

# Ambiguity Attitudes

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## Introduction

In many decisions under uncertainty, the decision maker has only vague information about the probabilities of potential outcomes of her actions. Following Ellsberg (1961), such situations with unknown or uncertain probabilities are often called *ambiguous*, to distinguish them from situations with objectively known probabilities, which are typically called *risky*. Ellsberg's 1961 article suggested that decision makers have a preference for risky over ambiguous acts that are equivalent under SEU (Savage, 1954). Ellsberg's conjecture has initiated a large empirical literature studying the prevalence and the causes of such *ambiguity aversion*. This literature has shown that attitudes towards ambiguity depend on the likelihood of the uncertain events, the domain of the outcome, and the source that generates the uncertainty. Because both ambiguity aversion and ambiguity seeking have been observed, we employ the more appropriate term *ambiguity attitude*.

A theoretical literature that is mostly independent of the empirical work has developed a large number of models of ambiguity-averse preferences. These models have subsequently been applied to explain a wide range of behavioral phenomena that are difficult to reconcile with agents who maximize SEU. For example, in financial economics, Easley and O'Hara (2009) show that ambiguity aversion can explain low participation in the stock market despite the potentially high benefits. In medical-decision problems, Berger, Bleichrodt, and Eeckhoudt (2013) find that ambiguity about the diagnosis or the treatment of a medical condition affects treatment decisions. Similarly, Hoy, Peter, and Richter (2013) explain low take-up of costless genetic tests by reference to ambiguity aversion. Interestingly, the empirical literature has so far provided relatively little evidence linking individual attitudes toward ambiguity to behavior outside the laboratory in these, theoretically, ambiguity-sensitive decisions. Are those agents who show the strongest degree of ambiguity aversion in some experimental

decision task also the ones who are most likely to avoid ambiguous investments or decline genetic testing?

In this chapter, we review the experimental literature on ambiguity attitudes, focusing on three topics. First, we consider various approaches to operationalize ambiguity in experiments. Second, we review basic findings in the field regarding the prevalence of ambiguity aversion and ambiguity seeking in static individual decision situations. Third, we consider studies that probe the external validity of these basic results. In particular, in the final section we summarize the as yet limited evidence on the link between experimental measures of ambiguity attitude and people's decisions in the field.

The current chapter considers only experimental work on ambiguity attitude, complementing a few review articles mostly focusing on theoretical work. Camerer and Weber (1992) review early empirical and theoretical literature on ambiguity. Siniscalchi (2008) summarizes theoretical approaches to explain the Ellsberg Paradox (see the following section, Ellsberg Urns and Other Operationalizations of Ambiguity). Wakker (2008) provides an interpretation of ambiguity attitude under prospect theory and discusses competing theoretical approaches. Etner, Jeleva, and Tallon (2012) provide an extensive overview of decision theory under ambiguity. They also discuss some empirical evidence. Al-Najjar and Weinstein (2009) discuss the normative status of ambiguity aversion in rational choice models.

## Ellsberg Urns and Other Operationalizations of Ambiguity

From a psychological perspective, ambiguity has often been conceptualized in terms of missing or conflicting information. Ambiguity is introduced by the absence of salient information that could in principle be available to the decision maker. Frisch and Baron (1988) thus define ambiguity as the subjective perception of missing information. Conflicting information leads to ambiguity when people find it difficult to aggregate different pieces of information (Cabantous, 2007; Einhorn & Hogarth, 1985; Viscusi & Magat, 1992). When experts disagree about the probability of an event there might be no obvious way for the decision maker to attach weights to their judgments. This section describes operationalizations of ambiguity that aim to capture these abstract notions of ambiguity by formalizing the contrast between precise information and missing or conflicting information.

### The Ellsberg two-color problem

Consider a “risky” urn containing five red and five black balls, and an “ambiguous” urn containing ten balls, each ball either red or black, but in an unknown proportion. There are four payment schemes that are contingent on the color of a ball drawn at random from one of the urns. These event-contingent payment schemes, or *acts*, are shown in Table 3.1.

$\text{Black}_{\text{Risk}}$  denotes the event that a black ball is drawn from the risky urn; the other events are defined similarly. Events  $\text{Black}_{\text{Risk}}$  and  $\text{Red}_{\text{Risk}}$  are *risky* because their

**Table 3.1** Ellsberg two-color problem.

<i>Act</i>	$Black_{Risk}$	$Red_{Risk}$	$Black_{Amb}$	$Red_{Amb}$
$f$	\$10	\$0		
$g$			\$10	\$0
$f'$	\$0	\$10		
$g'$			\$0	\$10

probabilities are objectively known. Events  $Black_{Amb}$  and  $Red_{Amb}$  are *ambiguous*, because they involve the unknown-composition urn. Act  $f$  yields \$10 if a black ball is drawn from the risky urn, and zero otherwise. We call this act a *bet* on black from the risky urn. Ellsberg (1961) conjectured that agents may dislike ambiguity and prefer act  $f$  to act  $g$ , while at the same time preferring act  $f'$  to  $g'$ . Assume that people hold beliefs about the likelihood of uncertain events and assign subjective probabilities  $P(\cdot)$  to these events, and that their beliefs agree with objective probabilities for risky events. The first preference then implies  $P(Black_{Amb}) < .5 = P(Black_{Risk})$  and the second preference implies  $P(Red_{Amb}) < .5 = P(Red_{Risk})$ , thus  $P(Black_{Amb}) + P(Red_{Amb}) < 1$ . Apparently, these beliefs are nonadditive and violate SEU and other models with additive beliefs. The joint preference  $f \succ g$  and  $f' \succ g'$  indicates ambiguity aversion in the two-color problem. Analogously,  $f \prec g$  and  $f' \prec g'$  indicates ambiguity seeking.

Many experimental studies using the two-color problem formulate the decision in slightly different terms. Often the decision maker is given only one decision, namely the choice between a bet on red and a bet on black as the winning color, from either the risky or the ambiguous urn. A strict preference to bet on a draw from the risky urn can then be interpreted as ambiguity aversion: under ambiguity neutrality any probabilistic belief about the ambiguous urn should lead to a choice of the ambiguous urn (and the color thought more likely) or to indifference between the two urns. This interpretation does *not* hold true if the decision maker is given the choice of the urn but not the choice of the color. A pessimistic belief about the probability of the winning color can account for a choice of the risky urn even in the absence of ambiguity aversion. An often-cited source of such pessimism is the mistrust of the experimenter who may want to economize on her budget or to dupe the decision maker for other reasons (Charness, Karni, & Levin, 2013; Chow & Sarin, 2002; Dominiak & Dürsch, 2012; Kühberger & Perner, 2003; Pulford, 2009; but see Oechssler & Roomets, 2013 for evidence against such strategic perceptions).

Note that we may not always be able to identify ambiguity attitudes with the color-choice and the multiple choices methods as described here (a similar argument applies to the methods in the next two sections). First, a choice of the ambiguous urn in the single decision with color choice does not allow distinguishing between ambiguity seeking and neutrality. Second, when offering subjects both the choice between  $f$  and  $g$  and between  $f'$  and  $g'$  we may observe behavior consistent with additive subjective probabilities and SEU, even if the decision maker is ambiguity averse or ambiguity seeking. This happens if she believes that the distribution of colors in the ambiguous urn is very unbalanced, for example that it contains nine red balls. For modest degrees

of ambiguity aversion, she may then strongly prefer  $f$  over  $g$  but also choose  $g'$  over  $f'$ . Under the heading Natural sources of uncertainty we discuss methods to control for beliefs when studying natural sources of uncertainty. Although beliefs will typically be more balanced in urn designs than for natural events, these methods can also be used to control for unbalanced beliefs in the urn designs discussed here and under the following two headings on the three-color problem, and on low- and high-likelihood events.

