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Individual decisions to vaccinate one's child or oneself: A discrete choice experiment rejecting free-riding motives

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ABSTRACT

It is essential for public health to understand what drives people's hesitance towards vaccination. Theoretical models of vaccination decisions are ubiquitous, often incorporating herd immunity, perceptions of vaccine-related side-effects (VRSE) and of vaccine-preventable burden of disease, but with little to no empirical exploration. Herd immunity is a (usually) positive externality where vaccinated individuals influence others' risks by their reduced capability to transmit an infectious disease to them. It is often assumed that (rational) individuals incorporate this externality in their strategic vaccination decision, from which free-riding behavior arises. We performed a Bayesian D-efficient discrete choice experiment in February–March 2017 to study vaccination behavior in 1919 Belgian respondents. Choice sets with vaccine profiles were constructed using six attributes: vaccine effectiveness, VRSE, accessibility (in terms of convenience and reimbursement), vaccine-preventable burden of disease, local (respondents' network of contacts) vaccination coverage, and population (the population at large) vaccination coverage. VRSE and accessibility are the most influential attributes, followed by vaccine effectiveness and burden of disease. Both population and local coverage are less important than the other attributes, but show a significant direct linear relationship with vaccine utility. This supports the existence of peer influence (more incentivized as more and more vaccinate), rather than free-riding on herd immunity. These findings were independent of whether respondents made vaccine choices for themselves or for their child. Around 40% of the respondents indicated accepting vaccination with little or no questioning. These 'acceptors' were less sensitive to changes in the vaccine-preventable burden of disease for their child's vaccination choices (but not for themselves). Public health institutions are critical in stimulating vaccine uptake by making vaccines conveniently available at an affordable price and by communicating pro-actively on perceived VRSEs. The free-riding assumption as a driver of individual vaccine decisions, seems inappropriate, but this observation needs confirming in other populations.

1. Introduction

Infectious disease prevention is increasingly challenged by globalization (Hufnagel et al., 2004). Not only pathogens spread globally in a matter of days through ever-increasing human mobility (Morse, 2001), but vaccine scares and hesitancy can propagate even faster via social media (Salathé et al., 2013; Larson et al., 2011). The communicability of both infections and rumors undermine hard-fought investments to prevent, control and eradicate infectious diseases (Larson et al., 2016). Hence, understanding individual vaccination decisions is highly relevant for policy-makers and vaccine program managers in order to anticipate and respond to drops in vaccination coverage. Empirical information on how individuals decide about vaccinating themselves or their children is however lacking (Verelst et al., 2016; Funk et al., 2015).

Yielding uncertain benefits in the future, prevention differs fundamentally from cure. People do not know upfront when (or if) they will contract a preventable disease. Other vaccine-specific aspects further complicate an individual's decision to accept vaccination (Corben and Leask, 2016). Widespread vaccination yields (mostly positive) externalities through herd immunity (Fine et al., 2011). Herd immunity - the indirect protection of unvaccinated people in a largely vaccinated population - provides a safety net for those who cannot receive vaccination for medical reasons (e.g. too young, immunocompromised,

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pregnant), those who deliberately reject or delay vaccination or those who are not or no longer immunized by the vaccine they received. Some theoretical models assume herd immunity is incorporated by individuals in their vaccination decision, implying many individuals are assumed to deliberately free-ride on others' vaccination (eg, (Barbagallo and Cojocaru, 2010; Zhang, 2013; Schimit and Monteiro, 2011), see (Verelst et al., 2016) for a systematic review). Though rarely discussed, it remains unresolved whether herd immunity contributes more to vaccine acceptance through altruistic motives (to protect the vulnerable) than to rejection or hesitance through free-riding motives (Quadri-Sheriff et al., 2012; Skea et al., 2008; Vietri et al., 2012). Moreover, vaccination is to a certain extent victim of its own success. Regions with high vaccination coverage experience less vaccine-preventable disease (VPD) burden, and when this occurs over a long period, the need for high coverage vaccination may be questioned to the extent that large VPD outbreaks occur until coverage rises again (Zipprich et al., 2015).

Discrete choice experiments (DCEs), which are well-established in health economics (Clark et al., 2014; de Bekker-Grob et al., 2012), have been used before to elicit preferences for vaccines (Sadique et al., 2013; de Bekker-Grob et al., 2010; Hall et al., 2002; Bishai et al., 2007; Determann et al., 2014; Oteng et al., 2011; Gidengil et al., 2012), but none of these compared adults' vaccine choices for themselves with those for their children, and only one investigated free-riding motives (Hall et al., 2002).

In Belgium, the administration of childhood vaccines up to age 15 months is organized at the regional level through well-baby clinics, which are attended by about 70% of infants (KindGezin, 2015). During five vaccination consults, these infants receive up to 13 vaccine doses (jabs and oral intakes combined) against 12 pathogens. Only poliomyelitis vaccination is mandatory in Belgium. Most recommended vaccines are available on site for free. Only the oral rotavirus vaccine requires parents to first get a prescription, buy the vaccines at the pharmacy (co-payment of 11.90 euro per dose), and take the vaccine to the well-baby clinic or general practitioner (GP) for its administration. School-age children are vaccinated through a regional-level institution of school nurses and physicians. In general, vaccination coverage of recommended vaccines (i.e. in the basic immunization schedule) in children is stable and high (92.9–96.2%) (Vandermeulen et al., 2017). Despite the above practical hurdles and personal costs, even rotavirus vaccine coverage attained 89.7% in Flanders, the Dutch speaking part of Belgium (Vandermeulen et al., 2017). As such, the Flemish population remained up till now largely indifferent to vaccine controversies (Larson et al., 2016; Vandermeulen et al., 2017), except for some clusters of susceptibles interfering with measles elimination (e.g. measles outbreak linked to an antroposophic school (Braeye et al., 2013)). Nonetheless, an understanding of the individuals' "vaccination blackbox" is important to inform simulation models, and to guide policy-makers in case of spill-overs of vaccine hesitancy or refusals from other countries (Larson et al., 2016; Hanley et al., 2015; Peretti-Watel et al., 2013).

Flemish adults are familiar with vaccination decisions as well. More specifically, they are familiar with seasonal influenza vaccine (recommended for risk groups and elderly), booster doses for tetanus, diphtheria and acellular pertussis (Tdap) every 10 years (with additional recommendations for future parents) and travel vaccinations such as typhoid fever, yellow fever and hepatitis A. Pneumococcal and shingles vaccines are licensed for adults, though the uptake remains low. Tdap is offered for free and is available at the vaccinator, while others require a subscription or a visit to the pharmacy or travel clinic (Belgisch Centrum).

In this paper we explore determinants of Flemish individuals' decision-making on vaccination by means of a DCE. As such, the decision-making process is represented as a multi-criteria decision in which we can determine the importance individuals assign to each attribute. We discuss the relevance of our findings for modeling and vaccine policy-making.

2. Methods

We conducted a survey among Flemish-Dutch speaking Belgian inhabitants in February–March 2017, recruiting respondents from a registered consumer panel. Multiple techniques guaranteed a high-quality panel, such as consistency checks, mobile phone ID verification and the identification of 'straight-liners' (respondents answering the same for each question) and 'speeders' (respondents completing the survey much faster than a reference time). Only one respondent per household could take part. Participation was incentivized through credit rewards, transferable into coupons, airline miles, etc. No physical samples were collected and the ethical committee of the Antwerp University Hospital (UZA) approved the study protocol.

A representative sample was drawn in terms of gender, age group and province with Flemish-Dutch native speakers. Respondents filled out the survey for themselves or for their youngest child (< 18 years), which we distinguish as the 'adult' and 'child' group, respectively. Demographic and household info was used to include and assign panel members until the sample quota were reached (Table 2). In total, 1919 panel members completed the full survey through a web-link directing them to an online version of the questionnaire. We surveyed 1091 respondents in the adult group and 828 in the child group. The participation rate was 88% (in a multi-source, routed environment with efficient participant allocation), implying 12% of respondents started but chose not to complete the survey. Other respondents completed the full survey or were dropped out automatically, when pre-defined sample quota were reached.

