic behaviour (Chen, 2013), particular care was taken to ensure that the information provided in each language was as interchangeable as possible. The information in the videos was presented through subtitles in the respective language of the respondent, and therefore also in either Dutch, French, German, Italian or Spanish. The videos that were distributed in the pre-test received complaints about the voice-overs used to narrate them, and the authors therefore decided to remove them and stick to subtitles.[4]

Respondents were first asked to complete questions relating to their personal situation, such as the number of people living in their household and their approximate spending on food per week. Further questions related to their environmental sensitivity, i.e., how often they consumed organic food and whether they had ever heard of glyphosate. The authors considered it important to include respondents that had not heard of glyphosate, as these respondents will be equally impacted by a potential price increase due to the proposed policy that will in the near-future be put in place on glyphosate use. Respondents were then asked about their views on pesticide restrictions: how these restrictions might affect food prices, and depending on whether they knew glyphosate or not, they were asked about either a) the effect of glyphosate or b) the general impact of pesticides on the environment and health, and whether they agreed with a tax or a ban on either glyphosate or pesticides in general. Relating to the contents of the DCE, respondents then ranked alternatives for how their government should spend hypothetical tax revenue from agricultural use of pesticides, from their favourite to least favourite: from environmental programmes, to health programmes, additional support for farmers, or finally for the revenue to flow back into the government's budget for unspecified use (e.g. reduction of income taxes, pension plans, and so on.).

[4]The voice-overs used in the videos in the pre-tests - that received negative feedback and that were eventually removed - were computerised. The budget of the study did not permit the use of voice actors, who would in an ideal situation have taken on this role (or authors with a good quality sound system and relevant linguistic ability).

A first mandatory introductory video was shown to respondents and one brief slide detailing what the authors considered the most critical components of glyphosate to take note of, and the video is available upon request.[5] The video sought to explain the context of glyphosate, the vote that will take place at EU level in 2022, and the two policy alternatives up for discussion in the study - of a ban of glyphosate and a tax on glyphosate. The authors sought to transmit the required information to complete the DCE in as much of an unbiased manner as possible. Neutrality was maintained through the explanation that prices would likely increase with *both* a ban and a tax, due to higher agricultural production costs in the transition phase to agro-ecological practices. We explained that an immediate ban may come at a cost to some farmers due to the required change in methods and techniques, but that with a tax, this transition can be eased while the state could use some of the revenue to earmark it to certain programmes. This question of maintaining neutrality of the videos presented was one of concern, and was often discussed in the seminars, discussions with experts and pre-tests relating to the study.

Upon completing the first video, survey respondents were asked to score their perception of the agricultural sector on an equidistant and symmetrical red-green labelled scoring scale from -100 to 100. Respondents scored their view of the sector for different glyphosate reduction levels, from their current view of the sector, to their view if glyphosate would be reduced by -75, -85, -95 to -100%. The respondents were required to watch a second video detailing the DCE set-up and tasks, before being shown the six choice sets, an example of which is shown in Figure 5.1. As a final step, respondents were asked whether the DCE and the questionnaire had been clear to them, whether they were satisfied with their answers and whether they had any comments. The latter was necessary order to detect what is referred to in the DCE literature as "protest answers" (Mariel et al., 2021). All respondents were asked about the clarity of the survey as a whole, and the extent to which they were satisfied with their responses, with the option to provide written comments.

5.3 Results

5.3.1 Descriptive statistics

Respondents were recruited by a subcontracted survey agency (IPSOS) which is recognised in the field and abides by the ICC/ESOMAR International Code on Market and Social Research regarding ethics in social sciences research (ICC, 2016). The survey targeted respondents at the household level, and in particular the main person in the household responsible for purchasing food (the primary grocery shop-

[5]The introductory slide, as well as the information in the video, were primarily created for respondents that had never heard of glyphosate and that were not familiar with the policy situation at hand. These media tools sought to ensure that all respondents were up to speed with what glyphosate exactly was, and what the vote would entail once they started the survey.

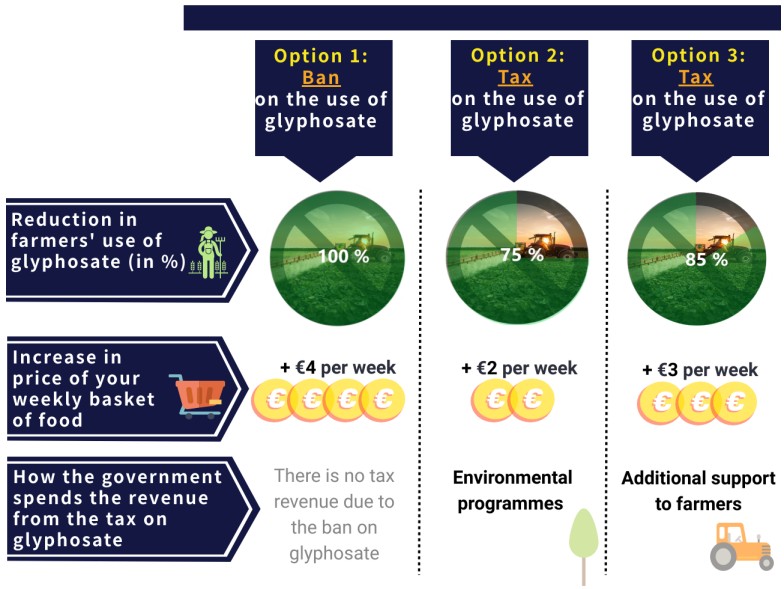

Figure 5.1: Example of a choice set (English translation)

per aged 18-70 years-old). Sample size for each country was chosen in proportion with the national population in each country (Eurostat, 2021), with a minimum sample size of 150 respondents per country in order to perform any meaningful econometric analysis (Ngene, 2012): Belgium is over-represented due to this minimum requirement.[6] Table 5.2 shows the sample size and the total population (in 1 000) in each country. In total, 2 050 household representatives took part in the study. Each country sample was representative of the national population at the household level on the following quotas: age and gender of the primary grocery shopper, geographical location (region; rural vs. urban) and level of education.

The characteristics of our final sample is summarised in Table 5.3. The average age of respondents was 45, with ages varying from 18 to 70 years old. The gender distribution was almost exactly 50/50, while the distribution of educational attainment was representative of the general population. For each country, the respondents' educational attainment was coded and divided into three main levels: low,

[6]If Belgium had been proportionally represented relative to the other four countries' populations (at 4 % of 2 050 respondents), the study would have included 82 Belgian respondents. In the end, Belgium represented 7 % of the sample with 150 respondents (to meet the suggested minimum requirement for meaningful econometric analysis in a country-by-country case). A robustness check was performed by dropping Belgium from the sample. Results remained similar and illustrated that Belgium did not skew the results despite its over-representativeness.

Table 5.2: Sample size adjusted from relative population ratios

	Belgium	**France**	**Germany**	**Italy**	**Spain**
Population of population (in 1 000)	11 455.5	67 012.9	83 019.2	60 359.5	46 937.1
Relative population (in %)	4 %	25 %	31 %	22.5 %	17.5 %
Sample per country (N [total]=2 050)	150	500	600	450	350

medium and high. Low referred to no degree, lower secondary education of three years (both general and technical); medium referred to upper secondary education of six years (general/technical or professional vocational education and training) and finally, higher education referring to tertiary level education (such as bachelor's level degrees, postgraduate, master's degrees and doctorate level degrees). In our sample, the majority of respondents had attained a medium level education, which corresponds to EU-wide statistics on educational attainment across a similarly distributed age group (Eurostat, 2020a).

In order to capture the purchasing power of respondents, they were asked how much their household spent on food per week: this amounted to an average of €94.13 per week. Eurostat data shows that in single person households average household spending on food ranges from €55.18 to €76.125 per week, while spending on food in a two-earner households with two children ranges from €112.93 to €166.06 per week (with lowest food consumption being Spain, to highest being in France; Germany, Italy and Belgium fall in the middle of the five countries in our sample, in said order) (Eurostat, 2020b). The average household size in our sample equalled 2.57 while the EU average household size is 2.3 (Eurostat, 2020c).

Due to the nature and context of our survey relating to the reduction and use of glyphosate, respondents were queried on questions that we take as proxies for environmental sensitivity. As such, they were asked how often they consumed organic products: from (almost) never to (almost) every day. The highest proportion of respondents stated that they consumed organic food at least once a week, and the second highest proportion stated they consumed organic food a few times a month. The lowest proportion of respondents stated that they consumed such products (almost) every day. It was further in our interest to gain an insight into respondents' perception of the agricultural sector and whether their opinion of it would change as a result of restrictions related to glyphosate use: this was indeed found; the benchmark opinion of the agricultural sector was 25.35, but this average opinion increased to 51.72 with a hypothetical reduction of glyphosate by 100 %.

In order to gain an understanding of respondents' views of glyphosate, and more generally of pesticides (if they had never heard of glyphosate), we asked them about their views on glyphosate and the environment, health, and what they

thought of a tax or a ban on either. First of all, for the respondents that had heard of glyphosate, a large majority believe that it is harmful to the environment and health. A larger proprtion believe it should be banned (75.5 % of respondents who had heard of glyphosate), compared to 63.9 % who believed it should be taxed (of respondents who had heard of glyphosate). Respondents who had never heard of glyphosate were asked these same questions but applied to pesticides more generally. Among this group of respondents (34.49 % of the total sample), saw that again a majority believed pesticides to be harmful to the environment and to health. A lower proportion, compared to those who had heard of glyphosate, believed they should be banned (56 %) or taxed 48.38 %). Lastly, respondents were asked to state how they thought pesticide restrictions would impact food prices. Most respondents believed they would increase food prices.

5.3.2 The Random Parameters Logit Model

In each of the six choice scenario respondents were faced with, they were asked to make a choice between three policy alternatives. The DCE was analysed as unlabelled as it was only the reference scenario that was named differently to the two alternative policy options. Continuous variables were assigned to the levels of two out of three of the attributes: i) an increase in the price of a weekly basket of food, and ii) the reduction in farmers' use of glyphosate. A categorical variable was assigned to the third attribute seeking to establish preferences for a potential redistribution of a tax revenue on glyphosate if this were the policy that were put in place (with values 'Environmental programmes', 'Health prorgammes', 'Additional support for farmers' and 'General budget of the state') via a dummy encoding, with the baseline referring to the 'General budget of the state'.

As the status quo in DCEs are perfectly confounded with a categorical variable's baseline, in our case, the results of this attribute indicate preferences for direct earmarking to specific programmes: 'Enviornmental programmes', 'Health programmes' and 'Additional support to farmers' compared to unspecified revenue allocation by the government or no revenue at all as a result of a ban. Coefficient estimates are assumed to be normally distributed, except price, which we assume to be log-normally distributed to avoid theoretical inconsistencies of positive preferences for price. Normal distribution has the advantage of not making assumptions on preferences; both positive and negative parameter values may be taken into account to capture heterogeneity in the population. Econometric analysis was performed using NLOGIT and Stata for the tests and model estimates, and R (Apollo package) for the willingness-to-pay estimates in WTP-Space.

