RISK ASSESSMENT IN ENTREPRENEURSHIP

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

Abstract

This PhD dissertation applies the science of decision making to management, specifically entrepreneurship. The purpose of this research is to better understand entrepreneurial behaviour under condition of Knightian uncertainty, or subjective ambiguity, a condition that characterizes entrepreneurship. Specifically, this dissertation focuses on people's attitude to ambiguity. I explain how attitude to ambiguity can be considered a subjective assessment of an event's likelihood under condition of ambiguity, or, in more generalized terminology, a subjective risk assessment for a context representative of entrepreneurship. The dissertation achieves its stated purpose in three ways. First, it translates and adapts theory from human decision making, and specifically behavioural economics, for entrepreneurship. Second, it contributes to empirical research by presenting my findings from two experimental studies I performed to measure subjective assessment in numerical and non-numerical ways. Third, it draws on this adapted theory to propose practical strategies to help entrepreneurs cope with ambiguity. The contributions of this work are primarily in the entrepreneurship discipline, broadly defined. With continued research, researchers might better understand entrepreneurial behaviour under condition of Knightian uncertainty, or risk assessment in entrepreneurship—a ubiquitous and yet incompletely researched topic.

This dissertation provides three key contributions, primarily in entrepreneurship. The first contribution is a collection of ways that this dissertation translates and adapts theory from human decision making, and specifically behavioural economics, for entrepreneurship. It does this in five ways. The first way is with a conceptual model of attitude to ambiguity in a context that is representative of entrepreneurship. This model is described in Chapter 2. This conceptual model can be used to help design experiments to study attitude to ambiguity for a context that is representative of entrepreneurship, and is used in the design of the study that was performed as part of this research

and is described in Chapter 5. The second way is with a pragmatic protocol that can be used to operationalize attitude to ambiguity in a context that is representative of entrepreneurship. This protocol is described in Chapter 3 and employed to develop a survey used in the study of Chapter 5. The third way is with a summary contrasting similar protocols from prior research. This summary is provided in Chapter 1.2. The fourth way is with a measure of unpredictability tolerance, a personality trait described in Chapter 4, which is used to study the relationship between this personality trait and attitude to ambiguity. This measure is used in the study of Chapter 5. The fifth way is with a reference table of relevant terminology across disciplines, provided in Chapter 1.1, which can be used to bridge understanding between decision making and entrepreneurship literatures.

The second contribution is a collection of empirical findings of two experimental studies I performed to measure subjective assessment in numerical and non-numerical ways. It does this in two ways. The first way is with a collection of findings of the study of Chapter 5, investigating factors that are anticipated to effect attitude to ambiguity, which is reinterpreted more intuitively as ambiguity additivity in Chapter 5.3.1, under condition of ambiguity in a context that is representative of entrepreneurship. These findings (1) provide strong evidence that people's subjective assessments of likelihoods under condition of ambiguity are sub-additive, (2) provide evidence that those who are more tolerant of unpredictability are more predictable in their additivity, and (3) suggest an interaction effect between time horizon and loss on additivity. The second way is with the exploratory result of a study described in Chapter 6. Briefly, this result not only supports a new metaphor for exploring ambiguity attitudes, namely, one that is psychometric, but also suggests that a measure might be developed that may be easier to administer, and self-administer, than prior protocols.

The third contribution of this dissertation is that it draws on its first contribution, adapted theory, to propose practical strategies to help entrepreneurs cope with ambiguity. It does this in two ways. The first way is with the “ambiguity risk-management advice framework”, a proposed guide to help

entrepreneurs to cope with ambiguity. The second way is with the “ambiguity risk-management strategy framework”, a proposed guide to help ecosystem policy-makers who provide support to entrepreneurs who cope with ambiguity. These frameworks are described in Chapter 7, and a worked example demonstrating the application of contributions of this thesis, including a framework, is provided in that chapter.

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Dedication

This work is dedicated to my late father, John M. Csonka.

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"Psychophysical theories of risky choice do without a psychological concept of risk, but people cannot."

– *Lola L. Lopes, Engineering Psychology Program, US Office of Naval Research (1986)*

Chapter 1

Introduction

Entrepreneurship is risky business. It is characterized by unknowable risk, or Knightian uncertainty. As will become clear, Knightian uncertainty can also be referred to as subjective ambiguity. While a multitude of studies have looked at an entrepreneur's perception of risks in entrepreneurship, something is missing. Most studies have not teased apart perception of known risk and unknowable risk, or have specifically studied perception of known risk. This is problematic because literature from both decision making and neuroscience have found that our reactions (biases) to known risk and unknowable risk are not only cognitively distinct but also uncorrelated. This means that an entrepreneur could have opposing reactions to known risk and unknowable risk. In other words, notwithstanding our attitude to risk, our attitude to ambiguity will affect our entrepreneurial behaviour. Further, these two types of risk (known and unknowable) are affected by different factors. Because this is widely unknown in entrepreneurship, some prolific measures of risks conflate these two reactions, rendering the measures less useful or even misleading to understand an entrepreneur's perception of unknowable risk, also referred to here as subjective ambiguity. This, then, reflects a significant shortfall in how researchers have studied the perception of risks in entrepreneurship. In sum, the research territory of this thesis is an entrepreneur's perception of unknowable risk (or Knightian uncertainty), a ubiquitous and yet incompletely explored area of entrepreneurship.

The purpose of this research is to contribute to our understanding of an entrepreneur's perception of unknowable risk. This aim is achieved by looking at entrepreneurship through the lens of Knightian uncertainty, or subjective ambiguity. As will become clear, this perception can be measured by a subjective assessment of likelihoods, or, in more generalized terms, a subjective risk assessment. The research inquiry demanded an interdisciplinary approach, applying the science of

decision making to empirical entrepreneurship. To begin, extensive literature searches were performed. These searches are detailed below and in Chapter 1.3 (motivating gap).

This literature was instrumental in helping address a first research challenge, namely to situate and compare relevant literatures. A number of challenges arose because the terminology, constructs and their operationalization vary both across disciplines and within a discipline. These next sections will attempt to demystify constructs and findings, and provide the reader with a sound grounding in the somewhat diverse literatures.

1.1 Nature of the unknowable, the knowable, and the known

It has been hard to compare what has been done across disciplines, in part because the terminology has made the landscape confusing. This section will attempt to demystify terminology across disciplines.[1] Table 1.1 (terminology) describes terminology commonly used in empirical research studies across academic disciplines of decision making and entrepreneurship, and compares it to probability theory. Terms within a row have similar meanings, and differences in meaning across a row are described. Terms within a column share the assumption of subjective or objective perception.

[1] Apparently, 100 years ago, Knight had a problem with this too!

Table 1.1 Terminology across disciplines. Terms within a row have similar meanings, and differences in meaning across a row are described. Terms within a column share the assumptions of their academic domain.