2.1. DCE attributes

The construction of choice sets with vaccine profiles by means of attributes is a trade-off between completeness and cognitive feasibility. We retrieved relevant elements from the literature (Determann et al., 2014; Oteng et al., 2011; Bults et al., 2011; Luyten et al., 2015; Brunson, 2013; Funk et al., 2010; Brown et al., 2012), departing from systematic reviews (Verelst et al., 2016; Quadri-Sheriff et al., 2012) in order to make vaccine profiles and to match attributes to the parameterization of vaccine-decision models. Attributes were then ranked and categorized through a focus group discussion. Final selection and tuning of relevant attributes occurred through a pilot study with free-form feedback, followed by a soft launch in the study population with respondent feedback scoring. Feedback from the focus group and the pilot study resulted in a reduced number of attributes (from 8 to 6) and an adapted DCE design with only 10 choice sets (instead of 15) of two vaccine profiles. Feedback from the respondents of the soft launch confirmed feasibility of the DCE with an average score of 8.1/10 based on survey length and experience (survey company tool). The details of the attribute and attribute level selection are displayed in Fig. 1. Table 1 lists the final attributes and corresponding levels, the rationale of which can be summarized as follows:

1. Vaccine effectiveness is described as the proportion of vaccinated persons protected by the vaccine and has two levels: 50% and 90%. These levels were chosen to represent vaccines with moderate effectiveness, such as seasonal influenza vaccination (CDD, 2017; Kelly et al., 2009) and high effectiveness, such as hepatitis B (Szmuness et al., 1981) and measles (Sudfeld et al., 2010) vaccination.
2. Burden of disease is a combination of disease prevalence and severity. Both these sub attributes have two levels, implying four levels describe the burden of disease attribute: rare/common and mild/severe (see Table 1). Mild/severe disease is further specified as hospitalization occurring exceptional/often and being not life-threatening/life-threatening. We chose two extreme levels for both

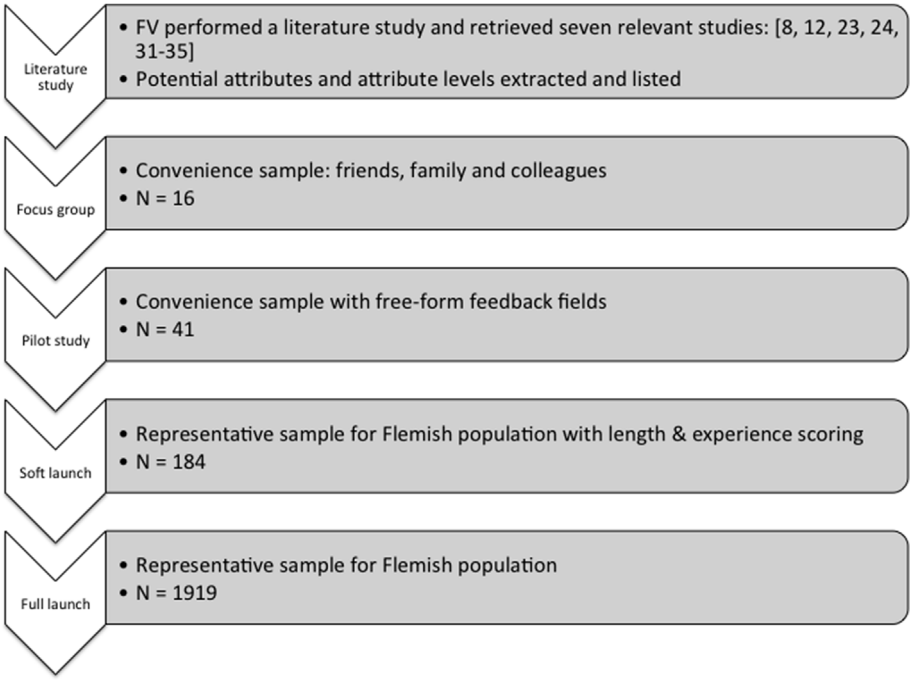

Fig. 1. Flow chart representing the selection and tuning of DCE attributes and attribute levels.

prevalence and severity to facilitate the choice task. Our pilot study validated the feasibility of this four level representation, with no reported interpretative difficulties.

3. VRSE are described by two possible levels: common and rare. The focus group discussion and cognitive feasibility considerations led us to represent risk of vaccination by frequency rather than severity of VRSE.
4. Accessibility was included as an attribute to represent practical hurdles of vaccine administration, represented by broad reimbursement policy and time cost. We defined two levels based on current vaccination practice in Flanders: 'The vaccine is provided for free and available at the vaccinator… ' versus 'The vaccine is not reimbursed and is only available with a prescription'. The first represents most current universal childhood vaccinations, such as Tdap vaccination. Without naming them, the latter describes non- or partially reimbursed vaccines (depending on target group), such as rotavirus vaccine, seasonal influenza vaccine, or travel vaccines against hepatitis A, tick-borne encephalitis or typhoid fever, and many new vaccines when they first enter the market.
5. Local coverage was specified as 30%, 60% and 90% of close acquaintances (friends and family) already being vaccinated. In the absence of previous explorations of this attribute, we retained the above specific description based on (1) the focus group study, confirming attribute importance in vaccine decisions, and (2) the pilot study where respondents indicated they clearly understood the attribute and different levels. We also intended to quantify to which extent individuals adhere varying degrees of importance to local and population coverage as a main driver for vaccination choices, as often assumed in vaccine-decision models (Verelst et al., 2016; Funk et al., 2010).
6. Population coverage, i.e. vaccination coverage in the intended target group, was also included as an attribute.

2.2. Survey

The four-part questionnaire probed for background characteristics, vaccine-related attitudes, the DCE-preferences and risk perceptions on infectious diseases and vaccination. We circumvented disease- or

Table 1
DCE attributes and levels.

Attribute	Level description
1. Vaccine effectiveness	a) Protects **50%** of vaccinated b) Protects **90%** of vaccinated
2. Burden of disease	a) The disease, against which the vaccine protects is **rare** and often **mild**: hospitalization is exceptional and the disease is not life-threatening b) The disease, against which the vaccine protects is **rare** and often **severe**: often with hospitalization and the disease is life-threatening c) The disease, against which the vaccine protects is **common** and often **mild**: hospitalization is exceptional and the disease is not life-threatening d) The disease, against which the vaccine protects is **common** and often **severe**: often with hospitalization and the disease is life-threatening
3. VRSE	a) Side-effects are **common** b) Side-effects are **rare**
4. Accessibility	a) The vaccine is provided for **free** and **available at the vaccinator** (GP, well-baby clinic, school- or occupational physician) b) The vaccine is **not reimbursed** and is **only available with a prescription**
5. Local coverage	a) **30%** of your acquaintances (friends and family) is already vaccinated b) **60%** of your acquaintances (friends and family) is already vaccinated c) **90%** of your acquaintances (friends and family) is already vaccinated
6. Population coverage	a) **30%** of the population in general is already vaccinated b) **60%** of the population in general is already vaccinated c) **90**% of the population in general is already vaccinated

Table 2
Comparison of sample characteristics with pre-defined sample quota and population characteristics.
Source for Flemish population rates: Algemene Directie Statistiek - Statistics Belgium: http://statbel.fgov.be/nl/statistieken/cijfers/bevolking/, retrieved on May 16, 2017.

Characteristic	Adult group (%)	Child group (%)	Predefined quota (%)*	Sample (%)	Flemish population (%)
Gender					
Male	55	46	50	51	49
Female	45	54	50	49	51
Age group					
18-34	23	35	25	28	26
35-49	15	50	25	30	25
50-64	27	14	25	21	26
65-85	35	1	25	20	22
Educational attainment					
Low	5	3	NA	4	25
Medium	50	48		49	41
High	45	47		46	34
Other	0	1		1	
Province					
Antwerp	31	29	28	30	28
Limburg	14	14	13	14	13
East Flanders	23	24	23	23	23
West Flanders	16	17	18	17	18
Flemish Brabant	14	13	17	13	17
Brussels	2	1		2	
Other	1	1		1	
Sample size	**N = 1091**	**N = 828**	**N = 1500**	**N = 1919**	

*Pre-defined quota were made on the full sample in absolute numbers (e.g. minimum 375 respondents aged between 65 and 85). Another pre-defined sample characteristic was a 70/30 ratio of child group respondents with their youngest child between [0–11] and (Schimit and Monteiro, 2011; Quadri-Sheriff et al., 2012; Skea et al., 2008; Vietri et al., 2012; Zipprich et al., 2015; Clark et al., 2014; de Bekker-Grob et al., 2012) years respectively.

vaccine-specific sentiments by not specifying (e.g. naming) an infectious disease until the fourth part on risk perception. The questionnaire was developed and honed through literature (Bults et al., 2011; Luyten et al., 2015), focus group discussion and a pilot study. The survey started with a general introduction, the questionnaire's outline and its estimated time to completion (20 min). Individuals were sampled employing a routing environment with efficient allocation of the respondents.