The conditional logit model (McFadden, 1973) was first run on our results. The conditional logit model explains respondents' choices in terms of descriptive variables of the characteristics of the alternatives shown (Mariel et al., 2021) - in our case reduction in farmers' use of glyphosate, increase in price of a weekly basket of food and finally the potential redistribution avenues for the revenue from a tax on glyphosate. While the conditional logit model is considered to be the workhorse

Table 5.3: Descriptive and socio-demographic statistics of sample (N=2050)

Variable	Mean	SD	%
Country surveyed			
Belgium			7
France			25
Germany			29
Italy			22
Spain			17
Age	44.85	14.42	
Gender (F = 1)			50.24
Education			
Low			30.94
Medium			42.16
High			26.63
Living in a rural area			12.57
Food expenditure p/ week	€94.13	44.48	
Household size	2.57	1.26	
Opinion of farming sector*			
Now (benchmark)	25.35	43.7	
If glyphosate reduced by 100 %	51.72	42.45	
Frequency organic consumption			
(Almost) never			29.27
1-3 times a month			20.20
1 to several times a week			35.02
(Almost) every day			15.51
Had heard of glyphosate before			65.51
Share of agreement to:			
Glyphosate is harmful to health			81.09
Glyphosate is harmful to env			82.65
Glyphosate use should be taxed			63.9
Glyphosate should be banned			75.5
Share of agreement** to:			
Pesticides are harmful to health			74.83
Pesticides are harmful to env			78.79
Pesticide use should be taxed			48.38
Pesticides should be banned			56.72
Share of agreement [N=all] to "restrictions on pesticide use...":			
Decrease food prices			10.39
Do not impact food prices			11.12
Increase food prices			58.78
Do not know			19.71

*The response was scaled from -100 to 100 **If respondent had never heard of glyphosate

model of DCEs, the assumption of Independence of Irrelevant Alternatives (IIA) is implicit in the model which is restrictive. The IIA assumption states the probability ratio of individuals choosing between two alternatives does not depend on the presence or absence of any other alternative within the set of alternatives included within the model (Hensher et al., 2015). Random parameters logit models, on the other hand - also known as mixed logit models - relax the IIA assumtpion, which allows the model to be specified in such a way that the error components in different choice situations from a given individual are correlated (Hensher and Greene, 2003) and allow for unobserved heterogeneity in the estimated parameters. While estimated preference parameters are fixed in conditional logit models, random parameters logit models allow preferences to vary across choices (Mariel et al., 2021).

A specification test was run on our conditional logit model to test the IIA property: the Hausman-test of the IIA assumption (Hausman and McFadden, 1984). The results of this test showed that the IIA assumption was rejected in our model ($p < 0.01$), which meant that the random parameters logit model was preferable to the conditional logit model. Further, due to the nature of the sample and respondents from different countries that took part in the study, a latent class model was also run - a model used to uncover possible different preference patterns among assumed respondent segments. However, tests used to establish best model fit between the random parameters logit model and the latent class model based on the Consistent Akaike Information Criterion showed that the random parameters logit model had a better model fit. Results of the random parameters logit model are therefore shown in Table 5.4.

The results of the DCE were highly significant, which means that the attributes and levels selected for analysis were relevant and important to consumers. First of all, the results of the positive constant shows that respondents held a strong preference for a ban on glyphosate, as opposed to a tax. Nonetheless, the standard deviation of the constant is also highly significant - indicating preference heterogeneity across the surveyed population. Secondly, there was a strong preference for lower grocery prices, despite the expected price increases of both a ban and a tax. The third attribute showed that if there were to be a tax on glyphosate, there was a strong preference for tax revenue to be earmarked, for i) additional support to farmers ii) for health programmes and finally iii) for environmental programmes in order of preference, all relative to using the tax revenue for unspecified government spending.

To examine whether there are different preferences in particular subgroups of the sample, we extend the main effects model with different interaction effects. The model with higher log likelihood value has the best model fit and should be preferred (Cameron and Trivedi, 2010) – in our case the main effects model, and we therefore focus on the main results of this model.

The subject effects of the extended model are nonetheless worth highlighting (see Appendix C for full results of the extended random parameters logit model). Due to a large number of significant subject effects, only the highly significant ones

Table 5.4: Random parameters logit model (N=2 050) using 1000 Halton draws.

		Coefficients	St. Errors	p-Values
Price as a log-normal parameter				
Price	Mean	-2.538***	0.375	0.000
Random parameters				
Constant (SQ: ban on glyphosate)	Mean	0.890***	0.133	0.000
	St. dev.	4.734***	0.174	0.000
Reduction in farmers' use of glyphosate	Mean	0.017**	0.003	0.000
	St. dev.	0.038***	0.006	0.000
Glyphosate tax revenue earmarked to:				
Environmental programmes	Mean	0.965***	0.051	0.000
	St. dev.	0.475***	0.088	0.000
Health programmes	Mean	1.040***	0.057	0.000
	St. dev.	0.563***	0.109	0.000
Additional support for farmers	Mean	1.551***	0.064	0.000
	St. dev.	1.282***	0.089	0.000
N				36 900
Log likelihood				-9322.119
AIC				18668.24
BIC				18770.43

Asterisks denote statistical significance at the *** p<0.01, ** p<0.05, * p<0.1 level.

(p<0.01) are discussed. Most interestingly, no major significant differences were found between the countries studied. Only one highly significant country-effect was found with regard to Spaniards significantly preferring a ban of glyphosate over a tax. Out of the five countries studied, only Spain (and Belgium) have not set a specific date for the ban on glyphosate so there may be a link - where consumers see higher importance in stating and making clear that they are willing to accept a price for a ban on glyphosate. The subject effects further show that the higher the age of the respondent, the higher the preference for a glyphosate ban. Women are more positive towards earmarking tax revenue to additional support for farmers, environmental and health programmes than the men in our sample. Furthermore, the higher the education of respondents (across all nationalities), the more likely they are to want tax revenue to be redistributed to environmental programmes. The more frequently the respondent consumes organic food (upper bound was "every day") - which we interpret as a proxy of sensitivity to environmental concern - the more likely the respondent is to prefer a ban of glyphosate, as well as a higher reduction in glyphosate use of farmers. A second proxy for environmental sensitivity was interpreted on the basis of whether the respondent had already heard of glyphosate before beginning the survey. Results showed that respondents that had already heard of glyphosate preferred a ban of glyphosate and earmarking the glyphosate tax revenue to additional support for farmers. As discussed above, respondents were also asked to indicate on a scale from -100 to 100 what their opinion was of the agricultural sector, as it is now. Respondents that had a higher opinion of the agricultural sector were more likely to prefer a tax and supported tax revenue to go to additional support for farmers.

Welfare estimates can be established through the marginal willingness-to-pay (WTP) for attributes considered in the study. The WTP estimations that are presented in Table 5.5 are calculated with price as a log-normally distributed parameter, and the estimates are derived at a 95 % confidence interval (CI) in WTP-Space using 1000 Halton draws.[7] With regard to farmers' reduction in the use of glyphosate, mean results show that consumers across the five countries studied are willing to pay the highest price - of €4.67 per week - if farmers' use of glyphosate is reduced by 100 %. This WTP decreases accordingly with the reduction in glyphosate for 95% (€4.44 per week), 85% (€3.97 per week) and 75% (€3.50 per week). In the case of a tax on glyphosate, consumers are willing to pay a higher price if its tax revenue is earmarked, meaning that consumers know that revenue will be spent on specific ptrogrammes, relative to unspecified government spending. For additional support for farmers relative to unspecified government spending, consumers are willing to pay on average €6.66 per week, while they are willing to pay €4.49 per week for tax revenue to be earmarked to health programmes, and €4.34 to environmental programmes: these findings support the literature that sees acceptability of a tax increases with earmarking as it strengthens the effectiveness of the tax (Baranzini and Carattini, 2017).

There is evidence that WTP can be sensitive to price levels chosen for the price attribute. The literature on cost vector effects indicates a tendency of finding higher WTP if cost vectors of greater magnitude are used (Ryan and Wordsworth, 2000; Hanley et al., 2005; Carlsson and Martinsson, 2008; Mørkbak et al., 2010; Kragt, 2013; Su et al., 2017; Glenk et al., 2019). However, Svenningsen and Jacobsen (2018) reveal mixed evidence about this effect, indicating that there is not conclusive evidence that price magnitude biases WTP. As discussed in section 5.2.2., we distributed a different survey to an additional 500 French consumers (in addition to the sample comprising 2 050 consumers) given the uncertainty regarding both our choice of price levels (for the attribute 'Increase in price of a weekly basket of food'). This second sample of 500 consumers received the same survey - the only difference was the price value of the status quo being lower: at €3 instead of €4 for the main sample. For this second sample, the price levels for -95 %, -85 % and -75 % reduction in farmers' use of glyphosate could therefore only take values €1 and €2 (as opposed to €1, €2 and €3 for the main sample).[8]

Our results show that as magnitude for the status quo price of a ban increases from €3 to €4 our results are substantially biased upwards for the attribute 'Glyphosate tax revenue earmarked to': i) environmental programmes, ii) health programmes, and iii) additional support to farmers. However, for the attribute 'Reduction in farmers' use of glyphosate', results are more similar, but biased downwards as magnitude increases from €3 to €4. We cannot conclude that respondents' WTP necessarily increases as magnitude increases as we present mixed

[7] WTP estimates derived at a 95 % confidence interval (CI) computed with bootstrapping (Hole, 2007) can be found in Appendix C.

[8] See appendix C for experimental design of the split-sample survey separately distributed - also distributed by survey company IPSOS - to 500 French consumers (representative of the general population). Descriptive statistics of consumers included in the split-sample survey are also presented in Appendix C.

results, as Svenningsen and Jacobsen (2018) did. However, the high WTP stated by respondents for earmarking glyphosate tax revenue to environmental and health programmes, as well as additional support to farmers may have been overstated in the main sample. While this is conjecture, it is possible values for the SQ €3 were deemed too low by respondents for earmarking (respondents could only earmark tax revenue with either €1 or €2. As discussed in chapter 4, if WTP values are too small, on the other hand, WTP values can become larger than the highest bid levels (Glenk et al., 2015). Results comparing the two samples can also be found in Appendix C and show that the signs of coefficients do not change but the weight does. Nonetheless, it is important to acknowledge the limitation that we are not making a perfect comparison due to the fact that the split sample-survey where the SQ price was represented by €3 was only distributed to French consumers. To compare the split-sample survey with remaining countries we would have to correct for purchasing power parity - an avenue for forthcoming research on this database. Nonetheless, given that we could not find any significant differences in preferences the main sample (of 2 050 respondents) between the country samples, the results and difference between WTP from the remaining countries could be similar based on conjecture.