Probability Theory	**Decision Making including Behavioural Economics and Ambiguity research**	**Entrepreneurship research including New Product Development**
Objective perception	**Subjective perception**	
• ***risk***: an exact probability (or probability distribution) is knowable and is ***known***, where knowable means it exists [objectively]	• ***risk***	
	• ***prospect with precise probabilities*** (e.g., Fox & Tversky, Aug., 1995)	• ***explicit risk:*** made known through sensitivity-type analysis (e.g., Forlani & Mullins, 2000)
	• ***sure amount:*** prospect with probability of 100% or 0% (e.g., Fox & Tversky, Aug., 1995)	
• ***uncertainty***: an exact probability (or probability distribution) is knowable and ***unknown***, where knowable means it exists [objectively]	• ***ambiguity***: "the subjective experience of missing information relevant to a prediction" and that could be obtained (Frisch & Baron, 1988) "uncertainty about probability, created by missing information that is relevant and could be known." (Camerer & Weber , 1992);	• ***the risk; risks***
• ***aleatory*** variability is uncertainty that is known to be random in nature. It can be modeled. It contains no cognitive bias.	• ***partial ambiguous gamble; partial ambiguity:*** outcome or probability is described by a numeric range (e.g., Rustichini et al., 2005)	• ***uncertainty***
	• ***ambiguity:*** an exact probability (or probability distribution) is unknown and unknowable, where unknowable means it does not exist objectively but may be estimated subjectively (e.g., Du & Budescu, 2005; Onay et al., 2013; Liu & Öncüler, 2017)	• ***uncertainty*** or ***Knightian uncertainty***: subjectively perceived by the Knightian entrepreneur as "unmeasurable and unquantifiable risk" (Knight, 1921); unknown and unknowable risk
	• ***aleatory uncertainty***: "attributed to outcomes that for practical purposes cannot be predicted and are therefore treated as stochastic (e.g., the result of a coin flip)" (Fox & Ulkummen, 2011)	• Knightian ***aleatory uncertainty:*** Knight's "*a priori* probability" (Knight, 1921, p. 224); perceived as indeterminate and based on known scientific laws (Townsend, under review) and exogenous (outside of the decision-maker's control). Any model is subjective and this bias is measurable by comparing to stochastic expectation.
•***ambiguity:*** an exact probability (or probability distribution) is unknown and ***unknowable***, where unknowable means it does not exist [objectively]; arising from a combination of high epistemic uncertainty and irreducible aleatory variability. It cannot be modeled.	• ***epistemic uncertainty***: "attributed to missing information or expertise (e.g., whether or not one has correctly answered a question on an exam) or inadequacy of one's model of aleatory uncertainty (e.g., whether or not a financial forecast is based on valid assumptions)" (Fox & Ulkummen, 2011)	• Knightian ***epistemic uncertainty***: Knight's "statistical probability" (Knight, 1921, p. 225); subjectively perceived by the Knightian entrepreneur as unknown, unknowable (Fox & Ulkummen, 2011; Townsend, under review) and exogenous Any model is subjective; it contains cognitive bias.
		• Knightian ***agentic uncertainty:*** Knight's "estimates" (Knight, 1921, p. 225); subjectively perceived by the Knightian entrepreneur as unknown, unknowable (Townsend, under review) and endogenous; Any model is subjective; it contains cognitive bias.

Probability Theory	Decision Making including Behavioural Economics and Ambiguity research	Entrepreneurship research including New Product Development
Objective perception	**Subjective perception**	
	• ***ambiguity:*** **"**a quality depending on the amount, type, reliability and "unanimity" of information, and giving rise to one's degree of "confidence" in an estimate of relative likelihoods." (Ellsberg, 1961)	• ***ambiguity***, ***equivocality***: ambiguous in interpretation; different interpretations of the same information exist between members of a [group of] decision-makers (Schrader et al., 1993; Spieth & Joachim, 2017)
	• ***irreducible uncertainty***: the "absence of critical information" and "high irreducible uncertainty [is that which] which cannot be eliminated through prior research". For instance, "the probability distribution of outcomes cannot be assessed" (Bhidé, 1999)	• ***uncertainty***
	• ***unknown risks*** (e.g., Blankenstein et al., 2017)	• ***the risk; risks***
	• ***highly ambiguous risks*** (e.g., Camerer & Weber, 1992)	
	• ***fuzzy uncertainties*** (Camerer, 2007)	
	• ***prospect with imprecise probabilities*** (e.g., Budescu et al., 2002)	
	• ***vague-prospect:*** prospect with probability and/or the outcome is unknowable (e.g., Onay et al., 2013)	
	• ***non-numerical probability*** (Keynes, 1921, p.41) that:can be related by method of "numerical approximation" to numerical probabilities (Keynes, 1921, p.176)	

1.1.1 Knightian uncertainty as subjective ambiguity

Probability theory, a branch of mathematics, has considered risky decision-making since before the time of Knight (1921)'s work. In probability theory, "ambiguity" describes conditions under which outcomes and their likelihoods are not only unknown (objectively and subjectively to the decision-maker) but also unknowable (does not objectively exits, not even subjectively known to the decision-maker[2]). In contrast, "risk" is a condition with a set of known outcome probabilities. For instance, a fair coin flip is a risky scenario where the coin has a 50% probability of landing on either side. "Uncertainty", on the other hand, refers to objectively unknown (even if only subjectively estimable) outcome distributions. This uncertainty can have a random dimension ("aleatory variability") and/or a non-random dimension ("epistemic uncertainty"). Probabilistic uncertainty can be objectively modeled with probabilistic methods. Furthermore, in probability theory, ambiguity refers to a condition under which outcomes and their likelihoods are objectively unknown and unknowable.

Entrepreneurship's use of the term "Knightian uncertainty" refers to ambiguity that is subjectively perceived. Knightian uncertainty is comprised of three types of ambiguity: a type that is subjectively perceived as random in its nature, which, if it is, can be more objectively perceived (Knightian "aleatory variability"), a type that is subjectively perceived as non-random and exogenous to the decision maker (Knightian "epistemic uncertainty"), and a type that is subjectively perceived as non-random and endogenous to the decision maker (Knightian "agentic uncertainty") (Knight, 1921; Townsend et al., under review).

Unfortunately, it is a source of confusion that Knight chose to use the term "uncertainty" to mean unknown and unknowable risk, while the traditional meaning of uncertainty in probability theory is unknown but knowable risk.

[2] i.e., …and even the decision maker would agree!;

KEY TAKEAWAY

In entrepreneurship, "uncertainty" refers to unknown and *unknowable* risk; in probability theory, "uncertainty" refers to unknown and *knowable* risk.

Probability theory treats ambiguity as objective; all decision makers are assumed to be exposed to the same condition of ambiguity. In contrast, Knightian uncertainty is treated as subjective; it allows ambiguity to be perceived differently by different decision makers.

In Behavioural Economics, ambiguity has broadly been described as perceived "missing information" (Frisch & Baron, 1988). Within the scope my empirical research described herein, which relies on empirical decision making, the nature of this missing information is limited to "Knightian uncertainty", which is what Knight (1921) described as "unmeasurable and unquantifiable risk", where "risk" is comprised of a distribution of both probabilities and *financial* outcomes.

To summarize, the unknowable described herein is referred to interchangeably as subjective ambiguity, Knightian uncertainty, or simply ambiguity. This is summarized in Table 1.1 (terminology), which will be referred to again later in this document.

1.2 Prior attempts to peer at the unknowable

Decision making researchers have a long history of peering at the unknowable. They have done this using an experimental protocol that taps into perception by measuring attitude to *subjective* ambiguity. In other words, decision making has been measuring attitude to Knightian uncertainty for decades! That has been unknown to entrepreneurship, until now.

As mentioned, it is a challenge to compare what has been done across disciplines because the constructs and their operationalization vary not only across disciplines but also within a discipline. This section will attempt to demystify the constructs. Relevant literature was found from two

literature searches, one focused on entrepreneurship literature and the other on decision making literature.

Entrepreneurship literature was found by doing Scopus data search using search terms "entrepreneur" and "empirical". Some 108,517 documents were found. Two of the top 5 by number of citations were by two entrepreneurship scholars. First, Shane and Venkataraman (2000)'s seminal entrepreneurship article, *The promise of entrepreneurship as a field of research,* remains part of mainstream entrepreneurship in two ways. For one, it remains an important primary scholarly source: This article was cited 5752 times, with 557 of those citations in 2020 alone. For another, it continues to shares a growing number of references with 66,554 other documents, mostly from the subject areas of business, economics and social sciences. Second, Lumpkin and Dess (1996)'s review of empirical constructs is another important entrepreneurship article, cited 4223 times and sharing references with 149,606 related documents. Over 10% of its citations, or 481 citations, occurred in 2020 alone. These two articles and their highly cited descendants identify several measures that have proliferated in empirical entrepreneurship research.