Background characteristics were derived on gender, age, ZIP code, educational attainment, job status, family situation, family size, age of youngest child, mother's country of birth, professional experience in the health care sector, experience with severe illness, experience with seasonal influenza vaccination, smoking status and religion. Respondents were then assigned to the adult or child group in accordance with our quota. Unconditional assignment to the adult group was performed until sample quota (based on the total sample) were reached, but to the child group assignment was conditional on parenting a child under the age of 18 at the time of recruitment. Parents of children under 18 were not excluded from the adult group. From this point onwards, child group respondents were instructed to fill out the questionnaire making hypothetical vaccine decisions regarding their youngest child. Adult group respondents filled out the questionnaire making these decisions for themselves. Background characteristics were tested as covariates with the DCE estimates to examine preference heterogeneity.

Vaccine attitudes were surveyed by means of 13 statements about vaccination sentiments and habits on a five-point Likert scale. We displayed these statements sequentially to minimize nonresponse (Liu and Cernat, 2016). Vaccine attitudes were tested as covariates with the DCE estimates to examine preference heterogeneity.

The DCE started with a general description and an illustrative example of a simplified choice set to familiarize the respondents with the choice tasks ahead. We then used 10 choice sets of two partial profiles each. Partial profiles vary the levels of only a subset of the attributes to limit cognitive burden (Kessels et al., 2011a; Chrzan, 2010). We presented three attributes with varying levels and three with constant levels (see Fig. 2). For each choice set, respondents indicated which vaccine profile they were most inclined to choose. Similar to several previous DCEs (Luyten et al., 2015; Kessels et al., 2011a, 2015a, 2015b; Cuervo et al., 2016), the evaluation of the choice sets was made easier and clearer by marking the varying attributes in yellow. However, we explicitly instructed respondents to also consider the constant, non-yellow attributes and to compare all the attributes jointly for a given profile. This helps preventing respondents imagining levels for the constant attributes, which improves the validity of the preference estimates (Dellaert et al., 2012) and enables estimating interaction effects.

In addition to the main effects of the attributes, we aimed to estimate all two-way interactions between the attributes 'vaccine effectiveness', 'VRSE' and 'accessibility'. To guarantee that these preference

Vaccine A	Vaccine B
Protects 50% of vaccinated individuals	Protects 50% of vaccinated individuals
The infectious disease, against which the vaccine protects is rare and often mild: hospitalization is exceptional and the disease is not life-threatening	The infectious disease, against which the vaccine protects is rare and often mild: hospitalization is exceptional and the disease is not life-threatening
Side-effects are rare	Side-effects are frequent
The vaccine is not reimbursed and is only available with a prescription	The vaccine is not reimbursed and is only available with a prescription
60% of your acquaintances (friends and family) is already vaccinated	30% of your acquaintances (friends and family) is already vaccinated
30% of the population in general is already vaccinated	90% of the population in general is already vaccinated
○	○

Fig. 2. Example of a choice set in the DCE, consisting of 2 vaccine profiles based on 6 attributes. The attributes with differing levels between the two vaccine profiles are displayed in yellow. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

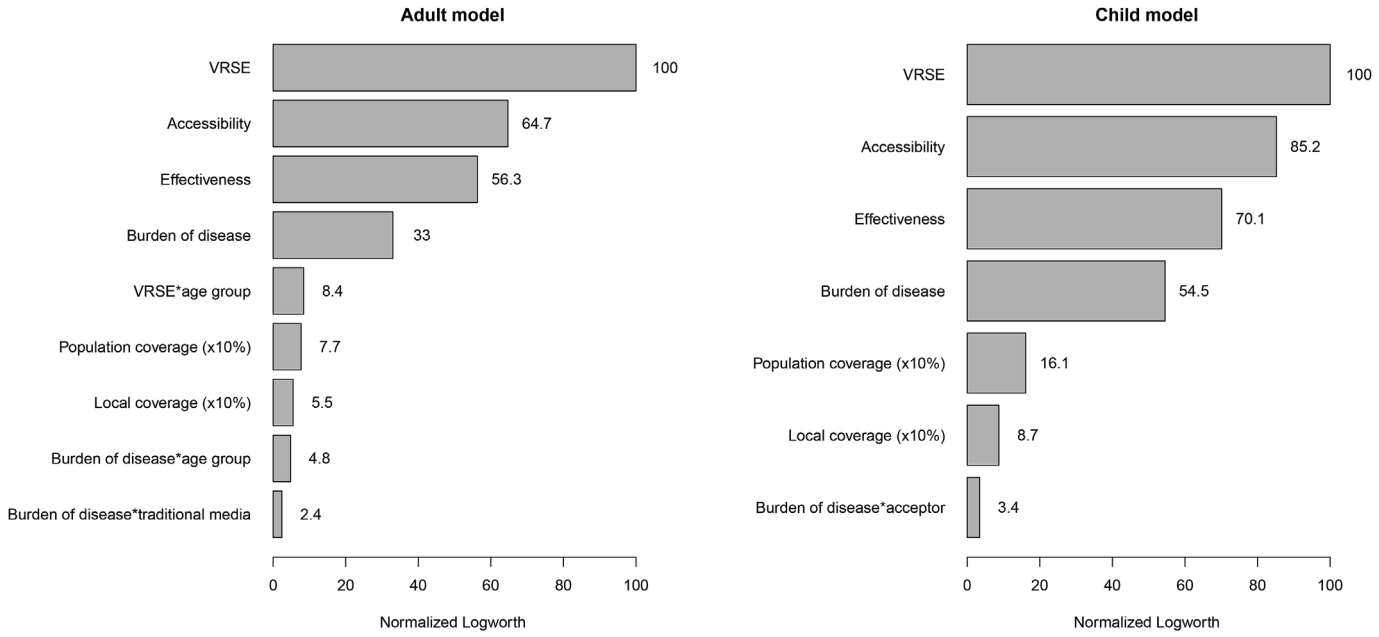

Fig. 3. Importance of the main and interaction effects of the six attributes in the panel mixed logit model relative to the most important attribute 'VRSE'.

parameters could be estimated with maximal precision, we opted for a partial profile design that is D-optimal (as measured by the log-determinant of the information matrix) for the basic multinomial logit (MNL) model (Kessels et al., 2011b). Because there are 34 model terms (10 main and 24 interaction effects), we constructed a sufficiently large design of 50 choice sets and divided it into five survey versions of 10 choice sets (Appendix A), about evenly presented to respondents. The three varying attributes in the design differ between choice sets. For each survey we determined them using the attribute balance approach that, for the given design dimensions, comes down to a balanced incomplete block design that enables each attribute to vary in exactly five choice sets and each pair of attributes in exactly two choice sets (Kessels et al., 2011a).

The D-efficient partial profile design in Appendix A is Bayesian because it includes prior knowledge. For example, the design assumes that 90% is favored over 50% vaccine effectiveness and that VRSE are desired to be rare rather than common. For all attributes, we similarly ranked the levels in order of expected importance. Based on literature (Determann et al., 2014; Oteng et al., 2011; Bults et al., 2011; Luyten et al., 2015; Brunson, 2013; Funk et al., 2010; Brown et al., 2012) and discussion, we also made a prior ranking of attributes. Table 1 displays the attributes and their levels in the resulting descending order of priority. We expressed our uncertainty regarding these a priori rankings in a prior multivariate normal distribution (Appendix B). A Bayesian D-efficient design maximizes the information content of the DCE when averaged over that prior distribution. This state of the art approach generally leads to the smallest possible standard errors in model estimation at the smallest sample sizes (Kessels et al., 2011b; Bliemer and Rose, 2010; Rose and Bliemer, 2013). We chose to generate a Bayesian D-efficient design for the MNL model because Bliemer and Rose (2010) have shown that such a design also performs well for the precise estimation of the more sophisticated panel mixed logit (PML) model, which we used for our main analysis.

Risk perception questions were adapted from Bults et al. (2011) inquiring about the perceived relative severity and susceptibility of measles compared to influenza, leukemia and bladder infection. The respondent's relevant sources of information, and knowledge about VRSE of the measles-mumps-rubella (MMR) vaccine were also queried. Risk perception responses were tested as covariates with the DCE estimates to examine preference heterogeneity.

2.3. Data analysis

To determine the relative importance of the attributes and attribute levels, we estimated for both the adult and child group a PML model using the Hierarchical Bayes (HB) technique in the JMP 13 Pro Choice platform (based on 10,000 iterations, with the last 5000 used for estimation). For each model we assumed normally distributed preference parameters without correlation between attributes. These random parameters accommodate unobserved heterogeneity in the respondents' preferences.