Table 5.5: Willingness-to-pay estimates (€ per week) for DCE sample: WTP-Space with 1000 Halton draws (N=2 050) with price as a log-normal parameter

Attribute	**Levels**	**Mean**	**95 % CI**
Reduction glyphosate	75 %	3.50	1.82 ; 5.18
	85 %	3.97	2.06 ; 5.88
	95 %	4.44	2.30 ; 6.56
	100 %	4.67	2.42 ; 6.91
Tax revenue earmarked to:	Environmental programmes	4.34	3.04 ; 5.65
	Health programmes	4.49	3.29 ; 5.69
	Additional farmer support	6.66	4.80 ; 8.53

5.4 Conclusion and policy recommendations

Farmers' use of glyphosate will once again be placed under the microscope when the EU sets out to vote on its future in 2022. This paper has analysed the acceptability of two alternative policies for consideration when this happens, if we make an assumption that governments aim to drastically reduce farmers' use of glyphosate. One policy studied looked to command-and-control regulation (a ban), while the other policy looked to a market-based instrument (a tax). In order to test acceptability on the relevant group, a representative sample of the general population in major European countries was surveyed on its preferences. A discrete choice experiment - allowing for the creation of hypothetical choice tasks - was therefore set up to establish consumers' preferences, with the aim in mind to

Table 5.6: WTP estimates in € / per week for two different SQ values: WTP-Space with 1000 Halton draws (split-sample results)

		SQ€3	**SQ€4**
Price as a log-normal parameter			
Reduction in farmers' use of glyphosate (75 %)	Mean	3.82	2.93
		(3.37 ; 4.2)	(2.4 ; 8.25)
Reduction in farmers' use of glyphosate (85 %)	Mean	3.97	3.32
		(2.06 ; 5.88)	(2.72 ; 9.35)
Reduction in farmers' use of glyphosate (95 %)	Mean	4.43	3.70
		(2.30 ; 6.57)	(3.04 ; 10.45)
Reduction in farmers' use of glyphosate (100 %)	Mean	4.67	3.91
		(2.42 ; 6.91)	(3.2 ; 11)
Glyphosate tax revenue earmarked to:			
Environmental programmes	Mean	1.265	7.255
		(1.067 ; 1.463)	(1.521 ; 12.989)
Health programmes	Mean	1.069	7.198
		(0.889 ; 1.249)	(1.573 ; 12.823)
Additional support for farmers	Mean	2.237	7.403
		(1.869 ; 2.604)	(2.529 ; 18.511)

95 % confidence interval in parentheses

understand better how to balance political feasibility with the design of an effective pesticide reduction policy mix. Even though this paper focuses on glyphosate and the EU specifically, the rationale is applicable first of all to pesticides and environmental taxation more generally, and secondly to beyond the borders of the European Union. Our main findings can be summarised as follows.

We can conclude that the overall result of the study sees that within the sample studied - that was representative of the general population of Belgium, France, Germany, Italy and Spain - there was a significant overall preference for a ban on glyphosate as opposed to a tax. It could therefore be appealing for EU policymakers to follow this path from a political economy perspective when it is time to vote on the EU-wide authorisation of glyphosate in 2022, especially, as interestingly, no major differences were found between the preferences of the countries targeted.

However, some within-group differences were found: the higher the sensitivity to the environment, the higher the preference for a ban. Further, one difference that was found on the overall policy preference between a tax and a ban, related to the sub-group of people that showed a higher opinion of and affinity for farmers and the agricultural sector: these respondents preferred a tax. While a tax will reduce the use of glyphosate and encourage more sustainable methods, it will do so in a more gradual way so as to ease farmers' transition: it is therefore unsurprising that this sub-group preferred a tax. What this highlights, is that given the difficulties some farmers may face in the transition to non-glyphosate based farming, is that they should receive adequate support if and when a ban takes place. In the European Union, the support (e.g. eco-schemes) of the Common Agricultural Policy can be

used to support this transition. Even though any policy aiming to reduce the use of glyphosate will likely increase grocery prices - at least in the short to medium term - respondents prefer lower prices. Despite this, the overall result sees that people are still willing to forgo this higher price in order to ensure a full ban of glyphosate.

Results of our study show that social acceptability of a tax increases with direct earmarking to specific programmes; from additional support to farmers, health programmes, and environmental programmes - relative to using tax revenue for unspecified government general spending. The acceptance and willingness-to-pay particularly increases with direct earmarking. This high willingness-to-pay for earmarking is especially the case for additional support for farmers: as a tax on glyphosate would especially impact and target farmers, this particular earmarking programme strengthens the effectiveness of the tax. While the results of the study suggest that a ban on glyphosate is the most preferred plan of action amongst the general population, the results are also important for the reduction of other pesticides. For instance, as it is unlikely we can ban all harmful pesticides at once; if this rationale of earmarking is applied to the reduction of pesticides more generally, by attaching a strong tax to them, it will likely ease both the political feasibility of the general population and the transition process of farmers to a fairer and greener agricultural sector. The split-sample results with 500 additional French consumers illustrated a significant change in WTP and magnitude of coefficients for earmarking (but not for the attribute 'Reduction in farmers' use of glyphosate), calling into question the accuracy of our results. Nonetheless, the results still remain relevant as main results remained similar despite magnitude.

It is important to acknowledge the boundaries of the study's limitations. A common drawback of discrete choice experiments is their hypothetical nature, and it is not possible to say with certainty that the respondents would have chosen the same alternatives in real world circumstances. Respondents are also more price sensitive in real life than in hypothetical choice scenarios: the willingness-to-pay can therefore be overestimated in discrete choice experiments (Murphy et al., 2005). Nonetheless, previous research has illustrated that it is possible to elicit real world choices with relative precision when real preference data is unavailable (Soekhai et al., 2019).

Furthermore, any policy related to the use of glyphosate impacts farmers more than any other sub-group. Research on farmers' preferences regarding future policies on glyphosate reduction should therefore be used to complement the study in question. Moreover, the difficulties of reducing glyphosate use are not confined to Europe's borders. To better generalise our findings, these questions should be applied to other regions around the world to capture a broader picture of the issue in question. Given the rich nature of the data set, further research is currently being undertaken by the institute leading the survey distribution (INRAE) - for per-country analysis, with a correction for purchasing power parity, among other analyses - including further investigation into the split-sample results, which is beyond the scope of this thesis.

Chapter 6

Conclusions

Even though distinctive processes define each of the three types of lock-in discussed in this thesis - from technological, to institutional and behavioural lock-in, they are highly interconnected, mutually reinforcing, and can create collective inertia concerning transitions to sustainability. Efforts to escape one of these types of lock-in, whether institutional, technological or behavioural, can result in resistance to change in the other types.

The complexity of lock-in mechanisms, coupled with the diversity of emerging policy mixes, reminds us that attention should not only focus on discrete technologies. This thesis has therefore focused on different technologies and markets - including the hydrofluorocarbon-replacement industry, policymakers' funding decisions when allocating R&D budgets to alternative transport fuels, and the agro-ecological transition through the eyes of both farmers and the general public. While a limitation to studying different applications lies in lost detail attached to these examples, by taking a variety of perspectives into account, the thesis has illustrated the way in which policy can influence the rate and direction of technological change, and as a result socio-technical transitions, at different stages of development and application.

We can look back to Figure 1.2. in the Introduction: Chapter 2 and 3 of the thesis focus on the early stages of eco-innovation and technological development - from the research, development and demonstration phases (regulatory push), whereas Chapter 4 and 5 focus on the later stages of eco-innovation and technological development - of market formation and diffusion (regulatory pull). With this in mind, we can draw two principle conclusions when applied to the discussed markets and technologies in the related chapters.

First of all, the second chapter argues that governments should not only be considered "market-fixers, but also — and especially — market-makers and shapers" and therefore builds on Mazzucato (2018). Innovation and technology development is something multifarious: policy impacts depend on the design of the policies and context in which they are used. Policymakers should go beyond their traditional role of simply financing technology, and should support both social and physical technologies, development and acceptance. In line with the claim that we 'should not confuse 'optimal' with 'what survives' (Schot and Geels, 2008; Maréchal, 2009;

van den Bergh et al., 2006), policies should therefore also aim to influence the selection environment such that only the greenest technologies survive. Allowing for context dependent policy with flexibility increased, the potential for error costs could be decreased, while it is argued - long-term, sustainable and economically viable solutions are better promoted at the same time. Furthermore, governments play a disproportionate role in funding and supporting early-stage, high-risk research and development (R&D). As lead investors in novel and risky projects and sometimes in start-ups, the "entrepreneurial" role of governments is most evident in the earlier stages of development when private actors may be more risk-averse (Mazzucato and Semieniuk, 2017). Results of the third chapter illustrate an example of institutional lock-in: the policymakers that took part in the study were more likely to fund projects that resembled the incumbent, rather than technologies that were more innovative. As policymakers can disproportionately influence the rate and direction of technological change, these insights are key to ensuring the success of innovation funding programmes and policy supporting early-stage technology development. As discussed, innovation targets and quotas, as well as unconscious bias training (when applied to issues such as incumbency and status quo bias) could be helpful. Moreover, so could tracking and making cross-comparisons of innovation progress, despite well-known difficulties with regard to tracking innovation, but efforts should be made to improve this (IEA, 2020).

Secondly, when considering who bears the responsibility to take action with regard to market formation and transformation - here applied to the agro-ecological transition, as presented in chapter 4 and 5, policymakers would first of all be well-advised to provide transition support, e.g., in the form of knowledge sharing and training projects, to help farmers react to new regulatory requirements and taxes. Policymakers also have an important role to play in ensuring that consumers have access to the information necessary to make informed choices about the products they would like to consume. Such policy action has the potential to grow the market for sustainable agricultural produce, in turn increasing the returns to farmers that transition to healthier and more environmentally sustainable practices. However, policymakers are not benevolent dictators who make such decisions irrespective of the preferences of voters and key stakeholders - here farmers. This is why an important responsibility for the necessary change lies with the voters and farmers. Consumers and voters have already begun voting with their wallet, considering the increasing demand for organic products in recent years. In addition, consumers and voters have the opportunity and responsibility to voice their concerns about legacy practices, and support for change, with their elected representatives. Farmers can equally work through their industry associations to ensure that policymakers design reform packages that take their idiosyncratic circumstances into account and ensure that the sector as a whole can transition successfully.

6.1 Chapter conclusions

6.1.1 Unlocking technological lock-in

The second chapter applied the conceptual framework of technological lock-in to the market for hydrofluorocarbon replacements in the European Union. It argues that the market is being locked-in, to the advantage of synthetic option R-1234yf, as opposed to natural solution CO_2. While it is not uncommon for one technology to take over the market, what was unusual in this case, was the degree to which the regulatory environment restricted the entry of alternatives, despite known risks and uncertainties of the dominant solution.