The methods for finding relevant decision making literature is described in Chapter 1.3 (motivating gap). To recap, the purpose of this search was to find the most reputable empirical studies in the domain of decision sciences relating to attitude to ambiguity.[3] The extensive literature search systematically narrowed and broadened the search in Scopus using keywords and including all journals related to the subject areas of economics, finance, business, management (including engineering management), and psychology. Thousands of articles were narrowed down to 38 by repeatedly refining the keyword search. From these 38, the search was extensively broadened by considering all citing articles. This was done in order to find any seminal (highly-cited) ancestors that

[3] By reputable, I mean items from top peer-reviewed journals, which served as a proxy for quality as this early stage of my scholarly education, and thus providing a reliable foundation for my research.

might have originated in another domain. The highly-cited citations of each ancestor was considered to find any additional article not found in the original search. Further, articles suggested by academics and their citing articles were also considered.

TERMINOLOGY USED HEREIN

Attitude to ambiguity: bias toward ambiguity

The protocol to measure perception of unknowable risk is called attitude to ambiguity. What became apparent was the extent to which experimental research on attitude to ambiguity has been done within the scientific discipline of decision making. Further, virtually all of those experiments were done under conditions of ambiguity that are "vague" or "imprecise" (i.e., within a known range of values with actual number provided). This type of vagueness has been referred to as "partial ambiguity" (Rustichini et al., 2005). Some of the same researchers also examined preferences under conditions of risk, where values were "precise" (having a singular known value), and under conditions of no risk, where values were "sure" (i.e., with no uncertainty, meaning having a 100% probability and singular known outcome). These terms are compared in Table 1.1 (terminology).

Laboratory experiments measuring attitude to risk and attitude to ambiguity are commonly done under condition of partial ambiguity; in other words, they have been limited to Knightian aleatory uncertainty. For this reason and other reasons described in Chapter 2 (conceptual model), none of these experiments are representative enough of a context of entrepreneurship to be generalizable to entrepreneurship. Herein lies a significant gap that this thesis research aims to help close.

Two other notable results of this search were evident. First, while a great deal of research has looked at human decision-making under conditions of financial risk, relatively little considers that under conditions of ambiguity. Second, decision sciences has separated out bias to risk and bias to

ambiguity. Entrepreneurship has not. I found a large difference in the quantity of published research related to financial risk as compared to financial ambiguity. This difference in research quantity is important because ambiguity and risk are processed differently by the human brain (Volz & Gigerenzer, 2012). For instance, "risky gambles" (i.e., gambles involving no ambiguous choice but at least one risky choice) activate more portions of the brain associated with emotions (Sturm et al., 2016; Hsu et al., 2005; Platt & Huettel, 2008), whereas "ambiguous gambles" (i.e., gambles involving at least one ambiguous choice) activate more portions of the brain responsible for controlling emotions (Krain et al., 2006; Tanaka et al., 2015) such as inhibition of impulsive behaviour (Huettel et al., 2006). This strongly suggests that different cognitive processes are invoked; therefore, the study of one is not necessarily revealing of the other. In fact, no evidence of correlation between risk attitudes and ambiguity attitudes has been found empirically (Camerer & Weber, 1992). In other words, notwithstanding our attitude to risk, our attitude to ambiguity will affect our entrepreneurial behaviour.[4]

KEY TAKEAWAY

Notwithstanding our attitude to risk, our attitude to ambiguity will affect our entrepreneurial behaviour.

[4] Because the two are uncorrelated.

Figure 1.1 Summary of prior protocols widely used in decision making and entrepreneurship literature. Italicized items that indicate features most suitable for experimental study of an "entrepreneurial gamble". Shaded rows indicate contributions.

Discipline	Literature	Measure / Protocol	Type	Perspective	Ease	Relevance
Entrepreneurship	Chapter 3 (state measure)	ambiguity additivity	State	***principal***	moderate	***yes***
Decision Making	Baillon et al. (2018).	ambiguity aversion index	State	***principal***	difficult	***yes***
Decision Making	Kahneman & Tversky (1979)	risk attitudes	State	***principal***	moderate	no
Decision Making	Koudstaal et al. (2015)	ambiguity aversion (precise probability)	State	***principal***	difficult	***yes***
Decision Making	Koudstaal et al. (2015)	loss aversion	State	***principal***	moderate	no
Decision Making	Koudstaal et al. (2015)	risk aversion	State	***principal***	moderate	no
Entrepreneurship	Robert (1980)	risk taking propensity	State	agent	moderate	no
Entrepreneurship	Cramer(2002)	risk attitude	State	agent	moderate	no
Entrepreneurship	Arenius and Minniti (2005)	opportunity perception	State	***principal***	***easy***	no
Entrepreneurship	Covin and Miller (2014)'s "Miller/Covin and Slevin (1989) EO Scale"	risk taking items. EO7-E09.	State	agent	***easy***	no
Entrepreneurship	Venkatraman (1989)	STROBE model. riskiness dimension. 1-5.	State	collective	***easy***	no
Entrepreneurship	Budner (1962)	tolerance for ambiguity	Trait	***principal***	***easy***	moderate
Entrepreneurship	Chapter 4 (trait measure)	unpredictability tolerance	Trait	***principal***	***easy***	moderate

Figure 1.1 (protocols) compares the protocols found in literature along the following lines of typology:

Type—Trait vs. State. The type of ambiguity-related measures used vary from those that measure an individual's personality (trait) to those that measure an individual's decision-making behavioural bias to a specific situation (state). For the reader who is familiar with personality literature, several terms are used interchangeably to denote the trait of "tolerance to ambiguity", namely "ambiguity tolerance", "tolerance to uncertainty", "intolerance to ambiguity", "uncertainty aversion" and "ambiguity aversion". Confusingly, the latter term has also been used in behavioural economics to describe one of the possible choice behaviours of an individual's measured ambiguity attitudes (the others being ambiguity-seeking and ambiguity-neutrality). (Gentle reader: I apologize in advance

because in Chapter 5 (study), I add to the mix by using "ambiguity additivity" synonymously with "ambiguity attitudes" when I employ a methodology that is referred to as "ambiguity aversion index" (Baillon et al., 2018); however, the term "ambiguity additivity" seems most descriptive for its proposed use in entrepreneurship practice. I explain this further in Chapter 5 (study).)

For readers who are less familiar with decision making literature, "ambiguity attitudes" refers to one or more measures; the term is pluralized even when it only refers to a single measure. Some literature refers to "ambiguity attitudes" as "ambiguity aversion" (e.g. Trautmann et al., 2011; Tanaka et al., 2015), which must be distinguished from the behaviour of "aversion" or "ambiguity aversion" that is also used to describe one of the possible choice behaviours of an individual's measured ambiguity attitudes (or, of their measured ambiguity aversion) (e.g., Kocher et al., 2018), or the phenomenon of ambiguity aversion, which refers to when the ambiguity attitudes of a group of individuals is one of ambiguity aversion (e.g., Fox & Tversky, 1995). Adding to the richness of the nomenclature, Baillon et al. (2018) defined an "ambiguity aversion index" and the "ambiguity-generated-insensitivity index", both of which classify as measures of an individual's ambiguity attitudes.

Notwithstanding an entrepreneur's personality traits, their situation-specific state will affect entrepreneurial behaviour.[5] This is because personality traits are arguably stable, and yet decision making research has found that situation-specific attitudes (states) will change with certain factors.

Perspective. Knightian uncertainty is subjective ambiguity; therefore attitude to ambiguity will depend on the decision maker's perspective. Principal: first person. Agent: third person; Collective: first person as part of collective.

[5] Because the two are uncorrelated.

Ease: Ease of Administration. This refers to the level of cognitive effort and complexity required of the subject to complete the protocol's experimental tasks. Those requiring fewer tasks and not requiring numeracy are anticipated to be easier than those with greater number and complexity of numeracy tasks. Those requiring numeracy are anticipated to be less easy to accomplish by those less skilled at numeracy, limiting the generalizability of this protocol across demographics.