The Ellsberg three-color problem

Ellsberg suggested another decision problem to probe people’s attitudes toward ambiguity. Imagine an urn containing three red balls and six balls that are either yellow or black in an unknown proportion. Consider the four acts shown in Table 3.2.

Ellsberg conjectured that many people prefer act  $f$  to act  $g$ , but also prefer act  $g'$  to act  $f'$ . While act  $f$  offers an unambiguous  $1/3$  chance of \$10, act  $g$  offers an ambiguous chance between zero and  $2/3$ . At the same time, the winning chance for act  $f'$  is ambiguous, lying between  $1/3$  and 1, but it is unambiguous for act  $g'$ , for which it equals  $2/3$ . A preference for  $f$  over  $g$  implies that the decision maker is pessimistic about the number of black balls in the urn,  $P(\text{black}) < 1/3$ , and thus optimistic about the number of yellow balls,  $P(\text{yellow}) > 1/3$ . It follows that winning chances for act  $f'$  are larger than  $2/3$ , and thus larger than for act  $g'$ . The joint preference  $f \succ g$  and  $g' \succ f'$  indicates *ambiguity aversion* in the three-color problem. Table 3.2 shows that in this case preferences between events Red and Black are not independent of the event Yellow, although Yellow gives the same payoff for acts  $f$  and  $g$ , and  $f'$  and  $g'$ , respectively. As in the case of the two-color problem, if only a single choice is offered to the decision maker, ambiguity aversion cannot be distinguished from pessimistic beliefs or mistrust, unless a choice of the winning color is offered to the decision maker.

Low- and high-likelihood events

A multinumber (or color, or symbol) two-urn setup allows decisions involving low- or high-likelihood events. Consider a risky urn containing ten balls numbered 1 to 10, with each number used exactly once. Further, an ambiguous urn also contains ten balls, each ball having a number from the set  $\{1, 2, \dots, 10\}$  with no limit on how many balls may have the same number. That is, in the ambiguous urn each number could

Table 3.2 Ellsberg three-color problem.

	<i>Red</i>	<i>Black</i>	<i>Yellow</i>
<i>Act</i>	(3 balls)	( $0 \leq x \leq 6$ balls)	(6- $x$ balls)
$f$	\$10	\$0	\$0
$g$	\$0	\$10	\$0
$f'$	\$10	\$0	\$10
$g'$	\$0	\$10	\$10

**Table 3.3** 10-number urns and (un)likely events.

<i>Act</i>	$i_{Risk}$	$not-i_{Risk}$	$i_{Amb}$	$not-i_{Amb}$
$f_i$	\$0	\$10		
$g_i$			\$0	\$10
$f'_i$	\$10	\$0		
$g'_i$			\$10	\$0

be present between 0 and 10 times, and the decision maker is uncertain about this composition.<sup>1</sup>

Consider the acts shown in Table 3.3 where  $i_{Risk}$  denotes the event that a ball with the number  $i$  is drawn from the risky urn, and  $not-i_{Risk}$  denotes the event that the ball drawn from the risky urn has a number that is different from  $i$ . Events  $i_{Amb}$  and  $not-i_{Amb}$  are defined similarly. A choice between acts  $f_i$  and  $g_i$  amounts to choosing between a known 90% chance of winning the prize and an ambiguous chance with nine winning numbers and one losing number. In contrast, a choice between acts  $f'_i$  and  $g'_i$  implies a choice between a known 10% chance of winning and an ambiguous chance with one winning and nine losing numbers. If we find for each number  $i$  that  $f_i \succ g_i$ , then we call the decision maker ambiguity averse. If we find that  $f_i \prec g_i$  for all  $i$ , we call the agent ambiguity seeking. Ellsberg conjectured that in contrast to moderate-likelihood events, for unlikely events people would become ambiguity seeking (Becker & Brownson, 1964, footnote 4; Ellsberg, 2011). In the third section of this chapter, Stylized Facts From Laboratory Experiments, we show that a typical finding is indeed that agents are ambiguity averse for moderate- and high-likelihood events, but ambiguity seeking for unlikely events.

### Second-order probabilities

Ellsberg urn experiments have been popular in the literature because they are very transparent and can easily be implemented with real incentives. However, other designs have also been used, and we discuss two methods here. The first involves the use of first-order and second-order probabilities, and the second involves natural sources of uncertainty.

The second-order probability approach involves the explicit specification of the probabilities with which some risky, known probability acts obtain. For example, Di Mauro and Maffioletti (2004) construct an ambiguous act by using an urn with five tickets each of which gives access to an act with known probabilities. One of the tickets provides access to an act that gives a 1% chance of winning the prize, three tickets carry a 3% chance, and one ticket carries a 5% chance. This ambiguous act is compared to a risky alternative that provides an unambiguous 3% chance of winning. The 1%-, 3%-, and 5%-risky acts were then resolved using an urn with one hundred balls of which one, three, or five, respectively, were of the winning color. Moore and Eckel (2006) implement ambiguity by considering baseline probability levels of 10%, 50%, or 90% for risk, and making them ambiguous by adding a known and uniformly distributed second-order spread.

For example, for the 50% risky act, the corresponding ambiguous act is specified by drawing a chip from an urn with eleven chips numbered 45 through 55. The number drawn determines the resulting probability in the ambiguous act. Du and Budescu (2005) and Keck, Diecidue, and Budescu (2011) employ similar methods.

The second-order probability method provides a convenient way to make any baseline probability ambiguous without using complex urn designs. It also allows for easy variation of the degree of the ambiguity, while at the same time controlling for beliefs. In the above example we could make the 50% risky act more ambiguous through a uniform spread ranging from 40% to 60% and observe the effect of this increase on preferences. Although second-order probabilities provide a convenient approach to model increasing uncertainty, it is not clear in how far the compound lotteries capture ambiguity in the sense of Ellsberg's unknown probabilities. Halevy (2007) reports results suggesting that attitudes toward ambiguity and toward compound risk are closely correlated. However, he also finds that people on average prefer a compound lottery with a uniform second-order probability to an ambiguous prospect. A similar finding has already been reported in Yates and Zukowski (1976). Abdellaoui, Klibanoff, and Placido (2011) also find pronounced differences between compound risk and ambiguity attitudes, which also depend on the statistical structure of the second-order probabilities. Apart from the empirical differences, theoretical reasons may sometimes speak against the operationalization of ambiguity in terms of second-order probabilities. When testing or calibrating decision theoretic models of ambiguity attitude it might be desirable to use stimuli that are identical to those stipulated by the theory: if the theory regards unknown probabilities it might be inappropriate to operationalize them with known-risk compound lotteries.

### Natural sources of uncertainty

Ambiguity aversion is sometimes interpreted as a special case of *source preference*: Keeping subjective beliefs and outcomes constant, the decision maker prefers some sources of uncertainty over others. An American investor may hold equal expectations regarding the changes in the Dow Jones index and the Nikkei index in the next year, but she may nevertheless prefer to invest her funds in the Dow Jones because she feels more competent about the American market. At the same time, a Japanese investor holding the same beliefs may prefer investing her funds in the Nikkei for similar reasons. Such preferences are often called *home bias*, and they have been suggested by financial market data on portfolio shares (French & Poterba, 1991). Studies on more general sources of uncertainty, such as asset markets, weather conditions, or outcomes of medical procedures, are desirable because they probe the external validity of the ambiguity effects shown with balls and urns. We demonstrate three approaches to elicit source preferences when working with natural sources, using the home bias example. Evidence on home bias and source preference is discussed in the next section under the heading Ambiguity attitude as source preference.