We look to how regulation reinforced a patented monopoly by, as we argue - 'picking winners' to the advantage of a less sustainable option. Governments require a more dynamic framing: it should be less about picking winners, and more about forming broadly defined directions for a policy designed for specific situations. In this case, as there was no lead-time to develop alternative solutions, regulation reinforced the market position of one solution over another, while simultaneously intensifying economies of scale, learning effects, adaptive expectations and network effects.

In this case, a situation of lock-in occurred when actors and decision-makers did not allow for the development or use of more sustainable alternatives, even though potential risks or costs of the dominant alternative were understood. Specifically, there was no lead-time to develop alternative solutions, and, as a result, regulation reinforced the market position of R-1234yf through an intensification of economies of scale, learning effects, adaptive expectations and network effects. The limits to 'technical fixes' need to be recognised (Parkhurst and Parnaby, 2008), in the sense that there is rarely a single solution to any problem. Policy needs to allow for the support of alternative technologies through incentives, subsidies and training, and needs to take costs and timing into account when determining how changes affect parties; these include administrative, legal, and institutional contexts.

Policymakers worldwide are increasingly responding to rapidly evolving environmental risks. Against this background, this chapter concludes by recommending that policy attach greater importance to market power when designing clean technology markets. If emerging markets for clean technology unnecessarily lock-in patented technologies - as we argued to be the case for hydrofluorocarbon replacements and effectively granting a monopoly to one firm - the monopolist is likely to reap most of the benefits of green technologies. As it is the state that often funds basic research that enables innovation (Mazzucato and Perez, 2015), it is vital that consumers and taxpayers also reap the rewards from these innovations. To avoid the monopolisation of clean technology markets, policymakers should ensure that their transition pathways leave sufficient time to develop competing technologies and substitutes. Consequently, we suggest placing a higher emphasis on the competitive benefits of substitutes for clean technologies, which can potentially be highlighted through regulatory impact assessments.

6.1.2 Unlocking institutional lock-in

The third chapter of the thesis seeks to shine a light on policymakers' funding preferences in the early iterative innovation stages, which may serve as input to any consequent debate on strategic public funding decisions, that may, in turn, affect the development of new products and services. The results provide indications as to whether policymakers may indirectly be contributing to institutional lock-ins that exist within established socio-technical regimes (Kemp et al., 2007). Using the example of carbon capture and utilisation (CCU) based fuels, a discrete choice experiment assessed whether 129 policymakers - working at European, national, regional and local levels - prefer to invest in technologies that resemble the incumbent than novel and more disruptive technologies. The targeted policymakers worked with European funding programmes or advisory bodies related to realising Europe's transport infrastructure policy.

Experimental evidence illustrates that people prefer to purchase familiar goods and make familiar choices. Investors have been shown to disproportionately buy stocks in culturally, geographically and linguistically proximate markets (Cao et al., 2009; Graham et al., 2009). This experimental evidence is primarily applied to investors in capital markets, yet little attention is leveled at policymakers. The choices decision-makers face when deciding how to allocate and invest public financial resources are complex and can significantly impact society (van der Vooren et al., 2012). Any decision-maker – be it in daily life or a policymaking context – interprets their surroundings through a lens of their past and experiences, learning by combining heuristics and cognitive filters and known processes (Witting, 2017). Samuelson and Zeckhauser (1988) maintain that various theories such as misperceived sunk costs and a wish for consistency can be reasons for a preference to remain within the current position.

The resilience of existing infrastructures often hinders socio-technical transitions. Therefore, this chapter investigates whether policymakers may be reinforcing such dominant, incumbent systems through reluctance in investing in novel products or services. Results indicate that policymakers indeed prefer to allocate funding to dominant technologies. Our results thus show that policymakers may be likely to avoid investing in a more innovative idea, not because of any intrinsic flaw in the technological system, but because it would require too much change. As a result of these lock-ins, governments can influence the rate and direction of technological change through investment in R&D for developing infrastructure. These insights should be made available to and communicated among policymakers overseeing innovation funding programmes to ensure better innovation is being steered in the right direction. The results also revealed an overall positive perception of CCU technologies among policymakers. As the commercialisation of such products and processes continues, acceptance among this group of stakeholders is critical.

6.1.3 Unlocking behavioural lock-in

The fourth chapter of the thesis looked at how sustainability transitions and policies imposed to target change may impact certain groups and livelihoods more than others, which may, in turn, induce a form of behavioural lock-in. The agricultural sector is expected to meet transitional challenges (UNFCCC, 2016), and policy efforts need to ensure that the shift to sustainable practices is fast but also fair. This chapter focuses on the French agricultural sector on the road to an agro-ecological transition, which from a European perspective is important, as France is one of the main European exporters of agricultural products and users of pesticides (Agreste, 2018). A mixed method approach was conducted - with a DCE complemented with semi-structured interviews.

Bringing the results together, both the quantitative and qualitative results illustrate that most farmers wish to change practices but are at odds as to how this could be done. The results of the latent class model illustrated that the majority of the farmers that took part (>75 %) wished to change practices (through a preference for an exit from the status quo) and showed a preference for reducing impact on health and the environment through a reduced use of pesticides, but disregarded the remaining attributes presented to them - including income, transition time, and optional and free agricultural support. The remaining farmers that took part in the discrete choice experiment showed a significant preference for *not* reducing impact on health and environment through the reduction of pesticides. Although there is a wealth of research on DCEs and environmental impacts, and also conducted with farmers, the authors question, given the disregard for many of the attributes presented to them, whether the DCE is an appropriate method and format to establish policy packages on the specific topic of pesticide use when impacting farmers' livelihoods, given: i) that farmers are both professionals and experts, making them less inclined to accept abstract and simplified approaches - such as DCEs - to mimic their decision-making process when attributes representative of their entire livelihoods are included (encompassing respondents' capabilities, assets, income and activities required to secure the necessities of life); ii) the political scrutiny currently aimed at the agricultural sector that may elicit resistance among the farmers (as evidenced by very high drop-off rates at the start of the survey) and, iii) the controversial pesticide issue which divides opinion, for example between communities such as farmers, ecologists and authorities.

While technological and financial aspects are critical to farmers' decision-making, the results of the semi-structured interviews highlight that group-mediated behaviour might have just as much an effect on change. Transitioning to alternative agricultural practices brings large amounts of uncertainty, be it financial, technological and social. One crucial motivation for group-mediated action is uncertainty reduction (Smith and Louis, 2009). Identifying with relevant reference groups and guiding behaviour based on what your peers are doing can reduce uncertainty and behavioural lock-in through knowledge and experience sharing (Smith and Louis, 2009; Cialdini and Goldstein, 2004). In times of uncertainty, norms within a group or community that a farmer belongs to may therefore be more likely to influence

their behaviour than anyone else's. Among other recommendations, we argue that policy taking within-group comparison standards between farmers into account could potentially be made use of to encourage behavioural change and to attain more targeted approaches, while bridges between farmers and policymakers should be encouraged through a reduction of technological, economic, social and governmental uncertainty. The farmers also highlighted a deep disconnect felt between authorities and themselves as a group - with authorities imposing policies they deem unrealistic and unfair, which made them less likely to follow government advice. Semi-structured interviews illustrated the wish for concrete and local policy measures based farmers' networks and peer support and increased face-to-face interaction with policymakers to increase mutual understanding of the situation at hand.

Policy recommendations are formulated based on these results:

1. Perceptions of peers may influence behaviour more efficiently than outside pushes: specifically, authorities could use within-group comparison standards between farmers to encourage behavioural change and attain more targeted approaches.
2. Bridges between farmers and policymakers should be encouraged, especially through face-to-face interaction.
3. The extreme uncertainty felt by farmers in several fields needs to be reduced, recommendations for which are outlined below.

Regarding technological uncertainty, research should be pursued on agro-ecological alternatives to pesticides and farmers should be regularly informed on the obtained improvements. Several interviewed farmers wanted to be informed on scientific advances on this topic. As discussed in (Chèze et al., 2020), authorities could offer cheap and good quality insurance to farmers to reduce their income variability and economic uncertainty. Regarding social uncertainty, the general population should be sensitised - with the media's help - on farmers' work, lives, and concerns to reduce the agricultural profession's stigma. As for governmental uncertainty, public authorities should certainly correct the problem of unpaid subsidies to farmers, simplify administrative procedures and implement reliable agri-environmental schemes to regain farmers' trust.

6.1.4 Unlocking lock-in: increasing acceptability of policy instruments to accelerate socio-technical transitions to sustainability

The two major policy categories often discussed with regard to accelerating eco-innovation in regulatory pull processes of i) regulatory instruments and ii) economic instruments (Bergek et al., 2014; Horbach et al., 2012; Kemp and Pontoglio, 2011; Peters et al., 2012; Rennings, 2000), are here discussed against the backdrop

of unlocking institutional, technological and behavioural lock-in. The chapter does not seek to establish whether one is better than the other - both policies should be used in today's policy mix where appropriate. We rather seek to establish preferences of the public, and how to increase acceptability of such policies and what trade-offs people make when choosing one over the other.

This fifth chapter analysed the acceptability of two alternative policies for consideration when when the EU sets out to vote on the future of glyphosate in 2022, if we make an assumption that governments aim to drastically reduce farmers' use of glyphosate. One policy studied looked to command-and-control regulation (a ban), while the other policy looked to a market-based instrument (a tax). In order to test acceptability on the relevant group, a representative sample of the general population in major European countries was surveyed on its preferences. A discrete choice experiment - allowing for the creation of hypothetical choice tasks - was therefore set up to establish consumers' preferences, with the aim in mind to understand better how to balance political feasibility with the design of an effective pesticide reduction policy mix. Even though this paper focuses on glyphosate and the EU specifically, the rationale is applicable first of all to pesticides and environmental taxation more generally, and secondly to beyond the borders of the European Union.

Our main findings can be summarised as follows. While the results of the study suggest that a ban on glyphosate is the overall plan of action, the acceptability of a tax on glyphosate and respective willingness-to-pay increases with direct earmarking for specific programmes - relative to using tax revenue on unspecified government spending. The high willingness-to-pay for earmarking is especially the case for additional support for farmers: as a tax on glyphosate would especially impact and target farmers, this particular earmarking programme strengthens the effectiveness of the tax. While we focus on glyphposate. the results are also important for the reduction of other pesticides. For instance, as it is unlikely we can ban all harmful pesticides at once; if this rationale of earmarking is applied to the reduction of pesticides more generally, by attaching a strong tax to them, it will likely ease both the political feasibility of the general population and the transition process of farmers to a fairer and greener agricultural sector. The split-sample results with 500 additional French consumers illustrated a significant change in WTP and magnitude of coefficients for earmarking (but not for the attribute 'Reduction in farmers' use of glyphosate), calling into question the accuracy of our results. Nonetheless, the results still remain relevant as main results remained similar despite magnitude.