Relevance: Relevance to ambiguity experiments. Protocols with greater flexibility to manipulate the nature of ambiguity and the factors that are known to affect measurements are most relevant. Trait measures are moderately relevant because their protocol is fixed, the scale items cannot be modified.

Figure 1.1 (protocols) provides a list of constructs that have proliferated from widely-cited empirical literature[6]. Each of these constructs cover a nomological net that includes either (1) only dispositional personality traits (trait), (2) only situation specific (state) attitude to risk, (3) a uni-dimensional combination of situation-specific (state) attitude to risk and attitude to ambiguity. The first two constructs are lacking in breadth, while the latter is wrongly blending two orthogonal measures. Let us consider each of these three in turn. First, there is the dispositional personality trait. Entrepreneurship research provides evidence that personality traits might be important. However, personality traits are arguably meant to be stable across situations. Decision making research has found that our situation-specific attitudes (states) will change with certain factors. Therefore, dispositional personality traits alone will not suffice to understand our reaction to ambiguity across conditions of Knightian uncertainty. Second, there is attitude to risk. Decision sciences knows that attitude to risk is distinct from attitude to ambiguity and, therefore, that attitude to risk alone does not contribute to our understanding of reaction to ambiguity across conditions of Knightian uncertainty. Third, there is a blend of attitude to risk and attitude to ambiguity. Decision sciences has managed to

[6] These empirical ones were identified from Lumpkin and Dess (1996), which is in the top 3 most widely-cited literature in entrepreneurship research.

operationalize attitude to risk and attitude to ambiguity as distinct, uncorrelated measures; in other words, decision sciences knows that attitude to risk and attitude to ambiguity are orthogonal.

In sum, decision making theory knows that probabilistic ambiguity is different from probabilistic risk, and theory has evolved for each. In contrast, entrepreneurship has not always succeeded in distinguishing between Knight's uncertainty and risk. Measuring both traits and states for both risk and ambiguity allows for the most insightful analysis. The next section will describe why ambiguity attitudes might help explain some puzzling findings.

KEY TAKEAWAY

Measuring both traits and states
for both risk and ambiguity
allows for the most insightful analysis.

1.3 Literature search reveals a motivating gap

A literature search was conducted to help find out what is already understood about an entrepreneur's perception of unknowable risk in their decision-making.

TERMINOLOGY USED HEREIN

decision making: the scholarly discipline
decision-making: studied by decision making scholars

Searches of the Scopus database were conducted in journals for the subject areas of "Economics, Econometrics and Finance" and "Business, Management and Accounting". A total of 21,084 journals that include the search terms "financial" and "risk" were uncovered, with the earliest in 1938. A total of 3,635 were found with the search terms "financial" and "uncertainty", with the earliest published in

1912. A total of 339 were uncovered with the search terms were set to “financial” and “ambiguity”. This number reduced to a total of 38 when the search terms were “financial” and “ambiguity” and “decision-making”, with the earliest in 1973. To clarify, “decision making” refers to the scholarly discipline, while “decision-making” is studied by decision making scholars.

In sum, while over 20,000 journal articles were uncovered related to financial risk, fewer than 350 were found for financial ambiguity. This number reduced to fewer than 40 when the search was narrowed to decision making. In sum, while a great deal of research has looked at human decision-making under conditions of financial risk, relatively little considers that under conditions of financial ambiguity. Platt and Huettel (2008) also remark on this. None of those articles describe a complete model of the relationships that have been found to impact decision-making under condition of ambiguity. A model of these relationships could help inform decision-making under condition of Knightian uncertainty. For this reason, I turned my attention to assembling a conceptual model, relying on robust empirical findings.

To find any additional relevant literature in decision making, I performed a new search for empirical or experimental findings in decision making with outcomes that were not restricted to financial outcomes. Specifically, I broadened my search by removing the keyword “financial” and narrowed it by further specifying the subject area to include “decision sciences” and adding keywords to specify empirical findings. Thus, the search terms became “ambiguity” AND “decision” AND (empirical OR subject* OR experiment*). A total of 65 journal articles were uncovered. The ones from top journals that were relevant or those that were highly cited, and the ones these cited were included in the literature review. A search of other databases was also done in a similar manner.

I considered all articles from top journals that were relevant or highly-cited, articles that those articles cited or were cited by those articles. I also considered additional sources that were recommended by scholars in decision making, neuroeconomics, and entrepreneurship.

A separate Scopus search was performed in journals in the subject area of "neuroscience" with the search terms "brain" AND "risk" AND "ambiguity". This yielded 64 documents, with the earliest of those published in 1990. As mentioned, the intention was to assemble a conceptual model from empirical studies. When search terms were added to specifically uncover empirical work within the scope of "decision sciences", only one article was found. However, this article was cited 85 times. This article and relevant, highly-citated documents that cited this one were added to the literature search.

Briefly, the most broadly used measure of decision-making behaviour under condition of ambiguity is called "ambiguity attitudes". This is distinct from the measure used to measure decision-making behaviour under condition of risk, which is called "risk attitudes". These measures are used in multiple disciplines including decision sciences (e.g., Du & Budescu, 2005), neuroeconomics (e.g., Huettel et al., 2006), and entrepreneurship (e.g., Lévesque & Schade (2005)). [7]

The large difference in the quantity of published research related to financial risk as compared to financial ambiguity is important for two reasons. First, experiments repeatedly find no correlation between risk attitudes and ambiguity attitudes. This is described in the reputable review of literature by Camerer and Weber (1992), has since been repeated (e.g., Huettel et al., 2006) and is widely accepted in neuroeconomics (e.g., Blankenstein et al., 2018; Levy et al.; 2010). Therefore, experimental results of risk attitudes do not inform ambiguity attitudes. Second, risk and ambiguity are processed differently by the human brain. Recall from Chapter 1.2 that neuroscience research has

[7] By convention, the terms "ambiguity attitudes", "ambiguity preferences", and "risk attitudes" are pluralized.

consistently and repeatedly provided evidence that the brain processes risk, uncertainty, and ambiguity differently. Because risk and ambiguity are processed differently by the brain, the neural pathways involved in their mechanism of action will be different; in other words, the causal variables affecting decision-making under condition of risk are not anticipated to be the same as those affecting decision-making under condition of ambiguity.

Literature search reveals a dearth in knowledge about an entrepreneur's perception of unknowable risk. Also, entrepreneurship researchers have recommended that future research on entrepreneurial behaviour consider theorizing and measuring ambiguity (Zhang & Cueto, 2017). This gap motivated this dissertation, and gave it a purpose, namely to contributing to our understanding of an entrepreneur's perception of unknowable risk, or their attitude to ambiguity. This gap motivates the overarching question of this thesis, namely, **how does ambiguity affect an entrepreneur's behaviour?**

This section has described the methodology followed for one of literature searchers. This search was typical of others that were performed to find relevant literature to answer the research questions addressed in each chapter.

1.4 Ambiguity as a missing puzzle piece

Entrepreneurship has not always succeeded in distinguishing between Knight's uncertainty and risk. Influential studies with puzzling empirical findings have proliferated through entrepreneurship literature, and these findings might be explained by attitude to ambiguity. Many studies are mentioned in Shane and Venkataraman (2000) in their seminal entrepreneurship article, *The Promise of Entrepreneurship as a Field of Research* or in their highly-cited descendants. As described in Chapter 1.2, Shane and Venkataraman's article remains part of mainstream entrepreneurship. Five studies and their protocols are summarized in Table 1.2.