Assume that we want to elicit source preferences of an American investor by offering her choices between bets on the value of the Dow or the Nikkei one week from now. The first approach involves simply offering multiple bets on complementary events, as in the Ellsberg two-color problem. We offer the investor a choice between betting on

an increasing Dow and an increasing Nikkei, and we also offer her a choice between betting on a decreasing Dow and a decreasing Nikkei. Let the investor prefer betting on the Dow in the first choice. In the absence of source preference this implies that  $P(\text{Dow up}) > P(\text{Nikkei up})$ , which is equivalent to  $P(\text{Dow down}) < P(\text{Nikkei down})$ . Thus the investor should prefer betting on the Nikkei in the second bet. In contrast, if the investor simultaneously prefers to bet on the increasing Dow rather than the increasing Nikkei, and on the decreasing Dow rather than the decreasing Nikkei, we say that she exhibits source preference for the Dow Jones.

Observing contradictory bets on complementary events reveals source preference irrespective of the actual beliefs of the investor. However, for very asymmetric beliefs we may not be able to observe a contradiction and identify an existing source preference (for a related problem in Ellsberg choices, see earlier in the chapter under the heading The Ellsberg two-color problem). Let the beliefs of the investor be  $P(\text{Dow up}) = .8$  and  $P(\text{Nikkei up}) = .4$ . She may strongly prefer the bet on an increasing Dow because of both her optimistic beliefs *and* source preference, but she may still prefer to bet on the decreasing Nikkei because the difference between  $P(\text{Dow down}) = .2$  and  $P(\text{Nikkei down}) = .6$  is too large to be overrun by source preference.

A second approach has been developed in the literature to overcome the problem of asymmetric beliefs for the identification of source preference (Abdellaoui, Baillon, Placido, & Wakker, 2011; Baillon, 2008; van de Kuilen & Wakker, 2011). We first elicit for both the Dow and the Nikkei a value  $x$  such that the investor considers the event “index in 1 week  $> x$ ” and “index in 1 week  $\leq x$ ” equally likely. We may simply ask the investor for this value or otherwise use choice-based methods to elicit a value  $x$  such that the investor is indifferent between betting on either event. Let the investor be indifferent between betting on the Dow being above or below 13,499 points, and between betting on the Nikkei being above or below 10,650 points, one week from now. Assuming additive subjective probabilities, indifference between betting on increasing and decreasing indexes implies .5 probabilities for each event and each index. Therefore, SEU models predict indifference between betting on an increasing Dow and an increasing Nikkei. An investor may exhibit a home bias, however, and strictly prefer betting on the increasing Dow over the increasing Nikkei. This observation already shows source preference. Moreover, if the investor is also presented with the bets on the decreasing indexes, source preference can always be identified because the asymmetry in beliefs has been eliminated by the initial calibration of the value  $x$ .

A third approach involves eliciting the subjective probability of an uncertain event, subsequently offering the decision maker a choice between betting on the event or betting on a matched, known-probability event. For example, a financial economist may be asked about her subjective probability of the Dow Jones going up, and her subjective probability of the temperature in her hometown going up. Assume her beliefs are given by  $P(\text{Dow up}) = .6$  and  $P(\text{temp up}) = .3$ . She is then offered a choice between betting on the Dow going up and betting on a red ball being drawn from an urn with 60 red and 40 black balls, and a choice between betting on the temperature going up and betting on a red ball being drawn from an urn with 30 red and 70 black balls. We may find her preferring the bet on the stock market to the bet on the 60-red urn, and at the same time preferring the bet on the 30-red urn to the bet on the

temperature. Thus, she may not have a preference for known over unknown probabilities but may have a preference for sources of uncertainty about which she feels competent (see under Ambiguity attitude as source preference later in this chapter). A meteorologist from the same town might prefer bets on the weather to bets on urns, and bets on urns to bets on the stock market. Both agents would exhibit source preference but no ambiguity aversion in the sense of generally preferring objectively known over subjective risks.

## Stylized Facts From Laboratory Experiments

Ambiguity attitudes have been the subject of a large number of studies in psychology, economics, biology, neuroscience, and philosophy. Many of these studies looked at the psychological causes and moderators of ambiguity attitudes; others probed the robustness of the phenomenon. Some studies used ambiguity experiments as a tool to study other topics.<sup>2</sup> In this section we discuss stylized facts about ambiguity attitude in the laboratory and laboratory-like settings. We first present the large literature on ambiguity in the gain domain with moderate-likelihood events, including an overview of ambiguity premia and a discussion of potential moderators. We then review the evidence for unlikely events and for the loss domain, which are important in applications to asset markets and insurance. In the section following that we consider the correlation between risk and ambiguity attitudes, and then we go on to discuss the empirical evidence on source preferences.

### Ambiguity aversion, ambiguity premia, and moderators

Much research has focused on the gain domain with moderate-likelihood events as in the two- and three-color Ellsberg tasks. The typical finding in this domain is that subjects are ambiguity averse (see e.g. Table 3.4; or Table 1 in Oechssler & Roomets, 2013). This result has been replicated with subjects who were not students (e.g., Butler, Guiso, & Jappelli, 2011; Dimmock, Kouwenberg, & Wakker, 2012; Dimmock, Kouwenberg, Mitchell, & Peijnenburg, 2013), with non-Western subjects (e.g., Akay Martinsson, Medhin, & Trautmann, 2012; Engle-Warnick, Escobal, & Laszlo, 2007; Ross, Santos, & Capon, 2012), with children (Sutter, Kocher, Glatzle-Rutzler, & Trautmann, 2013), and with monkeys (Hayden, Heilbrunner, & Platt, 2010). Given the clear evidence for ambiguity aversion in the literature, we discuss three recent studies that question the relevance of the phenomenon, which leads us to the role of the elicitation method on the observed attitudes. Keeping these elicitation issues in mind, we provide an overview of typical quantitative measures for the ambiguity premium. Finally we discuss some moderators of ambiguity attitude in the domain of moderate-likelihood gains.

*The robustness of ambiguity aversion and the role of the elicitation method.* Some studies have recently questioned the evidence on ambiguity aversion. Stahl (2014) studies heterogeneity in ambiguity attitudes across individuals and situations. He offers subjects choices in the two-color and three-color Ellsberg tasks, letting them



bet on both colors in separate bets as described in the discussions of the Ellsberg two- and three-color problems earlier in this chapter. In the two-color task, a risky option with a \$10 prize is compared to ambiguous options with \$10, \$12, and \$15 for each subject and each color. For the equal prize comparison Stahl finds typical results with about 70% of the subjects preferring risky. For a prize of \$12 for the ambiguous option, Stahl finds approximately equal preference for the two urns. For a prize of \$15 only a minority chooses risky. For the three-color task, much less ambiguity aversion is found. For equal prizes, only a slight majority of about 55% prefer risky. This drops to about 35% and 20% when the ambiguous prize is increased by 20% and 50% as described above. Thus, the three-color problem elicits much lower ambiguity aversion than the two-color problem. Stahl (2014) also considers the within-person consistency in ambiguity attitudes. Estimating various models that account for decision errors, he concludes that roughly 26% of the subjects behave in a manner consistent with SEU. More than 60% are best described as what he calls “level-0,” choosing almost randomly. Only 12% are categorized as ambiguity averse.