The average utility function of the adult and child group is the sum of the average values of the attributes' main and interaction effects. We computed the overall significance of the attributes using likelihood ratio (LR) tests and measured the relative importance of the attributes by the logworth statistic, i.e. $-\log_{10}$ (p-value of the LR-test). We started our analysis by estimating the a priori PML model for each group, i.e. the model with the attributes' main effects and all two-way interactions between 'vaccine effectiveness', 'VRSE' and 'accessibility'. Next, we dropped the insignificant model terms until we obtained two final models in which all effects had significant explanatory value at the 5% level. We explored the presence of observed preference heterogeneity (i.e. structural differences in the parameters by different respondent groups) by estimating interaction terms one by one, based on background characteristics, vaccine attitudes and risk perception questions. Finally, we tested the (individually significant) covariates in a joint model, dropping the insignificant ones until only significant covariates remained.

3. Results

The bar charts in Fig. 3 show the relative importance of the attributes' significant main effects and interactions with respondent covariates. All six attributes are statistically significant, but none of the anticipated two-attribute interactions are significant. The bar charts express the logworth statistic of each of the significant model terms relatively to the logworth statistic of 'VRSE', which is the most important attribute in both the adult and child model. For the two models, 'VRSE' is followed by 'accessibility', 'vaccine effectiveness' and 'burden of disease'. Lastly, the local and population coverage attributes are statistically significant, but with limited effect on decision-making.

Table 3
Panel mixed logit model estimates (means and standard deviations) and significances of the attribute effects obtained from likelihood ratio (LR) tests. Adult Model.

Term	Mean estimate (std dev; subject std dev)	LR Chi-square	DF	P-value
VRSE				
Common	−0.563 (0.023; 0.058)	640.612	1	< 0.0001
Rare	0.563			
Accessibility				
Co-payment & prescription	−0.410 (0.023; 0.058)	412.568	1	< 0.0001
Free & accessible	0.410			
Vaccine effectiveness				
50%	−0.487 (0.023; 0.075)	358.211	1	< 0.0001
90%	0.487			
Burden of disease				
Rare & mild	−0.423 (0.042; 0.070)	218.655	3	< 0.0001
Common & mild	−0.313 (0.042; 0.049)			
Rare & severe	0.204 (0.040; 0.034)			
Common & severe	0.532			
VRSE*age group				
Common*[18–34]	0.215 (0.028; 0.044)	57.915	3	< 0.0001
Common*[35–49]	0.022 (0.035; 0.051)			
Common*[50–64]	−0.133 (0.033; 0.051)			
Common*[65–85]	−0.104			
Rare*[18–34]	−0.215			
Rare*[35–49]	−0.022			
Rare*[50–64]	0.133			
Rare*[65–85]	0.104			
Population coverage (x10%)	0.055 (0.007; 0.044)	45.431	1	< 0.0001
Local coverage (x10%)	0.047 (0.008; 0.040)	31.638	1	< 0.0001
Burden of disease*age group				
Rare & mild*[18–34]	−0.161 (0.061; 0.089)	48.614	9	< 0.0001
Rare & mild*[35–49]	−0.001 (0.083; 0.094)			
Rare & mild*[50–64]	−0.081 (0.081; 0.074)			
Rare & mild*[65–85]	0.228			
Common & mild*[18–34]	−0.096 (0.060; 0.074)			
Common & mild*[35–49]	0.073 (0.068; 0.070)			
Common & mild*[50–64]	−0.134 (0.050; 0.067)			
Common & mild*[65–85]	0.157			
Rare & severe*[18–34]	0.105 (0.055; 0.056)			
Rare & severe*[35–49]	−0.107 (0.076; 0.055)			
Rare & severe*[50–64]	0.053 (0.059; 0.050)			
Rare & severe*[65–85]	−0.051			
Common & severe*[18–34]	0.152			
Common & severe*[35–49]	0.029			
Common & severe*[50–64]	0.162			
Common & severe*[65–85]	−0.343			
Burden of disease*traditional media				
Rare & mild*not selected	0.126 (0.033; 0.054)	17.930	3	0.0005
Rare & mild*selected	−0.126			
Common & mild*not selected	0.044 (0.034; 0.049)			
Common & mild*selected	−0.044			
Rare & severe*not selected	−0.024 (0.044; 0.032)			
Rare & severe*selected	0.024			
Common & severe*not selected	−0.146			
Common & severe*selected	0.146			

Note: Mean estimates corresponding to the last level of an attribute, either as a main effect or involved in an interaction, are calculated as minus the sum of the estimates for the other levels of the attribute.

There are three significant covariate terms in the adult model and one in the child model.

3.1. Adult model

'VRSE' is about 40% more important than 'accessibility' and 'vaccine effectiveness', and three times more important than 'burden of disease'. Table 3 presents the PML model estimates for the adult group. A positive marginal utility indicates a more preferable vaccine profile. For instance, the marginal utility for rare VRSE is 0.563, and −0.563 for common VRSE. Hence, the most favored vaccine profile has the following characteristics (ranked according to the logworth statistic): rare side-effects, free & accessible at the vaccinator, 90% protective effectiveness, prevents common & severe disease, with its population and local coverage at their highest level. Note that the coverage attributes are treated in a linear manner, such that a 10% rise in local vaccination coverage is associated with a 0.047 utility increase. The maximum attribute utility is reached when 100% of the person's acquaintances is vaccinated (yielding a marginal utility of 0.47). Hence, a vaccine that is already used at high levels of coverage, is preferred to a vaccine for which coverage is low. The marginal utility of the burden of disease attribute levels can be ranked as follows (from least to most desirable level): rare & mild, common & mild, rare & severe and common & severe, indicating that disease severity is more influential than disease prevalence in assigning a preference to a vaccine profile.

There are three significant covariate effects in the adult model. First, respondent's age interacts significantly with the VRSE attribute (Fig. 4a). The impact of VRSE variation on the marginal utility is lower for respondents in the youngest age group [18-34] compared to those in older age groups. The [50-64] age category is the most risk-averse for side-effects: their marginal utility of common VRSE is −0.696 compared to −0.348 for the [18-34] age group. Note that with its larger