Table 1.2 Summary of influential studies with puzzling findings that might be explained by attitude to ambiguity

Influential study	# citations		Trait		State	
	1st gen	2nd gen	Ambiguity	Risk	Ambiguity	Risk
Begley & Boyd (1987)	564	47,014	Budner (1962)'s Tolerance of Ambiguity (8 items)	Monetary risk-taking items (8 items) based on Jackson Personality Inventory	no	no
Devers et al. (2007)	76	4259	no	no	no	loss aversion (ex post)
Caliendo et al. (2009)	239	6456	no	no	Arrow-Pratt risk aversion	risk attitudes
Fitzsimmons and Douglas (2011)			no	generalized attitude to risk based on Douglas and Shepherd (2002)	no	no
Burmeister-Lamp et al. (2012)	60	894	no	no	no	risk attitudes

The first of those studies is Begley & Boyd (1987), cited 564 times. Its number of citations peaked in 2015 and is still cited in top entrepreneurship journals. A citation overview in Scopus reveals that the second-generation descendants of those cited articles are substantial in number: of those 564 articles that cite this document are collectively cited 47,014 times. Personality traits related to ambiguity and risk were measured separately using Budner (1962)'s Tolerance of Ambiguity scale and the Jackson Personality Inventory (JPI)'s monetary risk-taking items (Jackson, 1976). Researchers found some evidence that people with greater tolerance for ambiguity may be more likely to exploit, however evidence was not conclusive. These researchers also found that while CEOs differed on their risk-taking (trait) scores, scores could not explain corporate financial performance. The sample comprised CEOs of firms in the mature stage of growth. This study did not measure attitude to risk or attitude to ambiguity (states). As mentioned above, these are orthogonal measures. State is likely to have had an impact on behaviour, and by extension on firm performance. Recall

from Chapter 1.2 (prior attempts) that measuring both traits and states for both risk and ambiguity should have provided for the most insightful analysis.

A second important study that might have benefited from measuring ambiguity attitudes is Devers et al. (2007), cited by 76 items, with over 40% of those citations are from the five-year period 2016-2020. This study could not explain a manager's subjective valuation of their stock options by the phenomena of loss aversion. Stock option compensation essentially shifts from manager to entrepreneur, exposing the manager-entrepreneur to the financial ambiguities of the firm. Therefore, their attitude to ambiguity towards loss might help better explain their behaviour.

A third study is Caliendo et al. (2009), cited 239 times. Citations continue to increase year over year. These researchers used two state measures, namely risk attitudes and risk aversion. Risk aversion followed the Arrow-Pratt Risk Aversion protocol. The researchers unexpectedly found that individuals with a lower risk aversion are more likely to become self-employed, but this relationship depended on employment status immediately prior to self-employment. Ambiguity attitudes is known to be affected by prior experience. Had this study distinctly considered attitude to ambiguity, it might have been better able to explain their results.

A fourth study is by Fitzsimmons and Douglas (2011). Their study operationalized the entrepreneurial intention model (i.e., Krueger and Brazeal, 1994; Krueger et al., 2000). They were surprised to find that individuals who rated high on both perceived desirability of entrepreneurship and feasibility of entrepreneurship, rated low on their entrepreneurial intention to embark on a new venture "at some point in the future". Their measure of feasibility was a scale of self-efficacy by Chen et al. (1998). Their measure of desirability included a generalized attitude to risk based on Douglas and Shepherd (2002). Their study did not include a measure of attitude toward Knightian uncertainty, and their analysis may have been more insightful if it had.

The fifth influential study listed here is Burmeister-Lamp et al. (2012), which has a yearly increase in citations of its second-generation descendants. These researchers found no reliable relationship between risk attitudes and the amount of time an early-stage entrepreneur is willing to invest in their new venture. Given the ambiguity a nascent entrepreneur faces, interesting future work could also investigate the relationship between ambiguity attitudes and time allocation.

1.5 Main contributions, gaps, research questions, and document layout

The prior research described above makes clear that gaps exist in our understanding of how ambiguity affects decision-making in entrepreneurship. This gap motivated my dissertation and gave it a purpose, to contribute to our understanding of an entrepreneur's perception of unknowable risk, or attitude to ambiguity. The main research enquiry was: How does ambiguity affect an entrepreneur's behaviour? For reasons that become clear over the course of the chapters of this dissertation, this is the same as asking, how does ambiguity affect an entrepreneur's risk assessment?

The broad research design entailed completing three research objectives and obtaining answers to five research questions that guided this work. The research methodology for each of the objectives is described in detail in Appendix K (research program).

Objective 1 was to develop a protocol to measure attitude to ambiguity for a context representative of entrepreneurship. No study has explicitly looked at ambiguity attitudes towards a gamble that has a combination of the characteristics of an "entrepreneurial gamble", which is described in Chapter 2.4. Chapter 2 (conceptual model) makes use of robust, validated empirical findings from prior research to construct a conceptual model of ambiguity attitudes in an entrepreneurship context. This conceptual model includes a profile of (objectively perceived) ambiguity, or an "ambiguity profile". The conceptual model and the ambiguity profile are a contribution to empirical research in entrepreneurship. Chapter 3 (state measure) relies on this novel conceptual model and the prior

research described above to develop a protocol for attitude to ambiguity that can measure at a deep psychological level and for a context representative of entrepreneurship. In developing this measure, I had to first answer the question, **might there be a way of measuring ambiguity attitudes in the mixed domain and in a context that is representative of entrepreneurship?** To help in this work, I created a summary of the terminology across domains, described in Chapter 1.1 (nature of the unknowable), and a summary of prior research, described in Chapter 1.2 (prior attempts). These are a contribution to decision making and entrepreneurship.

Objective 2 was to use this protocol—developed under objective 1—to design a survey to measure attitude to ambiguity for a specific context representative of entrepreneurship. The study of Chapter 5 addresses a second research question, **is there an effect of time horizon and potential loss on ambiguity attitudes in an entrepreneurial context?** The answer to the second research question of this dissertation was anticipated to be influenced by personality. Therefore, under objective 2, a third research question arose: **can a personality trait help explain attitudes towards ambiguity in entrepreneurial gambling?** Chapter 4 (trait measure) describes a systematic methodology to devise a measure of tolerance to ambiguity (i.e., a trait) from sources of ambiguity found in a context representative of entrepreneurship, and validates one measure specifically from sources of ambiguity relevant to financial outcomes. This methodology is a contribution to both decision making and entrepreneurship. The relationship between this measure (trait) and ambiguity attitudes (state) in a context representative of entrepreneurship is explored, including the influence of this trait over states. As such, the finding from this exploration is a contribution to entrepreneurship.

Under objective 2, this study of Chapter 5—attitude to ambiguity in the mixed domain—extends the empirical coverage of the experimental design space of decision making. It covers the phenomena of loss aversion from a different dimension than previously studied, namely the dimension of ambiguity. In this way, a contribution is made to empirical decision making. Specifically, given that

the study makes use of the protocol of ambiguity attitudes in an ecological context of entrepreneurship, it contributes to validating the generalizability of the protocol for decision making (specifically for ambiguity research). The measure used is specific to a context representative of entrepreneurship and therefore is also a contribution to empirical entrepreneurship.

Objective 3 was to explore the possibility of developing a protocol to measure attitude to ambiguity that would be more practical to administer. To this end, Chapter 6 empirically explores whether there might be an easier way to measure attitude to ambiguity. Decision making literature suggests that there is, and this motivates a fourth research question, **might there be a way of measuring ambiguity attitudes psychometrically?** Decision making literature led me to a fifth and final research question, **can states of hope, fear, optimism and pessimism be used to help characterize ambiguity attitudes?** Empirically addressing relationships that until now decision making literature has only assumed, specifically one between state affect and ambiguity attitudes, is a contribution to decision making. This work provides a new metaphor for exploring ambiguity attitudes, namely, one that is psychometric, and this is also a contribution to decision making. Its entrepreneurial contextualization also makes it a contribution to entrepreneurship.

Chapter 7 summarizes overall implications of this work across disciplines of entrepreneurship. These implications include two proposed risk-management policy frameworks for choosing a management intervention in entrepreneurship practice, one for the individual entrepreneur (individual-level) and one for a population of entrepreneurs (population-level). Chapter 7.3.4 (entrepreneurship example) provides an example that puts both the theory and empirical results of this research into management practice. Future work to validate the frameworks and extend management implications, which include an engineering model, is detailed in Chapter 7.3.5 (detailed validation and modeling).