Interestingly, no major differences were found between the preferences of the countries targeted. However, some within-group differences were found: the higher the sensitivity to the environment, the higher the preference for a ban. Further, one difference that was found on the overall policy preference between a tax and a ban, related to the sub-group of people that showed a higher opinion of and affinity for farmers and the agricultural sector: these respondents preferred a tax. While a tax will reduce the use of glyphosate and encourage more sustainable methods, it will do so in a more gradual way so as to ease farmers' transition: it is therefore

unsurprising that this sub-group preferred a tax. What this highlights, is that given the difficulties some farmers may face in the transition to non-glyphosate based farming, is that they should receive adequate support if and when a ban takes place. In the European Union, the support - e.g., eco-schemes - of the Common Agricultural Policy can be used to support this transition. Even though any policy aiming to reduce the use of glyphosate will likely increase grocery prices - at least in the short to medium term - respondents prefer lower prices. Despite this, the overall result sees that people are still willing to forgo this higher price in order to ensure a full ban of glyphosate.

6.2 Limitations

It is important to acknowledge the limitations of the thesis. A discrete choice experiment was the method used in three chapters of the thesis. A standard, well-known limitation lies in its hypothetical nature (termed *hypothetical bias*) and over-estimations of willingness-to-pay for alternatives presented to respondents. This over-estimation may particularly be the case in the final chapter when consumers were faced with choosing policy options that would increase the price of their weekly basket of food. While respondents were willing to trade-off lower prices to reduce farmers' use of glyphosate, we cannot conclude whether the public would be as accepting were it to become a reality: would the public penalise the state for rising food prices in the end? Nonetheless, establishing this would mean that the policy was already implemented: the study aimed to investigate public perception of policy options beforehand. Furthermore, the respondent chooses based on options today, but this may disregard those of tomorrow and future generations, which could have led to underestimations of value. Nonetheless, hypothetical choices can be meaningful for improving real-world choices, and their strength also lies in their hypothetical nature. DCEs are a useful means to estimate non-use values or use values associated with changes that fall outside the range of current markets or observed conditions (Johnston et al., 2017). Previous studies also show that it is possible to elicit real-world choices with fair precision when field or real-world data is unavailable (Soekhai et al., 2019).

A problem as discussed in section 1.4.1.1 is that people tend not to have stable and pre-defined preferences that can be drawn upon when responding to a survey, especially when valuing complex goods that a respondent may not be familiar with - which was 35 % of the larger sample, but only 15 % in the French sample. As was shown in the split-sample results of chapter 5, the magnitude for the estimates for willingness-to-pay varied significantly when the price of the status quo changed. Nonetheless, it still gives important insights into people's preferences regarding acceptability and earmarking. Further investigation is necessary. Moreover, small pre-tests in chapter 3 and 4, as well as sampling strategy in chapter 4, may have had a bearing consequence on the design and eventual results. Results of chapter 4 - and insignificance of several attributes - raises questions about the importance of ensuring representativity in both the pre-test and sampling stage.

Further, a limitation regarding the experimental design of chapter 5 should be discussed. By including an attribute of what the tax revenues are used for, we value the benefits of the reduction in pesticide use, but also the benefits of those alternative policies (especially with regard to the baseline option of 'General budget' which also included the option of raising spending for priority areas such as education or pensions schemes) - this raises questions as to what the outcomes reflect. Any tax will raise revenues irrespective of the motivation behind its introduction, making it challenging to clearly separate the two effects in empirical work. While environmental taxes are indeed typically primarily introduced to achieve environmental policy objectives (and, in turn, change behaviour regarding pesticide use in an efficient way), the use of revenues is equally key in evaluating the social costs and benefits of the tax (including its distributional effects), and its political feasibility. One of the many political economy challenges associated with the introduction of environmental taxes is that even citizens who agree with the environmental motivation behind their introduction may be critical of such taxes because they oppose big government. To alleviate such concerns, governments could embed environmental tax reform in a broader fiscal reform package, that contains credible assurances from the government that it will not increase the size of the government budget even further. The government, could, for instance, outline that it will use the new revenues to lower taxes on labour or capital, keeping the size of the government budget constant *ceteris paribus*. Citizens may also be sceptical of the government's capacity to allocate tax revenues efficiently, and distrust any government assurances around tax cuts, preferring the revenues from certain taxes to be earmarked for specific uses they consider useful and productive. (Such tax revenues would still count towards government revenue and thus increase the overall size of the government budget, but may not be perceived as such as they have to be used for specific purposes.) In the discrete choice experiment, we allowed for all of these options. This means that respondents who were open to using taxes for environmental reasons, but wary of uncontrolled government spending, had ways to signal their support for the tax (being willing to accept higher food prices), without being forced to agree to an increase in the general budget. The interpretation of the outcomes of the experiment will nevertheless need to be treated with some caution: the reason is that we cannot be certain that preference for earmarking for a given purpose is truly the result of a willingness to support that purpose, or rather a way for respondents to keep the government in check.

The research approach chosen for the first chapter was a qualitative one, given that it characteristically enables an "exploratory, fluid, flexible, data-driven and context-sensitive analysis" (Mason, 2017), based on a literature review of the field of technological lock-in, as well as scientific developments within the area of hydrofluorocarbon replacement technologies. The paper argued that regulation reinforced a patented monopoly to the advantage of an inferior technology. A limitation in this work is that we do not observe the counterfactual - for instance, if regulation had in fact allowed for a more flexible entry for competitors and longer lead times to develop technologies. The results do not identify cause and effect, and should therefore be interpreted through a speculative lens.

A minor limitation of the thesis lies in the study's context dependence, and more specifically, its Eurocentrism. All four chapters investigate the interaction between European public policy and its impact on lock-in and the socio-technical transition, so further research would need to be undertaken to establish whether these results can travel to other parts of the world. For instance, in the second chapter, European policymakers' preferences are assessed. Would these results translate to policymakers in the United States or authoritarian regimes such as Russia and China? Furthermore, the third chapter investigated French farmers' trade-offs when adopting agro-ecological practices. These results - especially concerning trust in the state - would likely differ depending on the country the study took place. The final chapter studied public opinion and acceptability of a policy seeking to reduce farmers' use of glyphosate in Belgium, France, Germany, Italy and Spain - whether through a tax or a ban. Such a policy will inevitably increase food prices due to increased production costs. If the same study was undertaken with consumers in developing countries, results may differ, and even if it were conducted in Central or Eastern Europe, as opposed to Western Europe.

6.3 Avenues for future research

As discussed, this thesis sought to respond to recent academic literature seeking to reconcile lock-in and sustainability transitions studies with considerations of policy, institutions and political decision-making processes. Politics and power have been receiving increased attention in recent years due to criticism raised that they have been neglected within the field (Avelino et al., 2016; Kuzemko et al., 2016; Köhler et al., 2019). Thus, the thesis considered regime stability, and in turn dependence on dominant technologies, as a result of resistance, whether deliberate or not, by incumbent actors or institutions, through an intertwining of technological, institutional and behavioural lock-ins. The second chapter investigated the decision-making processes of policymakers in their responses to investment decisions, which serve as an input to any consequent debate on strategic public funding decisions, that may, in turn, affect the development of new products and services. A surprising finding in the lead-up to the DCE distribution of the second chapter was the limited research into policymakers' perspectives on their role on the road to socio-technical transitions to sustainability - whether through valuation studies such as DCEs, other survey-based methods, or qualitative interviews. While access may previously have been a hinder to undertaking such research, with the proliferation of online survey techniques, this should no longer be the case. Given that our research was highly Eurocentric - both in terms of region and connection of policymakers to strategies and programmes of the European Union, further research on policymakers' perspectives in other parts of the world would be recommended to corroborate, validate or falsify our findings. Given that policy represents one of the core dimensions of the socio-technical regime, along with user practices, science, cultural meaning and infrastructure, understanding decision-making, intentions and motivations of key actors within these policy processes - i.e., policymakers - would therefore be most welcome.

In terms of lock-in as a configuration playing a major role in socio-technical transitions, this thesis takes a systemic stance instead of focusing on specific products or market forces. The thesis illustrates how these processes are interlinked through a technological institutional and behavioural angle. The compelling complexity of lock-in mechanisms, coupled with the diversity of emerging policy mixes, reminds us that attention should not only focus on technologies on their own but also broader socio-technical systems (Kotilainen et al., 2019). Recent reviews have shown that the transitions literature has neglected the management of broader repercussions of regime destabilisation and change, with the management of broader societal impacts largely ignored (Kanger et al., 2020). For instance, Edmondson et al. (2019) saw that an overwhelming proportion of intervention points in current policy mixes literature (95.4%) is related to niche stimulation and niche acceleration - a finding confirmed by Kanger et al. (2020). The field of transitions studies has thus so far predominantly focused more on single systems and less on multi-regime interaction and broader impacts of systems change (Kanger et al., 2020). Moreover, a recent European Environment Agency report on the policy and practice of sustainability transitions explicitly acknowledges the importance of alleviating the negative consequences of systems change (EEA, 2019). By directing research further to identify root causes, critical problems (e.g., lock-ins) and intervention points that are not sufficiently covered by existing policy instruments would be helpful: this, in turn, could lead to the design of a complete portfolio of policy instruments and strategies, facilitating a change in the direction of socio-technical systems towards increased sustainability. A broader framework that therefore takes facets such as inclusivity, retraining and investments in alternative industries into account would be useful (Kastrinos and Weber, 2020). The importance of this systemic approach was especially shown in the third chapter of this thesis regarding farmers' perspectives and reactions as argo-ecological policies are implemented, and the transitional challenges expected for workers and communities as this shift takes place.

The thesis has relied heavily on interdisciplinary research by juxtaposing concepts from traditionally qualitative fields of research with the more quantitative approach of DCEs. As discussed in the introduction, while literature exists on the need for qualitative approaches in the DCE design phase, less research exists on their need in validating data acquired from the DCE itself (Powe et al., 2005; Rakotonarivo et al., 2016; Vass et al., 2017). Particularly when considering such complex socio-technical transitions that may affect entire livelihoods, respondents may need discussion forums that complement the more rigid DCE format. If DCEs are to be useful to policy, DCE researchers should gain a better understanding of the context behind respondents' choices (Loomes, 1999), so that policy implementation can be eased and improved: interviews are a useful way to do this. On the other hand, research on socio-technical transitions is also lacking in more quantitative methods of study (Hansmeier et al., 2021). Increased interdisciplinary research in fields of socio-technical transitions and energy studies more broadly would be useful. As illustrated by Schmidt and Weight, within energy studies, interdisciplinary work remains relatively rare: "despite the predominately socio-economic nature of energy demand, such interdisciplinary viewpoints – albeit on the rise –

are still the minority within energy-related research" (Schmidt and Weigt, 2015). Similarly, Schuitema and Sintov (2017) show that research within these fields also needs to improve in terms of "interdisciplinary reach (breadth), policy-relevance, and the communication of results." DCEs have an important role to play here, especially in relation to transitions studies. Making continued use of methods such as deliberative monetary valuation this would also be valuable to increase interdisciplinarity of the field.