Two other recent papers reach similar conclusions. Binmore, Stewart, & Voorhoeve, (2012) run a horse race of different ambiguity models, using decisions in the three-color task. They elicit *matching probabilities* (Kahn & Sarin, 1988; also called probability equivalents): the winning probability of the known-probability urn is adjusted until the decision maker is indifferent between betting on the known-probability urn or the unknown-probability urn. For example, in the three-color urn described earlier in the chapter, an ambiguity-averse decision maker may prefer betting on red if the urn contains three red and six black or yellow balls but may be indifferent between betting on red or black if the urn contains two red and seven black or yellow balls. Binmore et al. (2012) run three experiments along these lines and do not find any significant ambiguity aversion. Their estimation results suggest that subjects perceive ambiguity simply as an equal chance prospect and that there is some noise in their decisions that is modestly biased in the direction of ambiguity aversion. Another paper, by Charness et al. (2013), uses the three-color problem in a study on persuasion. In a baseline condition that elicits choices in individual decisions, they find the following proportions of behavioral patterns: the behavior of 60% of the subjects is consistent with SEU; 12% are ambiguity seeking; 20% choose randomly; and only 8% of the subjects are categorized as being ambiguity averse.

These results suggest (a) that the combination of the three-color task with choice-based elicitation procedures leads to low levels of ambiguity aversion, and (b) that there is significant heterogeneity and confusion in even the simplest tasks. The first observation is consistent with Trautmann, Vieider, & Wakker's (2011) finding that choice tasks elicit lower ambiguity aversion than valuation tasks, in particular willingness-to-pay measures. If different methods lead to a shift in the whole distribution of ambiguity attitudes, the ranking of agents according to their attitude is informative, while the absolute degree of ambiguity aversion observed in a particular study is not. However, if the ranking is also affected by the elicitation method, we may ask in the spirit of Fischhoff (1991): *Is there anything in there?*

Point (b) in the previous paragraph relates to this question. If people are not consistent in their attitudes, observing the ranking of decision makers in a single decision problem may not be very useful. Other studies have also demonstrated inconsistencies.

For example, Dürsch, Romer, & Roth (2013) probe the robustness of ambiguity attitudes in three-color tasks and find that about 30% of their participants are inconsistent across two repetitions of *exactly the same task*. Dimmock et al. (2012) elicit attitudes in a first task to predict choices in a second task. They find that 47% of the subjects do not choose according to their previously elicited preferences. These findings suggest that the robustness of ambiguity attitudes is an important topic that deserves more attention. Part of the effort to establish the robustness of ambiguity attitude relates to the external validity of the attitudes that we will discuss in the section on evidence on external validity of laboratory measures. It tells us whether the concepts we measure have any inherent relevance for decision making outside the laboratory. These caveats notwithstanding, there is clear evidence that on the average, and across various elicitation methods, ambiguity aversion is the typical qualitative finding. We next summarize the quantitative evidence.

**A survey of ambiguity premia.** Many studies have measured the strength of ambiguity attitudes. Such measurements allow calibrating theoretical models to derive quantitative predictions, which can then be employed descriptively or normatively in policy (Farber, 2011). As a descriptive application, a policy maker may want to predict the reaction of asset prices on improvements in the disclosure rules for listed companies. From a normative perspective, a policy maker may want to implement safety regulation for nuclear waste disposal, taking into account the electorate's ambiguity attitudes. Using measurements of the ambiguity premium in the domain of moderate-likelihood gains as an input to policy makes the implicit assumption that ambiguity attitudes are similar when considering other domains. The next sections will show that this assumption is problematic. However, because many theoretical studies assume universal ambiguity aversion, considering ambiguity premia from the widely studied gain domain is an important first step towards quantifying the impact of ambiguity on economic, medical, or legal settings.

We define two measures for the ambiguity premium. The first measure defines the ambiguity premium as the difference between the valuation of the risky act and valuation of the ambiguous act, divided by the expected value of the risky act. This measure can be calculated for studies that report both valuations and the expected value. The second measure is independent of the risk premium and can also be calculated for studies that do not measure risk aversion. We define this ambiguity premium as the difference between the valuation of the risky and the ambiguous act, divided by the valuation of the risky act. For studies that report matching probabilities, we define the ambiguity premium as the difference between the ambiguity-neutral matching probability and the actual matching probability for the ambiguous urn, divided by the ambiguity-neutral matching probability. Table 3.4 shows the ambiguity premia (in percentages) for studies that report the required statistics or for which we have the data available. For comparison we also report risk premia, defined as the difference between expected value and the valuation of the risky prospect, divided by its expected value.

As can be seen in Table 3.4, there is considerable heterogeneity in the observed ambiguity premium. However, the premium is positive for all studies considered, indicating ambiguity aversion. In comparison, the risk premium is even more variable and indicates risk seeking in some studies. We observe that studies vary strongly in

Table 3.4 Ambiguity premia in Ellsberg tasks for gains.

Study	Country	Task	Prize <sup>a</sup>	N	Valuation method <sup>b</sup>	Incentive method <sup>c</sup>	Risk premium	Ambiguity premium relative to EV	Ambiguity premium relative to risky
Abdellaoui, Baillon et al. (2011)	France	2-color	€25 (≈\$34)	66	CE	CL	-13.2	2.8	2.5
Abdellaoui, Klibanoff et al. (2011)	France	2-color	€50	64	CE	CL	3.5	5.6	5.8
		(2 balls) 2-color (12 balls)	(≈\$67) €50 (≈\$67)				1.9	17.3	17.7
Akay et al. (2012)	Ethiopia	2-color	ETB20 (≈\$.5)	93	CE	CL	50.3	6.4	12.9
Borghans, Golsteyn, Heckman, & Meijers (2007)	Netherlands	2-color	€2 (≈\$3)	347	WTA	BDM	6.8	12.3	13.2
Cettolin & Riedl (2010)	Netherlands	2-color	€15 (≈\$20)	55	MP	CL	-	-	10.0 <sup>+</sup>
Chew, Miao, & Zhong (2013)	Singapore	2-color	S\$40 (≈\$30)	56	CE	CL	32.5	15.5	22.9
Chow & Sarin (2001)	USA	2-color	\$100	42	WTA	BDM	-6.9	30.1	28.2
Cohen, Jaffray, & Said (1987)	France	2-color	FF1,000 (≈\$150)	134	CE	CL	2.4	22.8	23.4
Cubitt, van de Kuilen, & Mukerji (2014)	Netherlands	2-color	€16 (≈\$21)	88	CE	CL	11.9	7.1	0.6
Dimmock et al. (2012)	Netherlands	2-color	€15 (≈\$20)	675	MP	C	-	-	20.0
Dimmock et al. (2013)	USA	2-color	\$15	3,158	MP	C	-	-	3.6

(Continued)

Table 3.4 (Continued)

<i>Study</i>	<i>Country</i>	<i>Task</i>	<i>Prize<sup>a</sup></i>	<i>N</i>	<i>Valuation method<sup>b</sup></i>	<i>Incentive method<sup>c</sup></i>	<i>Risk premium</i>	<i>Ambiguity premium relative to EV</i>	<i>Ambiguity premium relative to risky</i>
Eisenberger & Weber (1995)	Germany	2-color	DM10 (≈\$7)	54	WTP	BDM	56.8	8.1	18.8
					WTA	BDM	38.9	5.5	9.0
Fox & Tversky (1995)	USA	2-color	\$100	67	WT	Hypo	51.3	19.0	39.0
		2-color	\$20	52	PCE	CLB	2.6	12.1	12.4
		3-color	\$50	53	WTA	DM	-12.3	9.8*	10.3*
			€15 (≈\$19.5) or €6.20 (≈\$8.5) <sup>#</sup>	20	WTP	BDM	9.5	6.5	7.2
Füllbrunn, Rau, & Weitzel (2013)	Netherlands	2-color	€15 (≈\$19.5) or €6.20 (≈\$8.5) <sup>#</sup>	12	WTP	BDM	3.4	4.7	4.8
				104	WTA	BDM	-6.0	18.0	17.0
Halevy (2007)	Canada	2-color	\$2	38	WTA	BDM	16.3	17.1	20.4
		2-color	\$20	90	CE	CL	8.2	16.1	17.5
Keck et al. (2011)	USA	2-color	\$20	90	WTP	Hypo	52.5	25.1	52.8
Keller, Sarin, & Souderpandian (2007)	USA	2-color	\$100	62	MP	Hypo	-	-	15.0 <sup>++</sup>
Lauriola & Levin (2001)	Italy	2-color	ITL100,000 (≈\$51)	19	MP	Hypo	-	-	20.0 <sup>+</sup>
MacCrimmon & Larsson (1979)	USA	2-color	\$1,000	25	WTA	BDM	3.8	23.3	24.2
Maffioletti & Santoni (2005)	Italy	2-color	ITL100,000 (≈\$51)	66	MP	CL	-	-	1.8
Ross et al. (2012)	Laos	2-color	LAK20,000 (≈\$2.5)						