In sum, contributions of this research can be grouped into three areas of key contribution. First, translation and adaptation of theory from human decision making for entrepreneurship. Second, empirical findings of subjective assessment. Third, practical strategies proposed to help entrepreneurs cope with ambiguity. The contributions of this work are primarily in the entrepreneurship discipline, broadly defined.

A broad and extensive search was performed to find academic literature relevant to these five research questions. The academic literature that was found comes primarily from two disciplines: decision making (including but not limited to the fields of decision science, behavioural economics, cognitive psychology, ambiguity research, and neuroeconomics) and entrepreneurship (including but not limited to the fields of entrepreneurial decision making, entrepreneurial characteristics, entrepreneurial mindset, and new product engineering management). Some of this literature has been described in Chapter 1 (introduction). Additionally, Chapter 3 (state measure) to Chapter 6 include review of literature that is specific to the chapter. Appendix L (research program) summarizes the location of motivating literature.

1.6 Practical implications of this research

In practice, the conceptual model of Chapter 2 (conceptual model) describes the "ambiguity profile", comprised of variables ("elements") that are relevant to a context representative of entrepreneurship, or to an "entrepreneurial gamble". The concept of entrepreneurial gamble is fully described in Chapter 2.4 (entrepreneurial gamble). Prior research described in Chapter 2 shows how these elements can influence a person's dynamic state of attitude to ambiguity ("ambiguity attitudes"). Ambiguity attitudes (singular but pluralized by convention) cannot be measured directly, it can only be observed by a subject's choice of "ambiguity preferences", also shown in the conceptual model of Chapter 2. A survey to measure attitude to ambiguity for an entrepreneurial

gamble can be developed following the novel protocol of Chapter 3 (state measure) where ambiguity preferences are referred to as “a pair of matching probabilities”, or “matching-pair probabilities”. From the theoretical development of Chapter 5.3.1, it is evident that a pair of matching probabilities provide an assessment of subjective likelihoods, or, in generalized terminology explained in Chapter 3.5.3 (risk assessment), a risk assessment. Observations of a pair of matching probabilities can be used to calculate two novel risk assessment measures, namely Ambiguity Sum and Ambiguity Ratio. Frameworks propose how both measures might be useful to choose a management intervention to help entrepreneurs cope with ambiguity. The proposed frameworks are provided in Chapter 7 (overall implications), and a worked example linking these concepts and using them in a novel engineering econometric model is found in Chapter 7.3.4 (entrepreneurship example). Future work to validate the frameworks and extend the model is detailed in Chapter 7.3.5 (detailed validation and modeling).

1.7 Summary

Attitude to ambiguity is important to entrepreneurship. For use in practice, attitude to ambiguity needs to be quantified. As will be explained in details in the chapters to follow, quantification of attitude to ambiguity in entrepreneurship can be interpreted as an assessment of subjective likelihoods, or, in generalized terminology, a risk assessment. Many protocols have been used to quantify attitude to ambiguity, including a widely-used ambiguity aversion protocol. This protocol has advantages over others in that it provides a state measure, and it can provide insight at a deep psychological level.

The next chapter describes the variables that have been robustly shown to influence ambiguity aversion, and provides a conceptual model of the experimental variables to consider when using the ambiguity aversion protocol in a context that is representative of entrepreneurship. It will become apparent that the extant protocol, the ambiguity aversion protocol, is not entirely suitable for a context

that is representative of entrepreneurship, and reasons for this will be explained in the next chapter (conceptual model).

> **Gentle Reader**, novel concepts, terminology and key takeaways are highlighted in boxes throughout this document for your ease of reference.

Chapter 2
Conceptual model

Notwithstanding an entrepreneur's attitude to risk, their attitude to ambiguity affects their entrepreneurial behaviour. This work looks at entrepreneurial behaviour through a new lens: that of ambiguity. This chapter will begin to provide a better understanding of an entrepreneur's perception of ambiguity, as distinct from their perception of risk. The objective of this chapter and Chapter 3 (state measure) is to develop a protocol to measure attitude to ambiguity for a context representative of entrepreneurship. As such, these chapters contribute to translating and adapting theory from human decision making for entrepreneurship. The work to achieve these contributions is described, in manuscript format, in the sections that follow. Much of the text from this chapter was originally published in Csonka-Peeren & Cozzarin (2021), and is included here with permission from the journal found in Chapter 9. Terminology used in this chapter is described in Table 1.1.

2.1 Introduction

Entrepreneurs regularly confront situations in which they must make decisions with virtually no information to help inform these decisions. For instance, in making a decision to pursue new opportunities, information that would be helpful such as market size, market growth rate, distribution channels, and funding alternatives, is limited, at best. This missing information creates "Knightian uncertainty", which is what Knight (1921) described as "unmeasurable and unquantifiable risk", where risk is comprised of a distribution of both probabilities and outcomes. Understanding decision-making behavior in entrepreneurship therefore includes understanding the nature of Knightian uncertainty and how people respond to it.

In behavioral economics, Knightian uncertainty is called "ambiguity". Under condition of ambiguity, outcomes or their likelihoods are not only unknown, but also unknowable. A good deal of

empirical research to understand decision-making behavior under condition of ambiguity has been done in behavioral economics. In fact, behavioral economics has an established history of rigorous experiments dating back to the first usage of the concept "ambiguity" in business literature. The operationalized construct is called "ambiguity attitudes" and has been validated through repeated experiments both within and outside of behavioral economics. For instance, behavioral decision-making experiments under condition of ambiguity have been repeated in neuroscience, helping to explain the neural mechanisms involved in determining ambiguity attitudes, e.g., Krain et al. (2006).

How does ambiguity affect decision-making behavior in general, and specifically in entrepreneurship? To begin to address this question, two needs arise. First, there is a need to understand what is already known about how ambiguity affects decision-making behavior and, second, there is a need to synthesize this knowledge in a format that can be helpful to study how ambiguity affects decision-making behavior in entrepreneurship in particular. This paper addresses these two needs by constructing a conceptual model of experimental variables to consider for future study of ambiguity attitudes in a context that is representative of entrepreneurship. These variables are identified from the findings of previous research. This work relies on empirical evidence of what is known about behavior under condition of ambiguity studied in behavioral economics. Specifically, this work relies on empirical evidence of ambiguity attitudes during financial decision-making under conditions of financial ambiguity. In synthesizing these findings, a third need arises to clarify the nature of ambiguity, namely to describe the nature of ambiguity endogenous to the conceptual model. This paper addresses this need by introducing a novel structure in the conceptual model called the "ambiguity profile".

The goal of this paper is to contribute to theory building about decision-making behavior under condition of ambiguity in general, and in entrepreneurship specifically. In theorizing, this paper provides three contributions. First, this paper introduces a new structure called the ambiguity profile,

which is a multi-dimensional array of elements that collectively describe an ambiguous situation as perceived by the decision maker. Each of these elements have been found to affect the ambiguity attitudes of a decision maker. The elements of the ambiguity profile include the following: whether the outcome could have gain, loss, or both; the relative magnitude of the outcome; the width of the range of the magnitude of the outcome; the relative probability of the outcome; the width of the range of the probability of the outcome, and the time horizon to the outcome. This ambiguity profile is intended to provide two advantages: to provide researchers with a means to completely describe the combination of elements that are manipulated in an experimental study and to facilitate the comparison of manipulations across studies.

The elements that are included in the ambiguity profile emerged during our literature review of the most reputable empirical research, and are comprised of the variables that were manipulated in previous research studies on ambiguity attitudes towards financial risk, financial uncertainty and financial ambiguity (collectively, financial likelihood). While the findings in each of these three research areas overlap, some differences are predicted. One reason for this is that the human brain is known to process [financial] risk and ambiguity differently (Hsu et al., 2005; Rustichini et al., 2005; Smith et al., 2002).