Related to increasing interdisciplinary, introducing more concepts within behavioural economics and cognitive psychology when interpreting DCEs would be helpful - i.e., that context matters. The notion of context-dependence is not new within the stated preference literature (e.g., behaviour will change if the respondent is observed or not (Alpizar et al., 2008), how questions are framed, if people are told what others have done (Carlsson et al., 2010), and whether the research is undertaken in field settings or not) (Carlsson, 2010). Further, the existence and relevance of 'choice anomalies' in stated preference surveys are now widely accepted in the field (Schläpfer and Getzner, 2020). Insights from psychology and behavioural economics do provide a window into the complexity of consumer decision-making in the presence of uncertainty, suggesting that people are boundedly rational (Simon, 1990). Faced with uncertainty and insufficient knowledge, individuals tend to rely on mental shortcuts, values, emotions and heuristics to make sense of an issue, which leaves them prone to cognitive and behavioural biases (Tversky and Kahneman, 1989; Yang and Hobbs, 2020). Authoritative guidance for stated preference research (Johnston et al., 2017) does suggest looking into behavioural issues such as those discussed above. However, in applied work, systematic testing of behavioral assumptions remains the exception rather than the rule (Schläpfer and Getzner, 2020): "this leads to the situation that even the very recent policy impact assessments rely on stated preference studies that do not take behavioral anomalies into account" (e.g., (Bishop et al., 2017; Díaz et al., 2019). As suggested by Carlsson (2010), further adaptation of DCEs could be helpful. This means that DCEs could be better increasingly adapted to different contexts (e.g., distributing the same survey to various groups, other parts of the world, or in different survey settings to avoid behavioural bias) to increase validity and test findings to understand whether results change based on such adaptations.

While context-dependence is important for future research, it is not necessarily relevant to the role of transitions in DCEs. To better ensure the complementarity of these two fields it is important to consider the role of uncertainty and risk in making these transitions and changes to new futures. When considering transitions, and the potential for DCEs, it is likely to consider that a respondent will have to value technologies, services or policies that may not exist on the market yet to accelerate the transition that is being studied, which causes a problem of complexity. As was the case in chapter 5 of this thesis, in DCEs, respondents are often asked to value goods, service and policies that may either be complex or not be familiar to them, which can lead to inaccurate estimates for willingness-to-pay. Related to the potential for respondents' lack of understanding of complex environmental problems in stated preference surveys, there is a growing literature

in the stated preference field concerned with handling risk and uncertainty. In the majority of stated preference research, expected benefits of an environmental policy are often presented to respondents without referring to the fact that outcomes can rarely be predicted with certainty (Glenk and Colombo, 2013; Glenk et al., 2015). This is a problem as these studies are often designed in risky and uncertain contexts (Torres et al., 2017) (and indeed, transition pathways), looking into preferences for environmental risk reductions, and often conclude that respondents are willing to pay to decrease risks (Faccioli et al., 2019). More studies have started introducing the concept of uncertainty into studies – which could involve comparing respondents' willingness-to-pay in both certain and uncertain settings (Roberts et al., 2008; Wielgus et al., 2009). When studies do not consider uncertainty, valuation scenarios can be less accurate or believable (Faccioli et al., 2019). Uncertainty can also be incorporated into DCEs through information disclosure (e.g., alerting respondents that predictions are not necessarily accurate). Including such information may allow respondents to make more informed choices, and, in turn, make choice scenarios more realistic as well as more reliable (Rolfe and Windle, 2015), which would be important for DCEs looking to contribute to the field of transitions.

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Appendix A

Chapter 3

A.1 Descriptive statistics

Variable	%	Mean	SD
Age		46	11.226
Gender (% male)	70.11		
Place of work			
European Commission	26.98		
European Parliament	26.19		
National Government	18.25		
Regional Government	10.31		
Local Government	5.55		
European Investment Bank	3.17		
Other	9.51		
Main topic of focus			
Transport	43.65		
Energy and environment	20.62		
Regional policy	8.73		
Research and innovation	6.34		
Development and cooperation	6.34		
Other	14.28		
Political spectrum			
Left-wing	17.45		
Centre-left	22.22		
Liberal/centre	23.80		
Centre-right	10.31		
Right-wing	1.58		
Prefer not to say/other	24.6		
Overall fuel preference			
Liquid-based fuel	48.46		
Gas-based fuel	30.76		
Prefer not to fund either	20.78		

A.2 Post-experimental questions

Attitudinal statements
1) It was easy to compare the different fuel alternatives with each other
2) New fuel technologies cause more problems than they solve
3) It is more effective to invest and improve existing fuel technologies, than in those that have not yet entered the market
4) Compared to other policy measures, decarbonising fuel is not a high priority.
5) If the choice of an alternative fuel choice were up to me, it would be compatible with current engines and infrastructure.
6) Policy plays an important role in ensuring clean technologies enter the market.
7) I consider myself well informed about sustainable technologies.
8) People are more likely to prefer vehicle technologies similar to those currently in use.
9) I would rather buy a car running on an alternative fuel such as CCU (that uses recycled CO_2)

A.3 Correlation matrix

	Emissions	Market share	Time to market	Budget	Low fuel cost	High fuel cost
Emissions	1.00	0.625	-0.401	0.543	0.253	-0.571
Market share	0.625	1.00	0.288	-0.043	-0.450	-0.727
Time to market	-0.401	0.288	1.00	-0.966	-0.933	-0.084
Budget	0.543	-0.043	-0.966	1.00	0.853	-0.097
Low fuel cost	0.253	-0.450	-0.933	0.853	1.00	0.853
High fuel cost	-0.571	-0.727	-0.084	-0.097	0.100	1.00

Appendix B

Chapter 4

B.1 Experimental design

```
Design
;alts = alt1*, alt2*, alt3*
;rows = 12
;block = 2
;eff = (rp,d)


;model:
U(alt1) = b1[0.1]*rev[-10,0,10]
         +b2[n,-0.02,0.000004]*santenvt[-95,-50,-20]
         +b3.dummy[n,0.4,0.004|n,0.4,0.004|n,0.4,0.004]*acc[1,2,3,0]
         +b4[u,-0.02,0.6]*trav[1,-1,0]
         +b5[n,-0.3,0.0006]*trans[2,3,5]/
U(alt2) = b1*rev+b2*santenvt+b3.dummy*acc+b4*trav+b5*trans
$
```

Figure B.1: Experimental design code (Ngene)

B.2 Descriptive statistics

	DCE sample		Qual sample	
Variable	Mean/Share	SD	Mean/Share	SD
Age				
18 - 29	10.11 %		6.66 %	
30-39	26.26 %		26.67 %	
40-49	31.31 %		20 %	
50 - 59	26.26 %		40 %	
60 +	6.06 %		6.67 %	
Income	18565.96	15084.1	17066.67	7721.163
Agricultural area	179.155	156.465	190.47	107.946
Organic farmers	6.36 %		13.33 %	
Field crops	72.56 %		40 %	
Market gardening	1.96 %		0 %	
Mixed crop/livestock	22.54 %		53.33 %	
Winegrowers	1.96 %		0%	
Education				
No education	1.96 %		0 %	
Vocational training	13.72 %		6.67 %	
High school	22.57 %		20 %	
Tertiary education	61.77 %		73.33 %	
Training frequency				
Never	10.38 %		0 %	
Rarely (>5 years)	15.09 %		0 %	
Occasionally (2 - 5 years)	21.7 %		13.33 %	
Often (<2 years)	52.83 %		86.67 %	
Outside revenue	58 %		51 %	
Reduced pesticide use	79.09 %		86.67 %	

B.3 Additional results

Table 9: RPL model estimates (n=110) using 1000 Halton draws.

		Coefficients	Standard Errors	*p*-Values
Main effects model				
Non-random parameter				
Impact on income	Mean	-0.014*	0.008	0.092
Random parameters				
Constant	Mean	-1.328***	0.445	0.003
	St. dev.	-2.663***	0.409	0.000
Transition time	Mean	-0.027	0.054	0.620
	St. dev.	0.144	0.138	0.296
Health and environment	Mean	0.002	0.002	0.372
	St. dev.	-0.008**	0.003	0.017
Condensed work schedule	Mean	0.150	0.248	0.547
	St. dev.	0.346	0.457	0.448
Spread Out work schedule	Mean	0.374	0.242	0.123
	St. dev.	-0.493	0.374	0.188
Advisor	Mean	0.161	0.196	0.412
	St. dev.	0.265	0.497	0.593
Network	Mean	0.072	0.177	0.683
	St. dev.	0.025	0.368	0.945
Training	Mean	0.169	0.190	0.375
	St. dev.	0.008	0.344	0.980
Interaction effects				
Age*Constant	Mean	-1.784*	0.946	0.059
Age*Advisor	Mean	-0.803*	0.450	0.079
Low Educ*Constant	Mean	3.112**	1.376	0.024
Large farm*Transition	Mean	-0.0007*	0.0004	0.068
Prefer Network support*Constant	Mean	-1.848**	0.935	0.048
Prefer Training support*Constant	Mean	-2.480**	0.842	0.008
Training*Constant	Mean	-2.480***	0.842	0.003
Organic Farmer*Health + Env Impact	Mean	-0.026 *	0.015	0.083
Organic Farmer*Advisor	Mean	2.061*	1.067	0.053
Organic Farmer*Training	Mean	2.003*	1.134	0.078
Organic Farmer*Workload - Spread Out	Mean	-3.434**	1.744	0.049
Training Frequency*Health + Env Impact	Mean	0.005**	0.002	0.033
Training Frequency*Constant	Mean	-1.150**	0.430	0.008
Pesticides Env Impact - Belief*Constant	Mean	-1.041*	0.562	0.064
Pesticides Health Impact - Belief*Health + Env Impact	Mean	-0.008 **	0.003	0.024
Pesticides Env Impact - Belief*Const	Mean	-1.041 *	0.562	0.064
Revenue Decrease - Belief*Constant	Mean	1.668*	0.894	0.062
Revenue Increase - Belief*Training	Mean	0.954**	0.403	0.018
Arable Farmer*Advisor	Mean	-1.052 **	0.471	0.026
Arable Farmer*Training	Mean	-0.812*	0.452	0.073
MixedCropandLivestock Farmer*Advisor	Mean	0.821*	0.489	0.093
MixedCropandLivestock Farmer*Network	Mean	0.778*	0.436	0.075
N				660
Log likelihood				-615.47508

Asterisks denote statistical significance at the *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ level.

Figure B.2: Extended RPL model

B.4 Interview guide and representative quotations - qualitative interviews

Note: These questions were a guide for the interviewer to encourage further discussion when necessary, but the respondents were encouraged to express themselves freely and could address any topic they found relevant.

Re-introduction to the study

- Was the survey and the tasks presented to you clear? Could you describe how you felt about the explanatory videos, the questions, and the choice cards that you received?

Topic under study

- The topic of the survey, as mentioned, was on your preferences for agricultural practices and the use of pesticides. Is the topic of change in practices and the use of pesticides a topic that interests you and that concerns you and your farming activities on a regular basis?