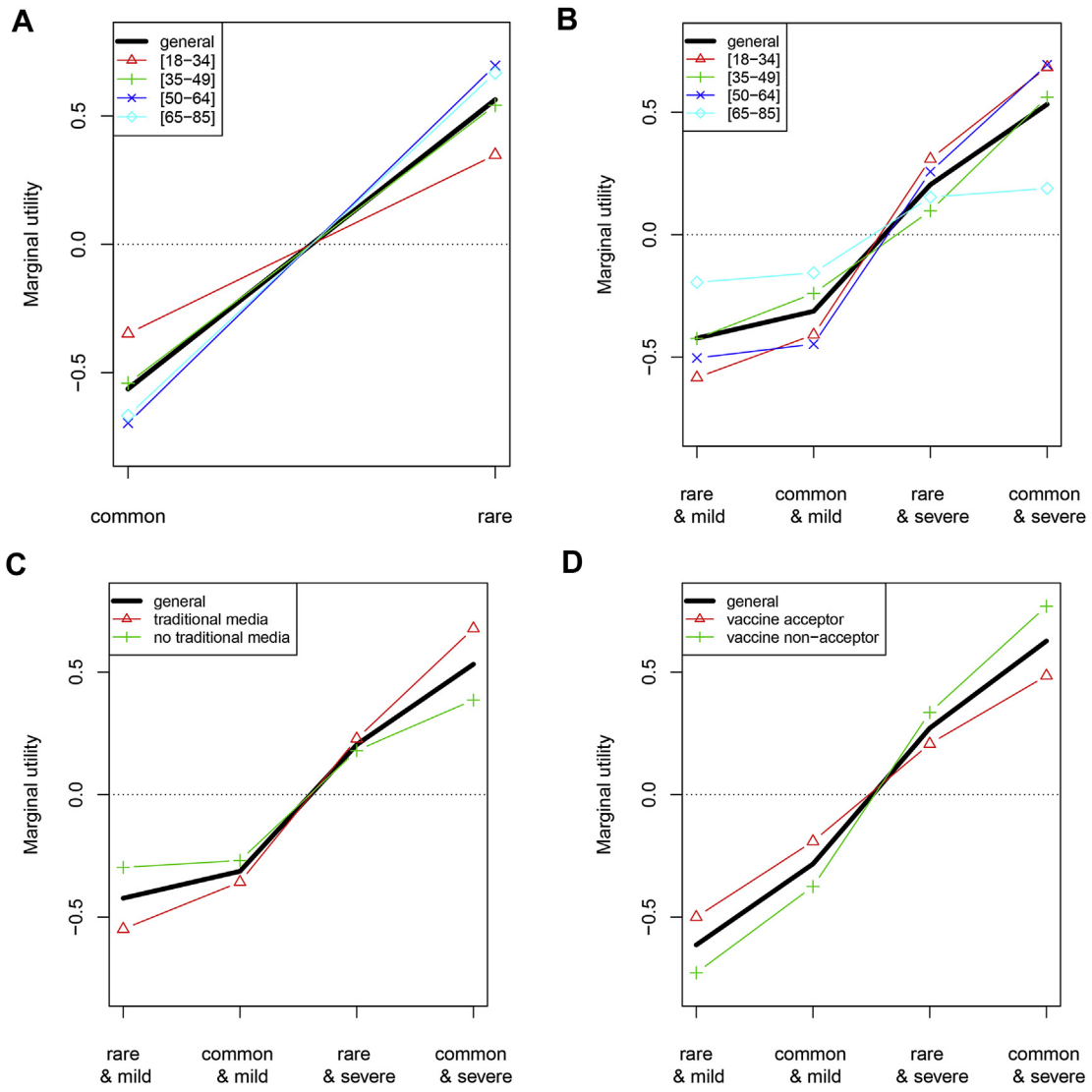

Fig. 4. Marginal utilities for the significant covariate interaction terms: a), b) and c) represent the three covariate terms in the adult model, and d) represents the single covariate term in the child model.
a) Adult model. VRSE and age group.
b) Adult model. Burden of disease and age group.
c) Adult model. Burden of disease and traditional media as information source.
d) Child model. Burden of disease and agree or disagree with acceptor statement.

logworth statistic (see Fig. 3: 8.4 vs 7.7 and 5.5), this interaction can be considered more important than the two main effects attributes on coverage.

Second, respondent's age is also significant with the burden of disease (Fig. 4b). The oldest age group is the most risk-averse, in the sense that they prefer a vaccine against rare & mild disease, more than younger age groups do. By contrast, younger respondents express greater utility when the burden of disease is large (common & severe) than the oldest respondents do. Overall, Fig. 4b shows that differences in burden of disease levels have less impact on individuals' utility in the oldest age group [65–85] compared to younger age groups.

The third covariate interaction effect is between the burden of disease attribute and the (non-) selection of 'traditional media' as a source of information (Fig. 4c). Individuals who use traditional media are less in favor of a vaccine that protects against rare & mild disease, compared to individuals not using traditional media as an information source on infectious diseases and vaccination. However, when the vaccine preventable disease burden is greater, the traditional media subgroup are more in favor of the vaccine. For intermediate levels of the disease burden, the two subgroups have similar preferences.

3.2. Child model

Similar as in the adult model, VRSE, accessibility, vaccine effectiveness, and burden of disease are the most important considerations in the decision-process on childhood vaccination (see Fig. 3 and Table 4). Although the population and local coverage attributes are more important than in the adult model, they remain less important than the other attributes, and the ordering of main attributes is unaffected. Side-effects are considered about twice as important as burden of disease, and accessibility is considered to be the second most important attribute. Again, more utility is attached to severity compared to frequency of occurrence in the burden of disease attribute.

The interaction between burden of disease and being an 'acceptor' is the only significant covariate term in the child model (see Fig. 4d). An acceptor is defined as a respondent indicating 'strongly agree' or 'agree' (5-point Likert scale) on the statement: 'I do not question vaccination, it's just something I do when it is offered to me'. Differing levels of the

Table 4
Panel mixed logit model estimates (means and standard deviations) and significances of the attribute effects obtained from likelihood ratio (LR) tests. Child Model.

Term	Mean estimate (std dev; subject std dev)	LR Chi-square	DF	P-value
VRSE				
Common	−0.516 (0.027; 0.118)	452.542	1	< 0.0001
Rare	0.516			
Accessibility				
Co-payment & prescription	−0.447 (0.026; 0.155)	384.639	1	< 0.0001
Free & accessible	0.447			
Vaccine effectiveness				
50%	−0.519 (0.034; 0.121)	315.617	1	< 0.0001
90%	0.519			
Burden of disease				
Rare & mild	−0.614 (0.052; 0.090)	255.510	3	< 0.0001
Common & mild	−0.283 (0.036; 0.103)			
Rare & severe	0.271 (0.041; 0.045)			
Common & severe	0.627			
Population coverage (x10%)	0.077 (0.009; 0.053)	69.391	1	< 0.0001
Local coverage (x10%)	0.058 (0.008; 0.052)	35.822	1	< 0.0001
Burden of disease*acceptor				
Rare & mild*agree	0.114 (0.041; 0.168)	18.069	3	0.0004
Rare & mild*disagree	−0.114			
Common & mild*agree	0.092 (0.037; 0.116)			
Common & mild*disagree	−0.092			
Rare & severe*agree	−0.064 (0.038; 0.046)			
Rare & severe*disagree	0.064			
Common & severe*agree	−0.142			
Common & severe*disagree	0.142			

Note: Mean estimates corresponding to the last level of an attribute, either as a main effect or involved in an interaction, are calculated as minus the sum of the estimates for the other levels of the attribute.

burden of disease have a smaller impact on the marginal utility of 'acceptors' compared to 'non-acceptors'. For instance, the marginal utility in the case of a common & severe (rare & mild) disease is 0.485 (−0.500) for 'acceptors' compared to 0.769 (−0.728) for 'non-acceptors'.

4. Discussion

Our study confirms that the decision to vaccinate or not is made by trading off different attribute levels, i.e. it is a multi-criteria decision (Hall et al., 2002). VRSE are pivotal in this process. Rapid dissemination of VRSE misperceptions, through social or traditional media (Salathé et al., 2013) can undermine vaccination programs. In addition to continuously providing scientific evidence to counter VRSE misperceptions, health policy institutions and program managers are instrumental in achieving and sustaining high vaccination coverage, by making vaccines as accessible as possible. Indeed, accessibility - inversely related to the opportunity costs (in terms of both time and money) faced by an individual to receive vaccines - as well as effectiveness and disease burden are important determinants of whether or not people become vaccinated. The fact that people are more inclined to demand vaccination when a disease becomes more prevalent supports the idea of a behavioral feedback mechanism. That is, as the prevalence of a vaccine preventable infectious disease increases, more and more people become vaccinated. Through the success of vaccination, the incentives to get vaccinated, along with disease prevalence, decrease to the point where they no longer outweigh perceived VRSE, and the cycle starts all over again. However, the (perceived) severity of disease leads to a larger gain in vaccine utility than disease prevalence does. This finding is supported by Sadique et al. (2013), who performed a DCE in 369 UK mothers, and found that severity of disease exerted an important influence on vaccination demand, in contrast to frequency of disease, that was found not to be significant. We estimated both models with a decomposition of the burden of disease into severity of disease (severe/mild) and frequency of disease (common/rare), and found no substantial differences in results from using the joint attribute (Appendix C). While also significant, population and local vaccine coverage turned out to be less important attributes compared to the previous four. The propensity to vaccinate was shown to increase with increasing local and population vaccination coverage.

A previous Belgian DCE investigating the public's preferences on how the government should prioritize health care interventions (Luyten et al., 2015), found patients' lifestyle and age to be the most important attributes. Although the research question and some attributes under investigation were different, three other significant attributes were similar, but they were ranked in descending order of importance as effectiveness, severity of illness, and adverse effects, compared to VRSE, vaccine effectiveness, and burden of disease in the current study. Hence, adverse effects seem more influential when the DCE is framed around vaccinations, compared to an unspecified curative or preventive intervention as in Luyten et al. (2015). The specific context of vaccination seems to make people more cautious about adverse effects. However, this may change in pandemic emergency situations, as suggested by Determann et al. finding vaccine effectiveness is more influential than VRSE, institutional advice, out of pocket costs and media coverage for pandemic vaccination in The Netherlands (Determann et al., 2014), and some other European countries (Determann et al., 2013). Explicitly specifying risk ratios associated with rotavirus and pneumococcal vaccines, Sadique et al. found severity, but not frequency, of VRSE to be a significant attribute (Sadique et al., 2013). Limiting our VRSE attribute to a cognitively much less demanding category of frequency, we found it to be highly significant, given the limitation that we did not attempt to describe the severity of these VRSE.