Second, this paper contributes a coherent conceptual model of all the factors that are known to affect ambiguity attitudes—including the elements of the ambiguity profile. This conceptual model is useful in two ways. First, it can be used to completely describe the experimental variables that were controlled, manipulated and measured in prior research, and the relationship between these variables. Second, it can be used to design further experiments. This paper describes how further experiments could help fill gaps in understanding ambiguity attitudes in an entrepreneurial context. The conceptual model can be used to choose experimental variables to control and variables to manipulate that, collectively, best represent an ambiguous entrepreneurial context.

Third, this paper contributes to understanding theoretical concepts by disambiguating potentially confusing terminology from various literature. This article identifies terminology that is similar or has been used synonymously with the terminology used in this paper, and clarify its usage in each case. The intention is to facilitate understanding of the terminology used here and reduce potential confusion for the entrepreneurship researcher who may be familiar with similar terminology used differently across entrepreneurship, behavioral economics, project management and corporate finance.

This paper begins by describing the gap in literature about financial decision-making behavior under condition of ambiguity. Next, it describes the conceptual model of factors affecting ambiguity attitudes, including the ambiguity profile, with a detailed explanation of each variable included in the model. Where applicable, the variables are interpreted in the context of entrepreneurship. This is followed by a description of factors that are known to influence risk attitudes and why those factors might need to be included in the conceptual model. Before concluding, this paper discusses how these novel items could be used by researchers who wish to further our academic understanding of how people behave under condition of ambiguity, and by entrepreneurship researchers in particular. Future theoretical and empirical work is suggested.

To begin, we describe how there is a dearth of empirical evidence about how people behave under condition of ambiguity. While this is true in general, it is also true in behavioral economics despite its established history of empirical work in decision making.

2.1.1 A gap in research on ambiguity

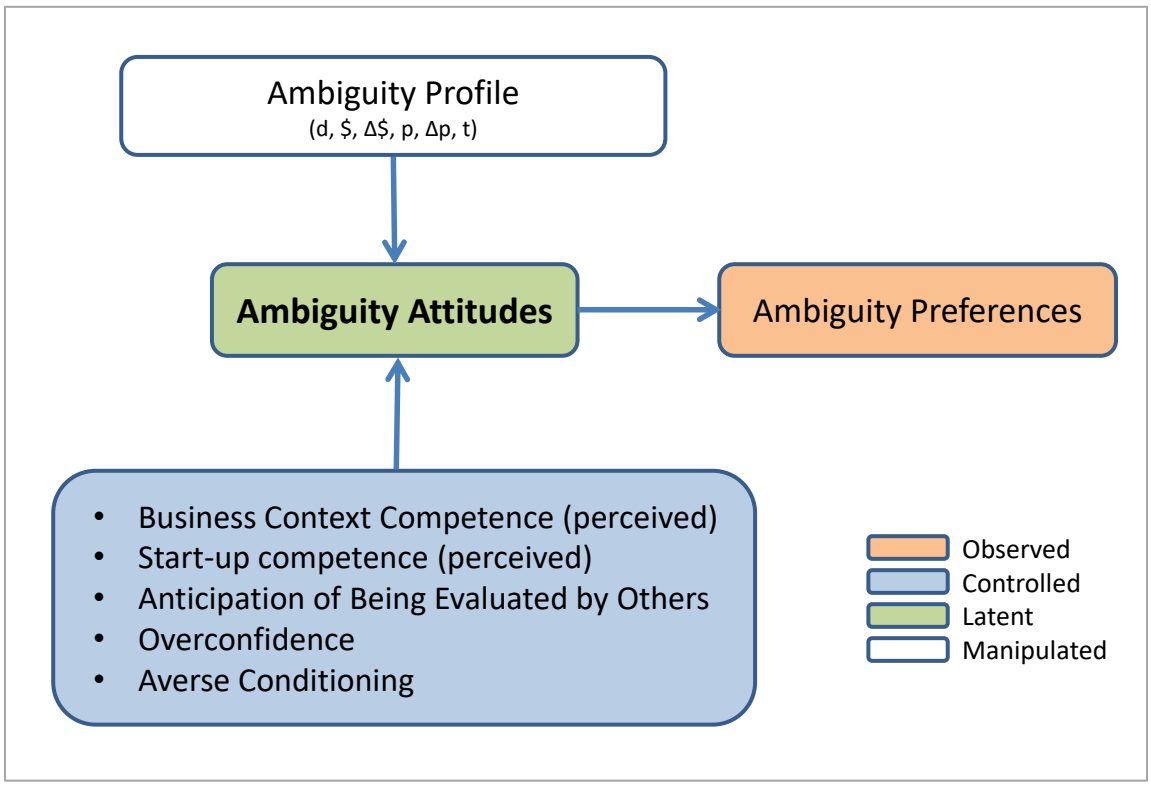
It has long been acknowledged that decisions made under conditions of risk or uncertainty are central to entrepreneurship phenomena (Knight, 1921; McMullen & Shepherd, 2006). In sum, Knightian uncertainty is comprised of ambiguity and relevant to the context of entrepreneurial

decision-making. Researchers have recently recommended that future research on entrepreneurial behavior consider theorizing and measuring ambiguity (Zhang & Cueto, 2017). This paper contributes to entrepreneurship theory to address this gap.

2.2 Empirical basis for the conceptual model

The literature described in the sections to follow detail how several variables are expected to impact ambiguity attitudes of entrepreneurs and how ambiguity attitudes, in turn, impact ambiguity preferences. These variables and their relationship are illustrated in Figure 2.1 and described in the sections of this chapter that follow. In Figure 2.1, each arrow from a variable to ambiguity attitudes represents a causal relationship between the variable and ambiguity attitudes. Each individual arrow is not meant to imply a mutually exclusive effect; interaction effects between variables are well documented and discussed below. Nor is an arrow meant to imply a direct effect on ambiguity attitudes. This is not necessarily an exhaustive collection of causal variables; however, it does include those that have ample empirical evidence to warrant their inclusion. Ambiguity preferences are used to operationalize ambiguity attitudes. In the terminology of statistics and engineering, ambiguity attitudes is the “true parameter”. In psychology, it is the “latent construct”. We cannot measure ambiguity attitudes directly. In terminology of statistics, engineering and psychology, ambiguity preference is the observed variable. Specifically, ambiguity is a preference between gambles, and this preference is used to calculate ambiguity attitudes, the true parameter.

Figure 2.1 Conceptual model of experimental variables to consider when studying ambiguity attitudes in a context that is representative of entrepreneurship



2.2.1 Ambiguity Attitudes

Several terms are used interchangeably in the literature to denote ambiguity attitudes, namely "ambiguity aversion" (e.g., Liu & Öncüler (2017) and "attitudes toward ambiguity" (Onay et al., 2013). By convention, the terms "ambiguity attitudes" and "ambiguity preferences" are pluralized in literature.

Relatively few studies have considered financial ambiguity attitudes; however, in those studies, two types of experimental tasks (protocols) are widely used, namely certainty equivalent task and pairwise choice task. Under a certainty equivalent protocol, ambiguity attitudes is calculated from a "certainty equivalent" measurement, and under a pairwise choice protocol, ambiguity attitudes is deduced from "ambiguity preferences" measurement.

In a certainty equivalency task, subjects reveal the amount of payoff they would require to be indifferent between this amount of payoff and a given gamble, and ambiguity attitudes is calculated from this payoff (subjective value). This is different from the more widely applied pairwise choice protocol.

Under a pairwise choice protocol, ambiguity attitudes is deduced from ambiguity preferences, which is observed (Du & Budescu, 2005; Liu & Öncüler, 2017; Onay et al., 2013). This protocol requires participants to choose their preference between two fictional alternatives that are the same except for the variable of interest, which is manipulated. Ambiguity associated with outcomes is manipulated separately from that of probabilities. Subjects may also be given a choice of "indifference" (equal preference). Ambiguity attitudes is made evident by a subject's preferred pairwise choice between two "vague" alternatives differing only in Expected Value (EV). Specifically, ambiguity attitudes is determined by comparing the EV of the choice to that of the un-chosen alternative. In these experiments, outcomes and probabilities are described with a range of values that are known and actual numbers are provided; consequently, a value for EV can be calculated. This type of ambiguity, with known range of values with actual numbers provided, has been referred to as "partial ambiguity" (Rustichini et al., 2005) and the values delineating a range is described as "vague" or "imprecise" (e.g., Onay et al., 2013). The pairwise choice protocol can be used to reveal tendencies in a population across a variable of interest. For instance, business students of the senior- and graduate-level have been shown to display a tendency toward preference for information about vague probabilities over vague outcomes for gambles that are resolved in the near-term (Onay et al., 2013).