Responses in the DCE

- You stated that you think the reduction in the use of pesticides will increase/decrease your revenue, why do you think this is?
- You stated that you were certain/uncertain whether the reduction in the use of pesticides would impact your costs and salary. What makes you certain/uncertain?
- You responded that you think the use of pesticides impacts your health and the environment to a negligible extent/somewhat/to a high extent – do you think this consideration impacts your choice in agricultural practices?
- Do you think the impact on revenue makes it less/more likely that you change practices?

Further discussion on topics addressed in DCE

- Can you tell us about government support for agricultural and alternative practices in France?
- What do you think the government could do to support the farming sector in the transition to alternative practices?

- Are there any measures of support that you would prefer in this transition to alternative practices that could help, such as e.g., training, an advisor, to be part of a network?
- Would an increase in governmental support make you more likely to change practices?
- You stated that you have reduced your pesticide use by ... % / are an organic farmer. How did this reduction impact your day-to-day work and life?
- Does the organisation of your work schedule – whether it will be more condensed or more spread out impact your choice in agricultural practices?
- If you could be sure that your income would increase, after a period of transition of a number of years, would you be more likely to use alternative practices?

Outside views

- Can you tell us about consumer and governmental demand for alternative practices?
- How do you feel about the local/organic food movement?
- Do you think French consumers are aware or care about this movement?

The future of their farms

- What changes do you predict farming in France will see over the next 15 years?
- How have advances in technology such as, machinery, or chemicals, affected your farm or competition with your farm?
- What are your plans for the future of your farm?

B.5 Representative quotes from the semi-structured interviews

Theme 1. Technological uncertainty
Technological hinders to adopting alternative practices:
Dependence on glyphosate
"The main problem, as is the case for all my colleagues, is glyphosate dependence."
"If glyphosate is banned, there is nothing I can do."
"The government has decided to get rid of glyphosate despite farmers saying there is no alternative."
"I want to stick to conservation agriculture by using plant covers. But that can only be done with glyphosate, so I am dependent on it."
"The ban of the use of glyphosate is a disaster because we [as French farmers] will no longer be competitive."
Efficiency of alternatives to pesticides
"Even with increased subsidies, I cannot reduce my use of pesticides any more than I already have. I see no other solution."
"There is no alternative to pesticides that will maintain the current level of production."
Conservation and direct seeding agriculture
"It is not clear how direct seeding farmers can get by without the use of herbicides."
Uncertain environmental impact of pesticides
"I protect myself and respect good practices and in so doing, I minimise the [negative] impact of pesticides - whether that impact is on biodiversity loss or the ecological balance."
"Even with the right equipment, I sometimes notice negative health effects from the pesticides I use."
"I was exposed to pesticides when I was very young, so I want to stop exposing myself to them now so that I can improve the quality of my life."
Workload of alternative practices
"Since I switched to mechanical weeding, my workload has increased significantly. Chemical weeding used to take me 2 days, but now it takes me at least 15 days a year."
"Alternative farming practices are good, but it just takes longer: using a harrow takes longer than using pesticides."
"[Transition] has increased my workload because it involves more monitoring and more observation."
"For me the problem lack of knowledge and experience required. After five years, it is much easier than after the first year."
Theme 2. Economic uncertainty
Transition period:
Impact on income after technological change
"How am I going to make a living when it is expected that we will be making less money during this transition period ? It has to be possible to maintain the farmer's income during the transition period."

"Earning somewhere between 7 and 800 euros per month I cannot afford to reduce my income just to change practices."
"If I have to invest in a big tractor and other machines, I have no income left. A 10% drop in income is inconceivable as I have not been paid for 1.5 years. My balance sheets are in the red."
"I cannot lose money 3 years in a row. Change [to alternative practices] must be valued."
"If farmers are profitable in the system they are currently operating in, they will not change."

Higher market prices for their products

"My main concern is that the efforts made are not valued at the level of their product. I don't want any subsidy or help. I want a remunerative price to make a living from my job."
"An increase in subsidies will not help people to change practices. I prefer price incentives rather than subsidies."

Time needed to change practices

"The time it takes to transition [to alternative practices] is a hinder."
"How am I going to make a living during this transition period when it is expected that we will be making less money"
"We are in a sector where you need transition periods of at least 5 years."
"The time expected to transition to new practices is too quick."

Maintenance of market standards:

Export capacity

"We have more environmental and regulatory constraints than any other country. If glyphosate is banned, we can no longer compete."
"There is an unfair competition with international products."

Product valuation and quality of crops

"To maintain commercial norms, I am forced to use fungicides. Without this I might lose 50 % of my yield and 50 % of the sales price on top of that.
"Consumers do not want to pay [high prices] for their food."
"I have the best yield in my area so I don't need to change practices."

Theme 3. Social uncertainty

Stigmatisation of non-organic farmers:

Media content

"I'm worried on a daily basis that I'll be attacked in the media."
"There is daily pressure – from the government, consumers, and especially the media."
"I have seen societal pressure increase."

Consumer pressure

"Whenever I go out with my pesticide protective gear on I feel like everyone is watching me."
"Societal pressure has increased."

Support in changing practices:

Experience of neighbours and peers

"The first advisor I listen to is my neighbour and innovative peers: it is what is done in the field that is proof of what works."
"It is by talking to farmers that we can find solutions."

"When I changed practices, I did it together with friends and neighbours."
"You have to directly see what works for farmers"."

Training with vested interests

"Agricultural chambers are incompetent. They are only looking to sell their products even when treatment is not necessary. The problem is that training is often provided by them. I don't trust anyone."
"I would prefer scientific support, but not a technical advisor because the latter have commercial training: I would rather partner with scientists."

Theme 4. Governmental uncertainty

Technocratic decision-making:

Disconnect between expectations and reality

"The government is out of touch with reality. Everything is decided in Paris. We need specific policies for each region."
"I have nothing against the government, but they do not know how to deal with people and professions different to them."
"The government is completely disconnected from the reality of farmers because it is led by technocrats, not by people who know what farmers know. The government needs to listen to farmers."
"I would like authorities to come and meet me and listen to me. The government should go directly to farmers that want to progress instead of going to chambers of agriculture or cooperatives."

Trust:

Delayed/unpaid subsidies

"The government is lagging behind. For example, I only received the payments and subsidies that were meant for 2017 today (two years later)."
"I am skeptical of any support from the government."

Unreliable policy future

"I am quite pessimistic about the future of agriculture."
"The future of my farm is very uncertain."

B.6 Explanatory information on the discrete choice experiment provided to respondents