The importance of vaccine effectiveness in vaccine decisions was documented in other studies as well (Bishai et al., 2007; Determann et al., 2014; Oteng et al., 2011). We distinguished - as the first DCE to our knowledge - two vaccination coverage attributes: local and population coverage. Vaccination coverage was incorporated in two other studies (Hall et al., 2002; Gidengil et al., 2012) as a single (statistically significant) attribute. The specification of the accessibility attribute incorporating both monetary cost and time cost differs from other studies as well, but yields a highly significant estimate in line with others (out-of-pocket cost, cost per visit etc.) (Sadique et al., 2013; Hall et al., 2002; Bishai et al., 2007; Determann et al., 2014; Gidengil et al., 2012).

We found no considerable differences in the decision-making process of the adult versus the child group. The rank order of the attributes is the same but there are differences in the attributes' relative importance, marginal utility, and significant covariate terms. Preference heterogeneity, investigated by estimating interactions between the attributes and covariates based on socio-economics, demography, vaccine attitudes and risk perception, is limited to four significant terms. In the adult model, significant interactions exist between VRSE and age group on the one hand, and burden of disease and age group on the other. Older age categories tend to be more risk-averse with respect to VRSE compared to younger age categories (Fig. 4a). This is in line with psychological literature (Figner et al., 2009) documenting declines in risk-taking by age. One could argue also that younger adults might be willing to risk more (side-effects) today as they benefit longer from the vaccine compared to older individuals. Older people may also have a more severe perception of VRSE, given that they are more vulnerable to

them.

However, when it came to burden of disease (in terms of prevalence and disease severity), our oldest age-group (65–85 years) was less sensitive to risk than the other, younger age groups (Fig. 4b). For the elderly, the difference in utility between a vaccine that protects against a rare & mild disease, and a vaccine that protects against a common & severe disease is much smaller. An explanation could be that younger individuals are generally in better health and less vulnerable to mild disease, and have comparatively more to lose from severe disease. The oldest age group seems more indifferent to the vaccine preventable disease burden, as long as the vaccine is safe.

We also found that those who use traditional media are more risk-sensitive than those who do not rely on these media for information on infectious diseases and their prevention (Fig. 4c). Presumably those using traditional media are better informed about which specific diseases could correspond to our descriptions of mild, common, severe and rare vaccine preventable diseases, and other information related to specific vaccines. This may help explain why they attach relatively more utility to a vaccine protecting against a common & severe disease, as opposed to a vaccine protecting against a rare & mild disease.

In the child model, we only found one significant covariate effect (Fig. 4d), when we observe a difference in risk sensitivity between 'acceptors' and 'non-acceptors'. Quoting Brunson (2013): 'Acceptors rely on general social norms as the basis of their decisions. They accept these norms with little or no questioning. They do not investigate vaccination.' We singled-out an acceptor subgroup by the two most positive response levels on a five-point Likert scale for the statement: 'I do not question vaccination, it's just something I do when it is offered to me'. They represented 40% of respondents in the child group, and 35% in the adult group. Unsurprisingly, 'acceptors' are less sensitive to vaccine-preventable disease burden. They just seem to accept each recommended vaccine offered to their child, trusting it is safe and effective as part of the package that comes with having an infant undergoing regular health check-ups. The fact that adult vaccination is less of a routine undertaking may explain why we do not observe this covariate for the adult group.

The Belgian population remained relatively unfazed by international vaccine controversies and corresponding drops in vaccination coverage in other countries (Larson et al., 2016; Vandermeulen et al., 2017). Yet, it is important to understand underlying attitudes towards vaccination in times of global exposure to fake facts through social media (Dunn et al., 2017). The identification of the accessibility attribute as an important contributor to vaccine acceptance provides public health institutions with further leverage to improve vaccination coverage. When a vaccine is available at first contact with the vaccinator (GP, occupational physician, pediatrician etc.), it is more likely to be taken, especially if it is offered to large groups simultaneously (e.g. at school or in the work place, such as influenza and HPV (Lefevere et al., 2016) vaccines). This avoids the time-consuming process of sequentially visiting a physician for a prescription, a pharmacy for buying the vaccine, and again a physician for vaccine administration. The basic recommended childhood vaccines are currently available at the vaccinator in Belgium. Naturally, policymakers can raise uptake by fully or partially reimbursing vaccines (Lefevere et al., 2016) (eg, only Tdap booster vaccine is fully reimbursed for Belgian adults (Zorg en Gezondheid, 2017)).

The authorities should communicate timely and transparently on VRSE - the most important attribute for vaccine decisions - to better align the public's perceptions with reality and to build trust. Numerous historical examples exist where misperceptions on VRSE have lowered vaccine coverage substantially, opening a window for outbreaks and re-emergence of vaccine-preventable disease. For instance, the MMR vaccine scare originating from a fraudulent paper, linking MMR vaccination with autism (Godlee et al., 2011) has significantly decreased the coverage in England & Wales from about 92% in 1995 to about 80% in 2003, resulting in measles re-emergence in subsequent years (Bauch and Bhattacharyya, 2012). Other examples include the whole cell pertussis vaccine scare in the UK, lowering vaccine coverage from around 80% in 1971 to under 40% in 1976 (Bauch and Bhattacharyya, 2012), and the HPV vaccine crisis in Japan (Hanley et al., 2015). Establishing and maintaining vaccine confidence requires many parallel activities, including clear communication about vaccines in general (Larson et al., 2011), or about post-marketing safety surveillance (Casiday and Cox, 2006), and a constructive dialogue with those who hesitate or refuse vaccinations (Larson et al., 2011; Corben and Leask, 2016).

Moreover, rapid and wide media communication about infectious disease outbreaks can help rationalize vaccination behavior. Especially, information on disease risk and severity (i.e. the burden of disease attribute) lacks in regions where vaccination coverage was high for a long time. The interaction effect of traditional media with burden of disease in our DCE confirms the potential of media to help rationalize vaccination decisions. Scrutinized information on the true burden of disease can function as a compensatory mechanism against potentially inflated misperceptions of VRSE in the individuals' trade-off.

'Free-riding on herd immunity' is often an assumption in (game-theoretical) vaccine-decision models. The reasoning is as follows. Individuals face some cost of vaccination (monetary, time and health cost (including VRSE)) and some cost of contracting the disease. They use these perceived costs to make a trade-off between vaccinating or not vaccinating, incorporating the choice of other individuals (either in his/her community, or on a population level). That is, individuals are assumed to calculate how herd immunity arising from vaccination in others affects their own risk of infection. As part of game-theoretical analysis, the decision whether or not to take vaccination, depends on the potential to free-ride on established herd immunity. Many examples exist of models explicitly applying free-riding on vaccine-induced herd immunity (Barbagallo and Cojocaru, 2010; Bhattacharyya and Bauch, 2011; Bauch et al., 2010; Laguzet and Turinici, 2015; Shim et al., 2012a; Reluga and Galvani, 2011; Goyal and Vigier, 2015), despite empirical studies suggesting there might also be an altruistic motive in vaccination behavior (Skea et al., 2008; Vietri et al., 2012; Shim et al., 2012b; Araña and Léon, 2002), i.e. the partial intention to protect others.

One would expect, following the above reasoning, that individuals would be less inclined to take vaccination if more and more people are already vaccinated against the disease. In line with the observation of Hall et al. (2002) on varicella vaccination coverage in a 'child group'-like Australian sample of 50 respondents, we observe this is not the case - neither locally nor for the population coverage - in Flanders for vaccination in general. Peer influence dominates free-riding on herd immunity, such that an individual prefers a vaccine against which a larger proportion of the population is already vaccinated (keeping the other attributes constant). Gidengil et al. (2012) also find coverage to be significant and positively associated with the demand for combination vaccines in the US. Importantly, we observe this for both the child and adult group, and find a direct linear relation between the utility of vaccination and local and population vaccination coverage. These results suggest it is more appropriate for modellers to integrate herd immunity implicitly through (clinical) disease prevalence rather than through vaccination coverage. The individuals' reasoning is thus replaced by 'not many people contract the disease, so the chances are low for me too'. This fits with the notion that demand for vaccines is prevalence-elastic, but is completely removed from an underlying free riding consideration. Note that vaccination coverage influences primarily the risk of infection, and not only the risk of disease, a distinction which is essential in modeling infectious disease dynamics.

4.1. Study limitations

Our sample represents the Flemish population well on all intended characteristics, with the possible exception of educational attainment. The lower-educated seem underrepresented, though this is somewhat

difficult to interpret since the age intervals of the government statistics on educational attainment (15–64 years) and our sample (18–85 years) do not completely overlap. Note that interaction terms were estimated based on educational attainment, though this was not found to be a significant characteristic for subgroup preference heterogeneity.