Sutter et al. (2013)	Austria	2-color	€10 (≈\$13)	487	CE	CL	12.6	13.4	15.3
Trautmann & Schmidt (2012)	Netherlands	2-color	\$100	90	WTP	Hypo	38.0	32.0	51.6
				88	WTA		4.0	20.0	20.8
Trautmann et al. (2011)	Netherlands	2-color	€50 (≈\$67)	59	WTP	Hypo	52.6	17.6	37.0
		2-color	€50 (≈\$67)	74	WTP	BDM	46.2	21.9	40.7
		2-color	€15 (≈\$20)	63	WTP	Hypo	28.8	26.9	37.8
		2-color	€50 (≈\$67)	79	CE	CL	38.2	6.8	10.9
		2-color	€50 (≈\$67)	89	WTA	Hypo	2.1	9.6	9.8
Qiu & Weitzel (2011)	Netherlands	2-color	€10 (≈\$13)	208	WTP	BDM	14.4	18.6	21.7
			€5 (≈\$6.5)				2.0	14.0	14.3
			€30 (≈\$39)				24.7	10.2	13.5
Vieider (2013)	Germany	2-color	€30 (≈\$39) or	47	CE	CL	15.7	1.5	1.7
			€10 (≈\$13) <sup>#</sup>						
			€30 (≈\$39) or				1.1	0.4	0.4
Yates & Zuckowski (1976)	USA	2-color	€20 (≈\$26) <sup>#</sup>						
			\$1	108	WTA	BDM	–	19.6	–

Notes. <sup>a</sup> Zero payoff when losing the bet, unless indicated otherwise.

<sup>b</sup> Valuations are measured by the certainty equivalent (CE), the willingness-to-pay (WTP), the willingness-to-accept (WTA) for an act, or the matching probability (MP) of the act.

<sup>c</sup> Hypothetical (Hypo) or real incentives, the latter implemented using a choice list (CL), separate choices (C), or the Becker–deGroot–Marschak procedure (BDM).

<sup>d</sup> Premium as reported by Camerer and Weber (1992).

<sup>++</sup> Matching probability derived from sample mean.

<sup>\*</sup> Mean premium over likely and unlikely act.

<sup>#</sup> Win high prize if guess is correct, and lower prize otherwise.

terms of the stake sizes, the valuation method, and the incentive method employed. There is large variation of sample sizes as well. A metastudy on the basis of the original data would be needed to assess the role of these methodological choices. Eyeballing the results suggests that choice-based methods with real incentives yield lower premia than hypothetical or WTP/WTB measurements, and that positive (rather than zero) payoffs in case the bet is lost strongly reduce the ambiguity premium. We also note that the average premia shown in Table 3.4 curtail significant heterogeneity across subjects within each study.<sup>3</sup>

***Moderators of ambiguity attitude.*** Many potential moderators of ambiguity aversion have been studied in the literature. We discuss four moderators that we consider important from the perspective of the ecological validity of the laboratory measures of ambiguity: comparative ignorance, peer effects, group decisions, and market interaction.

An important finding concerns the comparative nature of ambiguity attitudes. Fox and Tversky (1995; see also Chow & Sarin, 2001; Fox & Weber, 2002; Qiu & Weitzel, 2011) showed that ambiguity aversion is most pronounced in situations in which both risky and ambiguous options are considered jointly. A separate presentation of an ambiguous act without explicit mention of a risky act leads to roughly equal or only slightly lower valuations of the ambiguous option.<sup>4</sup> The effect is consistent with an interpretation of ambiguity in terms of source preference, where joint presentation emphasizes the difference of the decision maker's knowledge or competence regarding the two alternatives (see Conclusion and Outlook). Note that counterbalancing of tasks can therefore lead to significantly different valuations because ambiguity aversion will typically be lower when the ambiguous option is evaluated first (Fox & Weber, 2002; see also Dimmock et al., 2013, Table V for a demonstration of this effect). Given that many experiments use designs where risky and ambiguous bets are directly compared, while outside the laboratory there are often few truly unambiguous options, it is not clear how far quantitative laboratory measurements are representative of the preferences in potentially noncomparative real-world settings.

Some studies started from the observation that people often make decisions that are either observed by others or made jointly with others. Curley, Yates, and Abrams (1986) find that peer effects moderate ambiguity attitude: observation by peers increases ambiguity aversion. This effect has been replicated (Muthukrishnan, Wathieu, & Jing Xu, 2009; Trautmann, Vieider, & Wakker, 2008) and is consistent with the finding that people consider arguments for ambiguity neutrality unconvincing (Slovic & Tversky, 1974) and expect other people to be ambiguity averse (Kocher & Trautmann, 2013). Three papers have looked at group decisions. Keller et al. (2007) study dyads and find no difference between individual and joint decisions. Keck et al. (2011) compare individual decisions and decisions in groups of three people. They find a mild tendency towards ambiguity neutrality in the group compared to the individual decisions. Their result is consistent with the third study on groups, namely Charness et al.'s (2013) study on persuasion. Charness et al. show that in mixed groups, that is, groups consisting of subjects with different ambiguity attitudes, ambiguity neutrality seems to have a slight "persuasive edge" over both ambiguity aversion and ambiguity seeking. Interestingly, ambiguity aversion does not seem more justifiable than ambiguity seeking nor vice versa. These results are surprising in the light of the peer effect described above,

which suggests that ambiguity aversion is more socially acceptable. This effect seems not to manifest itself in group decisions.

When confronted with violations of SEU in individual decision situations, economists are often concerned about whether the effect is robust in market settings. If it does not show up in markets, the efficient allocation of resources may not be affected by a decision bias, which may thus be of minor importance to economics. Moreover, it is sometimes assumed that agents who violate SEU (or some other normative model of decision making) are driven out of the market. Given these reservations, and given the prominence of ambiguity-based explanations of market anomalies in asset markets, there is surprisingly little work so far on ambiguity in markets.

In an early study, Sarin and Weber (1993) let subjects trade risky and ambiguous acts as described earlier in the section Ellsberg Urns and Other Operationalizations of Ambiguity. The study found clear evidence for ambiguity aversion in double-auction and sealed-bid auction markets, in both simultaneous and sequential markets. Kocher and Trautmann (2013) study similar auction markets but let agents select into one market only. They find that most subjects prefer to enter the market for the risky asset, although they correctly anticipate more severe competition in the risky than the ambiguous markets (more bidders). Interestingly, market prices are similar in both markets. This pattern can be explained by a higher risk tolerance that is observed for the participants in the ambiguous market. These findings suggest that ambiguity attitudes correlate with other attitudes, making self-selection along the ambiguity dimension a potential factor for market outcomes (see below, “Correlation between risk and ambiguity attitudes”).