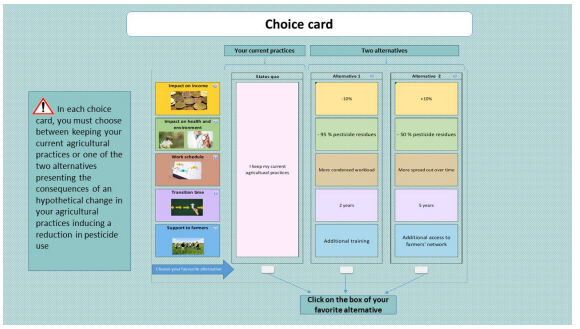

Figure B.3: Presentation of a choice card

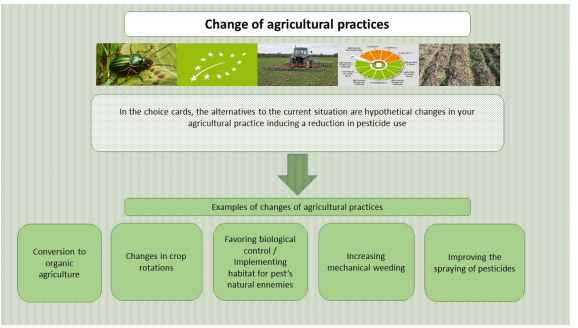

Figure B.4: Examples of changes of agricultural practices

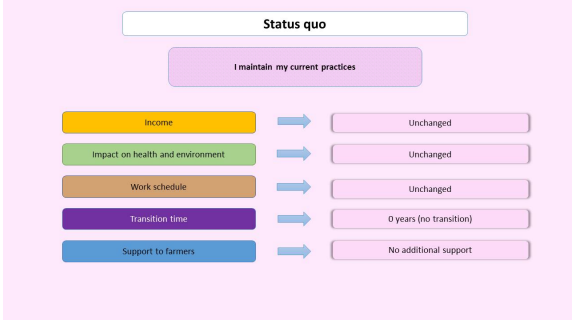

Figure B.5: Presentation of the status quo

Figure B.6: Presentation of what remains unchanged in all alternatives

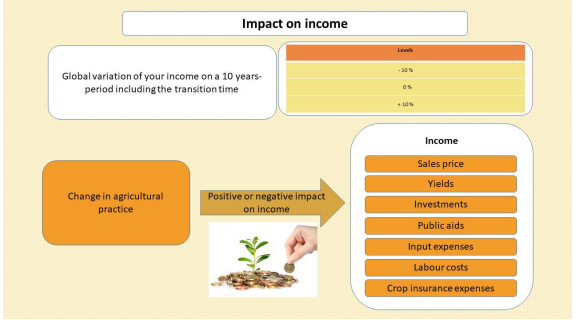

Figure B.7: Income attribute

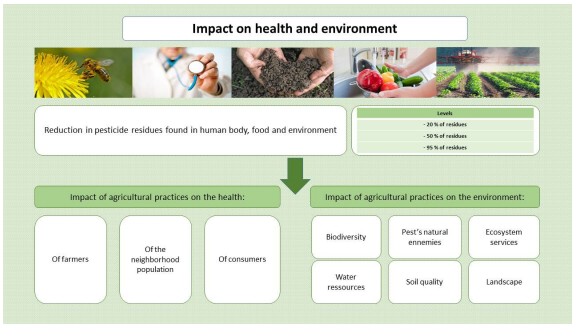

Figure B.8: Impact on health and environment attribute

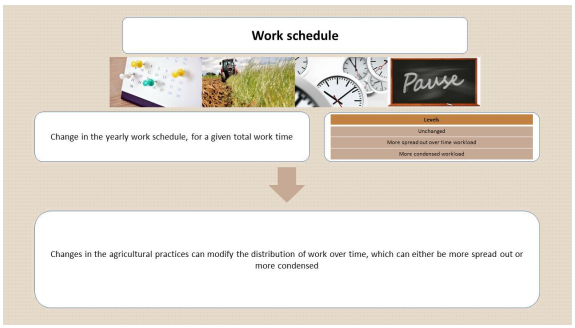

Figure B.9: Work schedule attribute

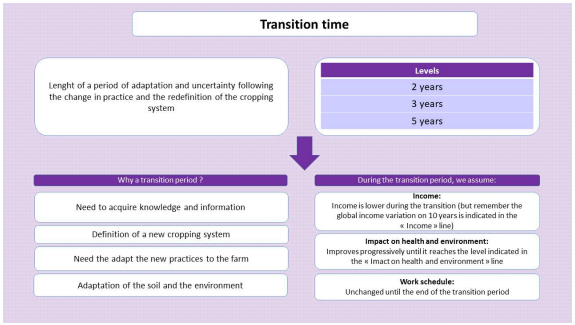

Figure B.10: Transition time attribute

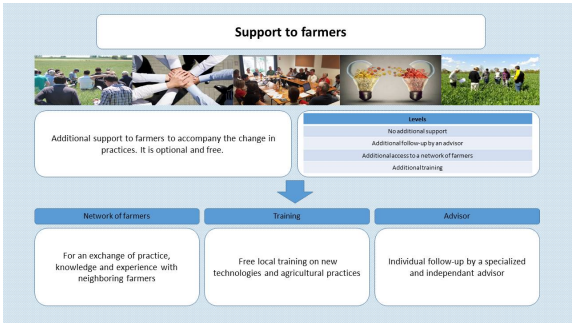

Figure B.11: Support to farmers attribute

Appendix C

Chapter 5

C.1 Experimental design

Experimental design code (Ngene) for status quo € 3:
Design ;alts=alt1*,alt2*,alt3* ;rows=12 ;block=2 ;eff=(mnl,wtp(ref1)) ;wtp=ref1(b2,b3/b1) ;model: U(alt1) = b1[-0.8]*price[-1,-2]+b2.dummy[0.1—0.1—0.1—0.1]*redis[1,2,3,4,0](1-12,1-12,1-12,1-12,0) +b3[0.09]*glypho[-5,-15,-25]/ U(alt2) = b1*price+b2.dummy*redis +b3*glypho

Experimental design code (Ngene) for status quo € 4:
Design ;alts=alt1*,alt2*,alt3* ;rows=12 ;block=2 ;eff=(mnl,wtp(ref1)) ;wtp=ref1(b2,b3/b1) ;model: U(alt1) = b1[-0.8]*price[-1,-2,-3]+b2.dummy[0.1—0.1—0.1—0.1]*redis[1,2,3,4,0](1-12,1-12,1-12,1-12,0) +b3[0.09]*glypho[-5,-15,-25]/ U(alt2) = b1*price+b2.dummy*redis +b3*glypho

C.2 Additional results

Table C.1: Extended random parameters logit model (N=2 050) using 500 Halton draws.

		Coefficients	Standard Errors	p-Values
Price as a log-normal parameter				
Price	Mean	-0.237***	0.043	0.000
Random parameters				
Constant (SQ)	Mean	-2.088***	0.477	0.000
	St. dev.	4.526***	0.174	0.000
Reduction in farmers' use of glyphosate	Mean	-0.001	0.005	0.786
	St. dev.	0.075***	0.004	0.000
Tax revenue earmarked to:				
Environmental programmes	Mean	0.445***	0.118	0.000
	St. dev.	0.404***	0.096	0.000
Health programmes	Mean	0.927***	0.088	0.000
	St. dev.	0.609***	0.105	0.000
Additional support for farmers	Mean	-0.158	0.132	0.232
	St. dev.	0.934***	0.070	0.000
Subject effects				
Age*Constant (SQ)	Mean	0.034***	0.008	0.000
Gender*Environmental programmes	Mean	0.397***	0.095	0.000
Gender*Health programmes	Mean	0.317***	0.107	0.003
Gender*Additional farmer support	Mean	0.527***	0.108	0.000
Education*Environmental programmes	Mean	0.164***	0.050	0.001
Spanish*Constant (SQ)	Mean	1.222***	0.302	0.009
Freq. organic food*Constant (SQ)	Mean	0.059***	0.012	0.000
Freq. organic food*Reduction in glyphosate use	Mean	0.001***	0.000	0.000
Know glyphosate*Constant (SQ)	Mean	1.726***	0.254	0.000
Know glyphosate*Additional farmer support	Mean	0.241***	0.098	0.014
Op. farming sector*Constant (SQ)	Mean	-0.018***	0.002	0.000
Op. farming sector*Additional farmer support	Mean	0.007***	0.002	0.000
N				36 900
Log likelihood				-9193.34
AIC				18442.68
BIC				18681.13

Asterisks denote statistical significance at the *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ level.

Table C.2: Willingness-to-pay estimates (€)

Attribute	Levels	Mean	95 % CI
Reduction glyphosate	75 %	3.50	1.35 ; 5.65
	85 %	3.97	1.53 ; 6.40
	95 %	4.44	1.72 ; 7.16
	100 %	4.67	1.81 ; 7.53
Tax revenue earmarked to:	Environmental programmes	3.96	2.29 ; 5.63
	Health programmes	4.23	2.46 ; 5.99
	Additional farmer support	6.37	4.15 ; 8.59

Calculated based on the main effects RPL model shown in Table 5.4, and the estimates are derived at a 95 % confidence interval (CI) computed with bootstrapping (Hole, 2007)

C.3 Split-sample results

	SQ43				SQ4			
Variables	Mean/Proportion	Std.Dev.	Min	Max	Mean/Proportion	Std.Dev.	Min	Max
Respondents' characteristics								
Age	44.85	15.20	18	70	44.79	14.96	18	70
Gender (F=1)	51.00%				51.00%			
Living in a rural areal	28.40%				33.20%			
Education:								
-Low	23.00%				23.0%			
-Medium	44.00%				44.00%			
-High	33.00%				33.00%			
Household size	2.50	1.25	1	8	2.43	1.19	1	8
Food expenditure per week	97.78	46.93	0	200	93.95	43.21	0	200
Frequency of organic consumption:								
-(Almost) never	30.80%				28.40%			
-1-3 times a month	21.60%				18.40%			
-1 to several times a week	34.40%				36.20%			
-(Almost) every day	13.20%				17.00%			
Respondents' general opinion								
Opinion of farming sector	24.02	43.60	-100	100	23.38	44.89	-100	100
Opinion of farming sector if:								
-Glyphosate/Pesticides use is reduced by 75%	30.14	42.28	-100	100	28.89	43.14	-100	100
-Glyphosate/Pesticides use is reduced by 85%	40.11	43.32	-100	100	37.18	46.18	-100	100
-Glyphosate/Pesticides use is reduced by 95%	53.25	45.31	-100	100	51.95	47.69	-100	100
-Glyphosate/Pesticides use is reduced by 100%	55.52	41.62	-100	100	53.89	41.3	-100	100
Tax revenue earmarked to Health:								
-First priority	10.00%				13.00%			
-Second priority	28.80%				26.20%			
-Third priority	48.60%				44.40%			
-Last priority	12.60%				16.40%			
Tax revenue earmarked to Environment:								
-First priority	23.80%				27.20%			
-Second priority	43.60%				42.80%			
-Third priority	22.80%				22.80%			
-Last priority	9.80%				7.20%			
Tax revenue earmarked to Farmers:								
-First priority	36.40%				35.20%			
-Second priority	19.20%				19.40%			
-Third priority	15.20%				16.60%			
-Last priority	29.20%				28.80%			
Tax revenue earmarked to State:								
-First priority	28.80%				24.60%			
-Second priority	8.40%				11.60%			
-Third priority	13.40%				16.20%			
-Last priority	48.40%				47.60%			
Questions were clear	95.80%				95.20%			
Satisfied with answers	95.20%				93.60%			
Respondents' opinion of Glyphosate/Pesticides								
Had heard of glyphosate before	85.60%				86.40%			
Agree to "Restrictions on Glyphosate/Pesticides":								
-Decrease food prices	5.60%				7.60%			
-Do not impact food prices	10.00%				10.60%			
-Increase food prices	62.00%				64.20%			
-Do not know	22.40%				17.60%			
Agree to:								
-Glyphosate is harmful to health	87.15%				87.04%			
-Glyphosate is harmful to environment	90.42%				88.66%			
-Glyphosate use should be taxed	67.29%				66.66%			
-Glyphosate should be banned	82.48%				80.56%			
Agree to:								
-Pesticides are harmful to health	79.16%				83.83%			
-Pesticides are harmful to environment	81.94%				83.82%			
-Pesticide use should be taxed	56.94%				54.41%			
-Pesticides should be banned	66.67%				60.29%			

Figure C.1: Descriptive statistics of split-sample study (N=1000)

	Price non-random		Price normal		Price log-normal	
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Choice in SQ3	Choice in SQ4	Choice in SQ3	Choice in SQ4	Choice in SQ3	Choice in SQ4
Parameters: mean						
Price	-0.531***	-0.237**	-0.536***	-0.244**	-0.987***	-3.481**
	(0.137)	(0.095)	(0.139)	(0.100)	(0.370)	(1.710)
Constant (SQ: ban on glyphosate)	0.889***	1.172***	0.905***	1.323***	0.844**	1.442***
	(0.288)	(0.339)	(0.290)	(0.301)	(0.351)	(0.335)
Reduction in farmers' use	0.036***	0.011	0.037***	0.015	0.037***	0.018*
	(0.010)	(0.011)	(0.009)	(0.011)	(0.010)	(0.011)
Environmental programs	0.872***	1.364***	0.886***	1.424***	0.901***	1.415***
	(0.140)	(0.150)	(0.142)	(0.157)	(0.144)	(0.156)
Health programs	0.981***	1.404***	0.986***	1.467***	0.998***	1.459***
	(0.138)	(0.156)	(0.138)	(0.164)	(0.141)	(0.163)
Additional support for farmers	1.691***	2.067***	1.719***	2.149***	1.730***	2.132***
	(0.157)	(0.190)	(0.158)	(0.200)	(0.163)	(0.200)
Parameters: standard-deviation						
Price			-0.342	-0.625***	-0.845***	-2.643**
			(0.431)	(0.118)	(0.114)	(1.056)
Constant	5.170***	5.691***	5.273***	5.606***	5.027***	5.551***
	(0.425)	(0.506)	(0.463)	(0.445)	(0.434)	(0.494)
Reduction in farmers' use	0.072***	0.109***	0.069***	0.103***	-0.071***	0.089***
	(0.011)	(0.011)	(0.014)	(0.012)	(0.016)	(0.012)
Environmental programs	-0.987***	-0.576**	0.992***	0.684***	-0.947***	0.639***
	(0.229)	(0.229)	(0.217)	(0.201)	(0.244)	(0.230)
Health programs	-0.764***	0.846***	0.825***	0.904***	-0.837***	0.844**
	(0.253)	(0.214)	(0.239)	(0.213)	(0.241)	(0.210)
Additional support for farmers	-1.448***	1.772***	1.452***	1.813***	-1.451***	1.828**
	(0.168)	(0.208)	(0.161)	(0.208)	(0.178)	(0.211)
Observations	500	500	500	500	500	500
Halton draws	1000	1000	1000	1000	1000	1005
Log-likelihood	-2237.6454	-2123.6955	-2236.937	-2120.8244	-2237.7296	-2119.2991

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure C.2: Results of split-sample study (N=1000)