Regarding the partial profile design, we colored the varying attributes yellow and asked respondents to also consider the constant, non-yellow attributes. However, it would be interesting to explore in future studies to what extent respondents actively study the levels of the constant attributes in the presence of the yellow highlighting, which is important for estimating interaction effects. Furthermore, we did not include VRSE severity as an attribute, next to VRSE frequency. In the vaccine-related DCE literature VRSE frequency is a much more widely used attribute than VRSE severity (7 versus 1 studies (Sadique et al., 2013)). However, since VRSE frequency was the most influential attribute, the addition of VRSE severity could have benefited the interpretation of our analysis, likely decreasing the logworth statistic, and hence the importance of VRSE frequency. Furthermore recent guidance recommends the use of natural frequencies to represent risks (Gigerenzer and Hoffrage, 1995). Nonetheless, we opted to use terms like ‘rare’ & ‘common’ to describe our attribute levels, based on the focus group and the pilot study showing this offered a clear and interpretable understanding. Finally, sample quota were pre-determined for the full sample (see Table 2). As such, subgroup-level samples do not necessarily reflect population characteristics.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.socscimed.2018.04.038.

References

Araña, Jorge E., Léon, Carmelo J., 2002. Willingness to pay for health risk reduction in the context of altruism. Health Econ. 11 (7), 623–635.
Barbagallo, Annamaria, Cojocaru, Monica-Gabriela, 2010. Dynamic vaccination games and variational inequalities on time-dependent sets. J. Biol. Dynam. 4 (6), 539–558.
Bauch, Chris T., Bhattacharyya, Samit, 2012. Evolutionary game theory and social learning can determine how vaccine scares unfold. PLoS Comput. Biol. 8 (4), e1002452.
Bauch, Chris T., Bhattacharyya, Samit, Ball, Robert F., 2010. Rapid emergence of free-riding behavior in new pediatric immunization programs. PLoS One 5 (9), e12594.
Belgisch Centrum Belgisch Centrum Voor Farmacotherapeutische Informatie: Vaccins. http://www.bcfi.be/nl/chapters/13?frag=11247. Accessed: 2018-03-27.
Bhattacharyya, Samit, Bauch, Chris T., 2011. 'Wait and see' vaccinating behaviour during a pandemic: a game theoretic analysis. Vaccine 29 (33), 5519–5525.
Bishai, David, Brice, Roger, Girod, Isabelle, Saleh, Aneta, Ehreth, Jenifer, 2007. Conjoint analysis of French and German parents' willingness to pay for meningococcal vaccine. Pharmacoeconomics 25 (2), 143–154.
Bliemer, Michiel CJ., Rose, John M., 2010. Construction of experimental designs for mixed logit models allowing for correlation across choice observations. Transp. Res. Part B Methodol. 44 (6), 720–734.
Braeye, Toon, Sabbe, Martine, Hutse, Veronik, Flipse, Wim, Godderis, Lina, Top, Geert, 2013. Obstacles in measles elimination: an in-depth description of a measles outbreak in Ghent, Belgium, spring 2011. Arch. Publ. Health 71 (1), 17.
Brown, Katrina F., Long, Susannah J., Ramsay, Mary, Hudson, Michael J., Green, John, Vincent, Charles A., Simon Kroll, J., Fraser, Graham, Sevdalis, Nick, 2012. UK parents' decision-making about measles–mumps–rubella (MMR) vaccine 10 years after the MMR-autism controversy: a qualitative analysis. Vaccine 30 (10), 1855–1864.
Brunson, Emily K., 2013. How parents make decisions about their children's vaccinations. Vaccine 31 (46), 5466–5470.
Bults, Marloes, Beaujean, Desirée JMA., de Zwart, Onno, Kok, Gerjo, van Empelen, Pepijn, van Steenbergen, Jim E., Hendrik Richardus, Jan, Voeten, Hélène ACM., 2011. Perceived risk, anxiety, and behavioural responses of the general public during the early phase of the Influenza A (H1N1) pandemic in The Netherlands: results of three consecutive online surveys. BMC Publ. Health 11 (1), 2.
Casiday, Rachel E., Cox, Anthony R., 2006. Restoring confidence in vaccines by explaining vaccine safety monitoring. Drug Saf. 29 (12), 1105–1109.
CDD Centers for Disease Control Vaccine Effectiveness - How Well Does the Flu Vaccine Work? https://www.cdc.gov/flu/about/qa/vaccineeffect.htm, 2017. Accessed: 2017-05-14.
Chrzan, Keith, 2010. Using partial profile choice experiments to handle large numbers of attributes. Int. J. Market Res. 52 (6), 827–840.
Clark, Michael D., Determann, Domino, Petrou, Stavros, Moro, Domenico, de Bekker-Grob, Esther W., 2014. Discrete choice experiments in health economics: a review of the literature. Pharmacoeconomics 32 (9), 883–902.
Corben, Paul, Leask, Julie, 2016. To close the childhood immunization gap, we need a richer understanding of parents' decision-making. Hum. Vaccines Immunother. 12 (12), 3168–3176.
Cuervo, Daniel Palhazi, Kessels, Roselinde, Goos, Peter, Sörensen, Kenneth, 2016. An integrated algorithm for the optimal design of stated choice experiments with partial profiles. Transport. Res. Part B: Methodol. 93, 648–669.
de Bekker-Grob, Esther W., Hofman, Robine, Donkers, Bas, van Ballegooijen, Marjolein, Helmerhorst, Theo JM., Raat, Hein, Korfage, Ida J., 2010. Girls' preferences for HPV vaccination: a discrete choice experiment. Vaccine 28 (41), 6692–6697.
de Bekker-Grob, Esther W., Ryan, Mandy, Gerard, Karen, 2012. Discrete choice experiments in health economics: a review of the literature. Health Econ. 21 (2), 145–172.
Dellaert, Benedict GC., Donkers, Bas, Soest, Arthur Van, 2012. Complexity effects in choice experiment- based models. J. Market. Res. 49 (3), 424–434.
Determann, Domino, Korfage, Ida J., Fagerlin, Angela, Steyerberg, Ewout W., Bliemer, Michiel C., Voeten, Helene A., Richardus, Jan Hendrik, Lambooij, Mattijs S., de Bekker-Grob, Esther W., 2013. Public preferences for vaccination programmes during pandemics caused by pathogens transmitted through respiratory droplets - a discrete choice experiment in four European countries. Euro Surveill. 21 (22) 30247, 2016.
Determann, Domino, Korfage, Ida J., Lambooij, Mattijs S., Bliemer, Michiel, Richardus, Jan Hendrik, Steyerberg, Ewout W., de Bekker-Grob, Esther W., 2014. Acceptance of vaccinations in pandemic outbreaks: a discrete choice experiment. PLoS One 9 (7), e102505.
Dunn, Adam G., Surian, Didi, Leask, Julie, Dey, Aditi, Mandl, Kenneth D., Coiera, Enrico, 2017. Mapping information exposure on social media to explain differences in HPV vaccine coverage in the United States. Vaccine 35 (23), 3033–3040.
Figner, Bernd, Mackinlay, Rachael J., Wilkening, Friedrich, Weber, Elke U., 2009. Affective and deliberative processes in risky choice: age differences in risk taking in the Columbia Card Task. J. Exp. Psychol. Learn. Mem. Cognit. 35 (3), 709.
Fine, Paul, Eames, Ken, Heymann, David L., 2011. ‘Herd immunity’: a rough guide. Clin. Infect. Dis. 52 (7), 911–916.
Funk, Sebastian, Salathé, Marcel, Jansen, Vincent AA., 2010. Modelling the influence of human behaviour on the spread of infectious diseases: a review. J. R. Soc. Interface 7, 1247–1256 page rsif20100142.
Funk, Sebastian, Bansal, Shweta, Bauch, Chris T., Eames, Ken TD., John Edmunds, W., Galvani, Alison P., Klepac, Petra, 2015. Nine challenges in incorporating the dynamics of behaviour in infectious diseases models. Epidemics 10, 21–25.
Gidengil, Courtney, Lieu, Tracy A., Payne, Katherine, Rusinak, Donna, Messonnier, Mark, Prosser, Lisa A., 2012. Parental and societal values for the risks and benefits of childhood combination vaccines. Vaccine 30 (23), 3445–3452.
Gigerenzer, Gerd, Hoffrage, Ulrich, 1995. How to improve Bayesian reasoning without instruction: frequency formats. Psychol. Rev. 102 (4), 684.
Godlee, Fiona, Smith, Jane, Marcovitch, Harvey, 2011. Wakefield's Article Linking MMR Vaccine and Autism was Fraudulent.
Goyal, Sanjeev, Vigier, Adrien, 2015. Interaction, protection and epidemics. J. Publ. Econ. 125, 64–69.
Hall, Jane, Kenny, Patricia, King, Madeleine, Louviere, Jordan, Viney, Rosalie, Yeoh, Angela, 2002. Using stated preference discrete choice modelling to evaluate the introduction of varicella vaccination. Health Econ. 11 (5), 457–465.
Hanley, Sharon JB., Yoshioka, Eiji, Ito, Yoshiya, Kishi, Reiko, 2015. HPV vaccination crisis in Japan. Lancet 385 (9987), 2571.
Hufnagel, Lars, Brockmann, Dirk, Geisel, Theo, 2004. Forecast and control of epidemics in a globalized world. Proc. Natl. Acad. Sci. U.S.A. 101 (42), 15124–15129.
Kelly, Heath, Carville, Kylie, Grant, Kristina, Jacoby, Peter, Tran, Thomas, Barr, Ian, 2009. Estimation of influenza vaccine effectiveness from routine surveillance data. PLoS One 4 (3), e5079.
Kessels, Roselinde, Jones, Bradley, Goos, Peter, 2011a. Bayesian optimal designs for discrete choice experiments with partial profiles. J. Choice Modell. 4 (3), 52–74.
Kessels, Roselinde, Jones, Bradley, Goos, Peter, Vandebroek, Martina, 2011b. The usefulness of Bayesian optimal designs for discrete choice experiments. Appl. Stoch Model Bus. Ind. 27 (3), 173–188.
Kessels, Roselinde, Van Herck, Pieter, Dancet, Eline, Annemans, Lieven, Sermeus, Walter, 2015a. How to reform western care payment systems according to physicians, policy makers, healthcare executives and researchers: a discrete choice experiment. BMC Health Serv. Res. 15 (1), 191.
Kessels, Roselinde, Jones, Bradley, Goos, Peter, 2015b. An improved two-stage variance balance approach for constructing partial profile designs for discrete choice