Bossaerts, Ghirardato, Guarnaschelli, & Zame (2010) study ambiguity aversion in a slightly different market setting. Bossaerts et al. model the uncertain future state of the world as a three-color Ellsberg urn. The true state is drawn from an urn with eighteen balls, six of them red, and the other twelve either green or blue in an unknown proportion. In some sessions there is no ambiguity, and the exact numbers of green and blue balls are known. Assets are state-dependent claims, that is, assets yield prizes depending on the color of the ball drawn from the ambiguous urn. Bossaerts et al. observe portfolio choices and market prices and find evidence that ambiguity affects both portfolios and prices. They conclude that ambiguity averters affect market outcomes. They are not driven out of the market.

While these results suggest that ambiguity aversion has an impact on market prices and asset holdings it is clear that the evidence is still limited. In an ongoing research effort to replicate and extend the current evidence, Füllbrunn et al. (2013) find that ambiguity aversion very quickly vanishes in various types of markets (call markets, double auctions). They replicate ambiguity aversion in an individual decision task, however, showing that market interaction must play a role here. More research on the effects of market interaction on ambiguity attitudes is clearly needed before robust conclusions can be drawn.

### Ambiguity seeking for unlikely events

Ellsberg already conjectured that ambiguity attitude might depend on the perceived size of the likelihood of the ambiguous event. Curley and Yates (1989) address this issue by asking subjects to compare a risky bet with a winning probability of .25 to an

ambiguous bet on a ball drawn from an urn containing five winning balls, fifty-five losing balls, and forty winning or losing balls in unknown proportion. The setup implies that an ambiguity-neutral decision maker is indifferent between the two bets. Curley and Yates find that the majority of subjects *prefer* the ambiguous act. Thus, they are not pessimistic about the distribution of the forty unknown balls. Ambiguity-seeking preferences for unlikely events have also been found by Chipman (1960), Kahn and Sarin (1988), Casey and Scholz (1991), Vieider, Martinsson, and Medhin (2012), and Dimmock et al. (2012, 2013). The latter two studies replicate the finding using a representative sample of the Dutch and U.S. population, respectively. For a .10 probability risky bet, Dimmock et al. find matching probabilities of .22 in the Dutch, and .24 in the U.S. population, for an equivalent ambiguous bet (like  $g_i$  in Table 3.3). Thus, on average, respondents are indifferent between betting on the event that one out of ten colors is drawn from the ambiguous urn and a more than 20% known chance of winning, showing a significant degree of ambiguity seeking for unlikely events.<sup>5</sup>

Some studies found less ambiguity aversion for unlikely events than for moderate- and high-likelihood events but no ambiguity seeking. Abdellaoui, Baillon (2011) elicit certainty equivalents of acts as shown in Table 3.3 but using balls of eight different colors instead of ten different numbers. Thus, the risky urn contained eight differently colored balls, and the ambiguous urn contained eight balls with an unknown composition of the eight colors. Abdellaoui, Baillon find that subjects prefer the risky acts over the ambiguous acts based on the high-likelihood event of drawing any one of seven colors, replicating ambiguity aversion for high-likelihood events. However, subjects have no clear preference between acts based on low-likelihood events, suggesting ambiguity neutrality. These preferences pertain irrespective of the winning color, excluding the possibility that the preferences are driven by beliefs about the distribution of colors in the ambiguous urn. A few other studies have also found ambiguity neutrality for unlikely events (Curley & Yates, 1985; Einhorn & Hogarth, 1986; Sarin & Weber, 1993).

The differences in ambiguity attitudes observed between unlikely events on the one hand and moderate- and high-likelihood events on the other hand suggest that a person's ambiguity attitude cannot easily be captured by a single number (as arguably we did in Table 3.4). Abdellaoui, Baillon (2011) and Dimmock et al. (2012) propose measures of ambiguity attitudes that capture the complexity of preferences once we move away from moderate-likelihood events as in the two- and three-color Ellsberg tasks.

### Ambiguity seeking for losses

Many investments, insurance decisions, and medical choices involve potential losses. An important question therefore concerns the robustness of ambiguity attitudes with respect to the outcome domain. In an early study, Cohen et al. (1987) use the two-color Ellsberg task to study ambiguity attitudes for losses. Cohen et al. elicit certainty equivalents of risky and ambiguous bets, involving gains or losses. For gains, the majority of subjects are ambiguity averse. For losses, Cohen et al. did not find significant differences between the certainty equivalents of risky and ambiguous bets. This combination of ambiguity aversion for gains and ambiguity neutrality for losses has also been found in other studies (De Lara Resende & Wu, 2010; Di Mauro & Maffioletti, 1996; Du & Budescu, 2005; Einhorn & Hogarth, 1986; Eisenberger



& Weber, 1995; Friedl, Lima de Miranda, & Schmidt, 2014; Mangelsdorff & Weber, 1994; Smith, Dickhaut, McCabe, & Pardo, 2002; Trautmann & Wakker, 2012; Tymula, Glimcher, Levy, & Rosenberg Belmaker, 2012).

A significant number of studies found a complete reversal of ambiguity attitudes between the (modest-likelihood) gain and loss domain, with ambiguity seeking for losses (Abdellaoui, Vossman, & Weber, 2005; Baillon & Bleichrodt, 2012; Casey & Scholz, 1991; Chakravarty & Roy, 2009; Ho, Keller, & Keltz, 2002; Kothiyal, Spinu, & Wakker, 2012). Indeed, there is some evidence of a fourfold pattern of ambiguity attitudes, with ambiguity aversion for high-likelihood and ambiguity seeking for low-likelihood gain events, and the opposite pattern for losses (Di Mauro & Maffioletti, 2004; Hogarth & Kunreuther, 1985; Hogarth & Kunreuther, 1989; Kahn & Sarin, 1988; Vieider et al., 2012; Viscusi & Chesson, 1999).

A few studies found ambiguity aversion for losses (Keren & Gerritsen, 1999; Inukai & Takahasi, 2009).<sup>6</sup> On balance, though, there is clear evidence for an effect of the outcome domain on ambiguity attitude. A careful consideration of these gain–loss differences seems warranted in applications in insurance of health, where losses play an important role.

### Correlation between risk and ambiguity attitudes

The correlation between risk and ambiguity attitude has received much attention in empirical studies. It is important because it can guide descriptive modeling of decisions under uncertainty and has empirical implications. Assume, for instance, that ambiguity-seeking individuals are also risk seeking. If ambiguity seekers invest in different asset classes than ambiguity averters, risk premia in the markets with many ambiguity seekers may then be lower than in the markets with ambiguity averters (e.g., Bossaerts et al., 2010; see Ambiguity seeking for losses, above).

Many studies report some evidence on a positive correlation between risk aversion and ambiguity aversion. For example, Charness and Gneezy (2010, p. 139) and Bossaerts et al. (2010; see Ambiguity seeking for losses, above) report that ambiguity seekers hold more volatile/risky portfolios. Kocher and Trautmann (2013) find that participants in ambiguous markets are more risk seeking than those in a risky market, where risk aversion was measured by an independent task. Abdellaoui, Baillon et al. (2011), Dimmock et al. (2012, 2013), and Butler et al. (2011) find direct evidence for a positive correlation when risk and ambiguity attitudes are measured for the same person but in different tasks. While Dimmock et al. (2012, 2013) find correlations of around  $\rho=.16$ , Abdellaoui, Baillon et al. (2011) identify different components of risk and ambiguity attitude and find high correlations ( $\rho=.8$ ) between the pessimism component in risk and ambiguity as modeled in a prospect theory framework (pessimism in probability weighting/event weighting). This finding thus suggests an underlying mediating mechanism for the correlation. Butler et al. find that both risk attitude and ambiguity attitude are related to an agent's decision style (intuitive vs. thoughtful). In particular, intuitive decision makers are less risk and ambiguity averse. Butler et al. find a positive correlation of  $\rho=.07$ .<sup>7</sup> Qiu and Weitzel (2011) and Chew et al. (2013) report large positive correlations of  $\rho=.49$  and  $\rho=.567$  in experiments measuring WTP and CE for each prospect, respectively.

A few studies find less clear, but suggestive evidence for a positive correlation. Lauriola and Levin (2001) find evidence in the domain of losses only, while Chakravarty and Roy (2009) find it only for the gain domain. Lauriola, Levin, and Hart (2007) find a correlation only when excluding subjects with relatively weak ambiguity attitudes, and Koch and Schunk (2012) find it only when real losses are possible. Potamites and Zhang (2012) find a weakly significant correlation.

On the other hand, there are also a few studies that find no correlation or negative correlation. Cohen, Tallon, and Vergnaud (2011) run a large-scale study with the explicit goal to test for correlations among preference measures and find no correlation between risk and ambiguity attitudes. Levy, Snell, Nelson, Rustichini, and Glimcher (2010) find a small and insignificant correlation. Akay et al. (2012), Cubitt et al. (2014), and Sutter et al. (2013) find a moderately negative correlation between risk and ambiguity aversion.<sup>8</sup> These three studies define ambiguity aversion as the normalized difference between the certainty equivalent of the risky act and the certainty equivalent of the ambiguous act in an Ellsberg two-color task. This design may reduce the observed correlation, or even lead to negative correlation, because of the comparative-ignorance effect on valuations of risky lotteries previously discussed and for purely statistical reasons (the maximally risk-averse subjects cannot reveal ambiguity aversion, etc.). In contrast, most of the cited papers that find clear evidence for a positive correlation use methods where ambiguity attitude is measured independently of risk attitude and risk attitude is measured in a separate task.

Although the overall evidence is suggestive of a positive correlation between risk and ambiguity aversion, it should be discounted by the fact that many studies may not report the absence of a correlation. The correlation may also be sensitive to the elicitation method and to the way it is calculated (e.g., based on raw choices or in terms of model parameters). Little is yet known about the potential causes of the correlation. Pessimism and decision mode have been suggested as possible mediators, but other factors may play a role. More research is needed to identify the empirical link between risk and ambiguity attitudes.

### Ambiguity attitude as source preference

A few studies used natural uncertainty as discussed earlier under the heading Natural sources of uncertainty. The important insight emerging from this literature is that in the domain of gains agents prefer sources of uncertainty they feel more competent or knowledgeable about over those about which they feel less competent (Abdellaoui, Baillon et al., 2011; De Lara Resende & Wu, 2010; Fox & Weber, 2002; Heath & Tversky, 1991; Keppe & Weber, 1995; Kilka & Weber, 2001; Tversky & Fox, 1995). Kilka and Weber calibrate a two-stage prospect theory model where people form subjective beliefs which are subsequently weighted nonlinearly (see Fox & Tversky, 1998; Wakker, 2004, 2010, p. 292; Wu & Gonzalez, 1999). They show that competence about the source of the uncertainty affects both subjective probability judgments and the weighting of these beliefs in the decision. Using German subjects they employ stock prices of large German and Japanese banks as sources of uncertainty. They find source preference for the German bank, illustrating the link between home bias discussed earlier and source preference driven by feelings of knowledge and

competence: investors shun the markets they feel less competent, and thus more ambiguous, about.

Another example of this effect concerns the comparison between an ambiguous bet and a belief-matched risky bet. In this case, people typically prefer betting on the known risk if they feel incompetent or unknowledgeable about the source of ambiguity, but they prefer betting on the ambiguous event if they feel knowledgeable about the ambiguous source (Heath & Tversky, 1991). The classic example is the basketball fan who prefers betting on his beliefs about the next game rather than on a matched risky act. Similar effects have been found for other domains of expertise. Moreover, De Lara Resende & Wu, (2010) also extend the competence paradigm to the loss domain and find neutrality with respect to the source of uncertainty, resembling the pattern observed in Ellsberg urn studies.

While these studies support the view that ambiguity attitude is a special case of the broader concept of source preference a recent study by Chew, Ebstein, and Zhong (2012) suggests that there might be important differences. For a sample of Chinese subjects from Beijing, Chew et al. elicit ambiguity attitudes in an Ellsberg two-color task and source preferences regarding bets on the temperature in Beijing or Tokyo (controlling for beliefs) in a within-person design. They also collect genetic data on their participants. Chew et al. replicate both ambiguity aversion and the competence effect, that is, preference for bets on Beijing temperature. However, the two attitudes are uncorrelated at the individual level. Moreover, the two attitudes are related to different genetic markers. Thus, the relation between ambiguity and source preference might be more complex than the former simply being a special case.

## **Evidence on External Validity of Laboratory Measures**

Complementing the experimental literature discussed in the section Stylized Facts From Laboratory Experiments is an equally extensive theoretical literature that aims to explain empirically observed phenomena by ambiguity aversion. In economics and finance, ambiguity aversion has received much attention as a potential explanation for asset market anomalies (from the SEU point of view) like the equity premium puzzle, the stock market participation puzzle, or home bias.<sup>9</sup> In the medical field, treatment decisions and test take-up have been studied under ambiguity (Berger et al., 2013; Hoy et al., 2013). In the law, far-reaching proposals regarding the structure of the criminal process have been based on the assumption of ambiguity-averse defendants (Stein & Segal, 2006). These studies often refer to the experimental evidence to motivate an approach based on ambiguity aversion. However, there is surprisingly little evidence yet in support of the assumed link from Ellsberg-urn ambiguity attitude to behavior outside the laboratory, and thus on the external validity of the ambiguity attitude concept.

Muthukrishnan et al. (2009) provide evidence for the external validity of Ellsberg measures in a marketing setting. The authors observe both ambiguity attitudes and preferences between products from different brands. Brands are classified in a pretest as being perceived as more or less ambiguous in terms of quality. The study finds that subjects who are more ambiguity averse are also more likely to prefer an

established, low-ambiguity brand. Although the study concerns only laboratory behavior of student subjects it shows that ambiguity attitude can predict behavior across different tasks.

Rieger and Wang (2012) collect ambiguity attitudes of students as well as published estimates for local stock market equity premia for 27 countries worldwide. They find an economically (in the range of  $\rho=.5$ ) and statistically significant correlation between the share of ambiguity-averse subjects and the local equity risk premium, and interpret the result as support for ambiguity-based explanations of the equity premium puzzle. On a cautionary note, we observe that Rieger and Wang (2012) do not allow subjects to choose the winning color in their hypothetical three-color Ellsberg problem.<sup>10</sup> Although mistrust toward the experimenter cannot affect the choices in the hypothetical survey, trust issues may nevertheless affect subjects' answers: they may simulate real-life situations in which (self-interested) people offer them ambiguous bets and avoidance behavior is a good heuristic (Al-Najjar & Weinstein, 2009; Morris, 1997). This could explain the observed correlation.

Three studies have recently run large-scale ambiguity experiments using populations other than students with the aim of relating ambiguity attitude to behavior outside the laboratory. Sutter et al. (2013) measure risk, ambiguity, and time preference in children and observe background data relating to economic and health behavior. Ambiguity-averse children are found to be less likely to smoke, drink, or misbehave at school. However, in contrast to very sizable and robust effects for time preference, the empirical correlations for ambiguity are statistically and economically weak.