experiments. Appl. Stoch Model Bus. Ind. 31 (5), 626–648.
Kind, Gezin, 2015. Preventieve Gezondheidsondersteuning - Kerncijfers.
Laguzet, Laetitia, Turinici, Gabriel, 2015. Individual vaccination as Nash equilibrium in a SIR model with application to the 2009–2010 influenza A (H1N1) epidemic in France. Bull. Math. Biol. 77 (10), 1955–1984.
Larson, Heidi J., Cooper, Louis Z., Eskola, Juhani, Katz, Samuel L., Ratzan, Scott, 2011. Addressing the vaccine confidence gap. Lancet 378 (9790), 526–535.
Larson, Heidi J., de Figueiredo, Alexandre, Xiahong, Zhao, Schulz, William S., Verger, Pierre, Johnston, Iain G., Cook, Alex R., Jones, Nick S., 2016. The state of vaccine confidence 2016: global insights through a 67-country survey. EBioMedicine 12, 295–301.
Lefevere, Eva, Hens, Niel, De Smet, Frank, Beutels, Philippe, 2016. The impact of non-financial and financial encouragements on participation in non school-based human papillomavirus vaccination: a retrospective cohort study. Eur. J. Health Econ. 17 (3), 305–315.
Liu, Mingnan, Cernat, Alexandru, 2016. Item-by-item versus matrix questions: a web survey experiment. Soc. Sci. Comput. Rev. 1–17 page 0894439316674459.
Luyten, Jeroen, Kessels, Roselinde, Goos, Peter, Beutels, Philippe, 2015. Public preferences for prioritizing preventive and curative health care interventions: a discrete choice experiment. Value Health 18 (2), 224–233.
Morse, Stephen S., 2001. Factors in the emergence of infectious diseases. In: Plagues and Politics. Springer, pp. 8–26.
Oteng, Bridgette, Marra, Fawziah, Lynd, Larry D., Ogilvie, Gina, Patrick, David, Marra, Carlo A., 2011. Evaluating societal preferences for human papillomavirus vaccine and cervical smear test screening programme. Sex. Transm. Infect. 87 (1), 52–57.
Peretti-Watel, Patrick, Verger, P., Raude, J., Constant, A., Gautier, A., Jestin, C., Beck, F., 2013. Dramatic change in public attitudes towards vaccination during the 2009 influenza A (H1N1) pandemic in France. Euro Surveill. 18 (44), 20623.
Quadri-Sheriff, Maheen, Hendrix, Kristin S., Downs, Stephen M., Sturm, Lynne A., Zimet, Gregory D., Maria, S., Finnell, E., 2012. The role of herd immunity in parents' decision to vaccinate children: a systematic review. Pediatrics 130 (3), 522–530.
Reluga, Timothy C., Galvani, Alison P., 2011. A general approach for population games with application to vaccination. Math. Biosci. 230 (2), 67–78.
Rose, John M., Bliemer, Michiel CJ., 2013. Sample size requirements for stated choice experiments. Transportation 40 (5), 1021–1041.
Sadique, Md Z., Devlin, Nancy, Edmunds, William J., Parkin, David, 2013. The effect of perceived risks on the demand for vaccination: results from a discrete choice experiment. PLoS One 8 (2), e54149.
Salathé, Marcel, Vu, Duy Q., Khandelwal, Shashank, Hunter, David R., 2013. The dynamics of health behavior sentiments on a large online social network. EPJ Data Science 2 (1), 1–12.
Schimit, P.H.T., Monteiro, L.H.A., 2011. A vaccination game based on public health actions and personal decisions. Ecol. Model. 222 (9), 1651–1655.
Shim, Eunha, Grefenstette, John J., Albert, Steven M., Cakouros, Brigid E., Burke, Donald S., 2012a. A game dynamic model for vaccine skeptics and vaccine believers: measles as an example. J. Theor. Biol. 295, 194–203.
Shim, Eunha, Chapman, Gretchen B., Townsend, Jeffrey P., Galvani, Alison P., 2012b. The influence of altruism on influenza vaccination decisions. J. R. Soc. Interface 9, 2234–2243 page rsif20120115.
Skea, Zoë C., Entwistle, Vikki A., Watt, Ian, Russell, Elizabeth, 2008. 'Avoiding harm to others' considerations in relation to parental measles, mumps and rubella (MMR) vaccination discussions–An analysis of an online chat forum. Soc. Sci. Med. 67 (9), 1382–1390.
Sudfeld, Christopher R., Marie Navar, Ann, Halsey, Neal A., 2010. Effectiveness of measles vaccination and vitamin A treatment. Int. J. Epidemiol. 39 (Suppl. 1), i48–i55.
Szmuness, Wolf, Stevens, Cladd E., Zang, Edith A., Harley, Edward J., Kellner, Aaron, 1981. A controlled clinical trial of the efficacy of the hepatitis B vaccine (Heptavax B): a final report. Hepatology 1 (5), 377–385.
Vandermeulen, Corinne, Hoppenbrouwers, Karel, Roelants, Mathieu, Theeten, Heidi, Braeckman, Tessa, Maertens, Kirsten, Blaizot, Stéphanie, Van Damme, Pierre, 2017. Studie van de vaccinatiegraad in Vlaanderen 2016.
Verelst, Frederik, Willem, Lander, Beutels, Philippe, 2016. Behavioural change models for infectious disease transmission: a systematic review (2010–2015). J. R. Soc. Interface 13 (125), 20160820.
Vietri, Jeffrey T., Li, Meng, Galvani, Alison P., Chapman, Gretchen B., 2012. Vaccinating to help ourselves and others. Med. Decis. Making 32 (3), 447–458.
Zhang, Yan, 2013. The impact of other-regarding tendencies on the spatial vaccination game. Chaos, Solit. Fractals 56, 209–215.
Zipprich, Jennifer, Winter, Kathleen, Hacker, Jill, Xia, Dongxiang, Watt, James, Harriman, Kathleen, Centers for Disease Control, Prevention (CDC), et al., 2015. Measles outbreak - California, December 2014-february 2015. MMWR Morb. Mortal. Wkly. Rep. 64 (6), 153–154.
Agentschap Zorg & Gezondheid correct gebruik van de gratis vaccins. https://www.zorg-en-gezondheid.be/correct-gebruik-van-de-gratis-vaccins. Accessed: 2017-06-21.