Dimmock et al. (2012) and Dimmock et al. (2013) measure ambiguity attitudes on the Dutch LISS panel and the American Life Panel, respectively, to test for a relationship between ambiguity aversion and stock market participation. Both panels allow conducting experiments with real payments and provide extensive financial background data on the participants. Dimmock et al. (2012, 2013) use the source method of Abdellaoui, Baillon et al. (2011) to measure ambiguity aversion and *likelihood insensitivity*: people may distinguish well between impossible and possible events, and between uncertain and sure events, but they may not make a great distinction between events bounded away from zero and one. This leads to an overweighting of unlikely events and an underweighting of high-likelihood events. Both studies elicit attitudes in the domain of gains. Dimmock et al. (2012) find no evidence for a correlation of stock market participation and ambiguity aversion. However, they find that stronger likelihood insensitivity predicts lower stock market participation and business ownership.<sup>11</sup> They explain these findings by the fact that insensitivity leads to an overweighting of rare economic disasters. In contrast, Dimmock et al. (2013) do not find any evidence for the suggested effect of likelihood insensitivity, but they do find that ambiguity aversion reduces stock market participation as predicted by ambiguity-based theories. We may conclude that the stock market participation puzzle remains puzzling in view of these findings.

Two studies consider ambiguity attitudes in the context of development economics, relating ambiguity attitudes to farming choices. Engle-Warnick et al. (2007) find that Peruvian farmers who avoid ambiguity in an experimental task are less likely to adopt new varieties of crop. Similarly, Ross et al. (2012) find that ambiguity-averse farmers in Laos are less likely to adopt a new variety of rice, and, when adopting, use it less

intensively than the less ambiguity-averse farmers. In a related study, Cardenas and Carpenter (2013) test theories suggesting that risk aversion leads to poverty because risk-averse people miss out beneficial economic opportunities. They study the effect of various components of uncertainty attitude on economic outcomes in a large representative sample. They find evidence that ambiguity aversion, but not risk aversion, explains variation in economic outcomes.

There is thus some initial evidence that experimental measures of ambiguity correlate with behavior outside the laboratory. Two problems may add to the difficulty in establishing clear links between ambiguity attitude and behavior. First, the fourfold pattern of ambiguity attitudes discussed above suggests that the moderate-likelihood gain domain, which is predominantly used to measure ambiguity attitudes, might not be a good predictor for investment, insurance, or health choices where both gains and losses are relevant. Second, the evidence on source preference suggests that it is highly ambiguous which prospects decision makers perceive as ambiguous in the field.

## **Conclusion and Outlook**

We have reviewed the experimental literature on ambiguity attitudes. Our two main insights can be summarized as follows. First, ambiguity aversion is most prevalent in the domain of moderate-likelihood gains. This is the domain that has received by far the most attention in the field, probably because of the ease of implementation. In the domains of low likelihood or loss acts, ambiguity seeking is the typical finding, although admittedly based on fewer studies. Given the relevance of these domains in the field, the universal focus of theoretical work on ambiguity aversion seems misplaced. More attention in experimental work to ambiguity-seeking preferences may be fruitful as well. The recent financial turmoil also suggests that there is more to financial behavior than “aversion.”

Second, our review of potential moderators of ambiguity attitude, the underlying psychological mechanisms, and its relation to behavior outside the laboratory have revealed mixed results. This ambiguity about the psychology of ambiguity might be caused by the pattern of ambiguity aversion and seeking we discussed. How can we interpret a finding that peer effects increase ambiguity aversion in domains where people are typically ambiguity seeking? Are the psychological mechanisms leading to ambiguity aversion in one domain and ambiguity seeking in another domain the same? Another reason for the mixed results relates to the interpretation of ambiguity in terms of source preference and competence effects. In particular for decisions outside the laboratory like treatment decisions, investments or crop choice, it may not be obvious which alternative the decision maker perceives as ambiguous. Similarly, group decisions or market interaction and prices may influence the decision makers' feelings of competence and knowledge, and thus their perception of alternatives as more or less ambiguous.

We want to mention three promising directions of experimental ambiguity research that we could not discuss in detail because of space limitations. First, though there is a large literature on learning and a large literature on ambiguity, there is yet little

evidence on how learning influences ambiguity attitude and how ambiguity attitude may affect the decision to experiment and learn (Anderson, 2012; Baillon, Bleichrodt, l'Haridon, Keskin, & Li, 2012; Ert & Trautmann, 2014; Qiu & Weitzel, 2013; Trautmann & Zeckhauser, 2013). Learning opportunities are common to dynamic settings, making it empirically relevant. It is also interesting from a (descriptive) theoretical perspective to observe how people update ambiguous probabilities. Second, a few papers have experimentally tested specific assumptions of axiomatic ambiguity models (Dominiak, Dürsch, & Lefort, 2012; Dominiak & Schnedler, 2011; Eichberger, Oechssler, & Schnedler, 2012; L'Haridon & Placido, 2010). Such tests are interesting because theories are often used descriptively in applications and the tests inform us which theories are based on sound empirical foundations. Third, various studies have looked at the demographic correlates of ambiguity aversion. Overall, we could not identify any consistent patterns in the existing literature so far (Borghans et al., 2009; Butler et al., 2011; Dimmock et al., 2012, 2013; Sutter et al., 2013). We expect that future research on balls and urns, and maybe on ambiguous real-life decisions, will help to answer these open questions.

### Acknowledgments

We are grateful to Olivier Armantier, Han Bleichrodt, Nicolas Treich, Alex Voorhoeve, Peter Wakker, Utz Weitzel, the editors Gideon Keren and George Wu, and an anonymous reviewer for very helpful suggestions and comments. All errors, omissions, and interpretations are our own.

### Notes

1. A potential composition of the ambiguous urn is (1,1,1,5,6,7,7,7,7,7).
2. For example, Haisley and Weber (2010) employ ambiguity experiments to study moral behavior. Inbar, Cone, & Gilovich (2010) use an ambiguity task to study intuition.
3. A file with the calculations underlying Table 3.4 is available at <http://dx.doi.org/10.11588/data/10011>.
4. It is noteworthy that the comparative-ignorance effect does not typically lead to decreased valuations for the ambiguous act, but to *increased* valuations of the risky act. Loosely speaking, the presence of ambiguity seems to make known-probability risk look nicer. This can have implications for the elicited risk attitudes when measured jointly with ambiguity attitudes (see the section, Correlation between risk and ambiguity attitudes).
5. Some of the ambiguity seeking observed in these studies could be driven by participants' optimistic expectations.
6. Note that Inukai and Takahasi (2009) do not offer subjects the choice of the winning color as discussed above in the section on the Ellsberg urns, and their results might have been affected by trust issues.
7. The correlation is not reported explicitly in Butler et al. (2011) but is given in Guiso and Jappelli (2008).
8. No correlations were discussed in Akay et al. (2012) and Sutter et al. (2013). Own calculation based on the original data.

9. The equity premium puzzle refers to the finding that in EU-based asset pricing models the empirically observed equity premia imply unreasonably high degrees of risk aversion. Assuming that stocks are ambiguous and investors are ambiguity averse allows reconciling observed equity premia with reasonable risk attitudes. The stock market participation puzzle refers to the finding that, in contrast to the portfolio theory prediction based on EU, a large share of people do not hold any risky assets. See Epstein and Schneider (2010) and Guidolin and Rinaldi (2013) for reviews of this literature.
10. Note that Rieger and Wang (2012) employ an Ellsberg urn with thirty red and seventy yellow or blue balls. Thus, even modestly ambiguity-averse subjects would choose the ambiguous bet. The absolute degree of ambiguity-averse choices in their study is thus not directly comparable to other studies.
11. Holm, Oppen, and Nee (2013) find no differences in ambiguity aversion between entrepreneurs and non-entrepreneurs. They do not measure likelihood insensitivity, though, and their measure of ambiguity aversion does not control for differences in risk aversion.

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