Our extensive literature review reveals several variables that are expected to impact on ambiguity attitudes, namely specific elements of the ambiguity profile, business context competence

(perceived), start-up competence (perceived), anticipation of being evaluated by others, overconfidence, and averse conditioning. These variables are described in turn below.

2.2.2 Ambiguity Profile

Collectively, researchers have empirically found that ambiguity preferences (e.g., where ambiguity attitudes is deduced from pairwise choice) and ambiguity attitudes (e.g., where ambiguity attitudes is calculated from certainty equivalent) are affected by several variables. We have assembled some of these variables into what we have labeled the ambiguity profile. The ambiguity profile is a combination of elements that describe an ambiguous situation. The elements (variables) of the ambiguity profile are denoted in Figure 2.1. These elements are domain (**d**), magnitude of outcome (**$**), width of the range of outcome (**Δ$**), magnitude of probability (**p**), width of the range of probability (**Δp**), and time horizon (**t**). The effects of these elements can be described as follows: reference-domain effects arising from an outcome that is anticipated to fall in the domain of either a gain or a loss (i.e., in **d**); magnitude effects arising from the anticipated magnitude of an outcome (i.e., from **$**) or for the probability (i.e., from **p**); range effects arising from manipulation of the width of the range of anticipated magnitudes of an outcome (i.e., of **Δ$**) or from the width of the range of probability (i.e., of **Δp**), and temporal effects arising from an outcome that is anticipated to occur after a time horizon that is either nearer- or longer-term (i.e., after **t**).

As discussed, ambiguity attitudes is deduced from ambiguity preferences; therefore, ambiguity attitudes will precede ambiguity preferences in a causal chain and there is a direct relationship between the two measures. Manipulating elements of the ambiguity profile will affect both ambiguity attitudes and ambiguity preferences; however, ambiguity profile will have a direct effect on ambiguity attitudes and an effect on ambiguity preferences via the causal link from ambiguity attitudes. Some studies have reported their findings in terms of effects on ambiguity attitudes and

other studies have reported their findings in terms of effects on ambiguity preferences. The two sections below describe findings by type of reporting.

2.2.3 Ambiguity Profile effects on Ambiguity Attitudes

Some studies have reported their findings in terms of ambiguity attitudes. From those studies, the elements of the ambiguity profile reported to influence ambiguity attitudes are domain (**d**), magnitude of outcome (**$**), magnitude of probability (**p**), and time horizon (**t**). These findings, and how they relate to an entrepreneurial context, are described below.

Domain. A study of insurance premiums found that clients are willing to pay higher premiums for certainty when there is either ambiguity regarding the probability of a particular loss event occurring and/or uncertainty about the magnitude of the resulting loss. This study was performed for the loss domain. (Kunreuther et al., 1995). Entrepreneurial events have the possibility of high potential loss and high potential gain, e.g., "market segment A could help grow my company but, if it fails, I will be bankrupt." This type of mixed domain is representative of an entrepreneurial context and has not been studied experimentally in prior literature. It is a gap in experimental entrepreneurship.

Magnitudes. In both probability and outcome, subjects display ambiguity seeking when performing a certainty equivalency task under a condition of unlikely (i.e., low probability) gains or likely (i.e., high probability) losses (Budescu et al., 2002). This is fortunate for entrepreneurship activity because low probability gains and high probability losses are representative of an entrepreneurial context; it implies behavior that seeks Knightian uncertainty. Additionally, in a repeated pairwise choice task, Liu and Öncüler (2017) ran experiments in the gain domain and found that individuals display greater ambiguity aversion for high probabilities than for low probabilities when there was no time horizon (present time).

Time horizon. Temporal effects (timing of consequences, i.e., near- vs. long- term) reportedly have a significant influence on ambiguity preferences and, by deduction, on ambiguity attitudes. Specifically, subjects are less averse to imprecise probability and more seeking for imprecise outcome when potential gains would be realized in future as compared to in present (Liu & Öncüler, 2017; Onay et al., 2013). Onay et al. (2013) found this attitude to be more prominent when both probability and outcome were imprecise. As discussed, aversion was determined relative to EV. This finding has impact in an entrepreneurial context. For instance, the amount of precision provided is anticipated to influence financing behavior, e.g., "should I take this equity offer (near term, more precision) or wait for a better one (long-term, less precision)?" This has not been studied in prior experimental research and constitute a gap in experimental entrepreneurship.

2.2.4 Ambiguity Profile effects on Ambiguity Preferences

Some relevant studies have reported their findings in terms of ambiguity preferences. Collectively, those studies point to three elements of the ambiguity profile that influence ambiguity preferences. These elements are domain (**d**), time horizon (**t**), and width of the range of probability (**Δp**). These findings, and how they relate to an entrepreneurial context, are described below.

Domain. In the loss domain, research reports an even split between subjects who prefer more information about probability or outcome when presented with a pairwise choice. (Schoemaker, 1989, Table 2) However, as magnitude of potential losses increased, subjects desired more information about outcome (magnitude of loss) (Schoemaker, 1989). This could explain the results of Du & Budescu (2005) who found a clear split in the loss domain, where more subjects were willing to allocate funds to acquire more precision about the magnitude of outcome than probability. All these findings contrast with results in the gain domain, where most subjects want more information about probability over outcome. (Schoemaker, 1989, p.47 Table 2)

Time horizon. Subjects prefer a future prospect that is vague in both probability and outcome than one that is vague in only one of those dimensions. (Onay et al., 2013). In this experiment, subjects' preference was determined through pairwise choice.

This time horizon effect implies that highly ambiguous entrepreneurial ventures may be have a higher valuation when their forecasts are vague in both probability and outcome than when these are more precise in probability or outcome. At the same time, the domain effects described above are anticipated to reward some precision, for instance when large losses are at stake. This combination of time horizon and domain effects has not been studied experimentally, and is relevant to an entrepreneurial context. This is a gap in experimental entrepreneurship.

Range. As the width of the probability range narrows, the value of information on probabilities is lessened (Schoemaker, 1989, p.49 Figure 3). We believe an alternative explanation to a range effect exists for this change in preference; in Schoemaker's survey questions about this, not only was the width of the range of probability narrowed to 40% from 100% but also the expected value of probability (given that subjects were told that distribution was uniform) was also decreased to 20% from 50%. As discussed above, ambiguity attitudes are affected by magnitude of probability. In particular, ambiguity aversion diminishes (and ambiguity seeking increases) at low probability. This in turn can affect ambiguity preferences such that information about probabilities would be less valued. This range effect, in combination with the domain and time horizon effects, has implications in the valuation of highly ambiguous entrepreneurial ventures. This gap in understand the range effect, and its interaction effects with domain and time horizon, could be further explored in the context of entrepreneurship.

No experimental study has explicitly looked at the effect on ambiguity attitudes of a combination of characteristics representative of an entrepreneurial context. From the description of effects of

factors above, interaction effects between factors are possible. Consequently, it is reasonable to anticipate that ambiguity attitudes in an entrepreneurial context will differ that those that have been studied in literature, and this constitutes a gap in experimental entrepreneurship.

In sum, the ambiguity profile describes an ambiguity situation. Elements of the ambiguity profile influence ambiguity attitudes, which in turn influence ambiguity preferences. The conceptual model of Figure 2.1 includes both a direct link between ambiguity profile and ambiguity attitudes and the causal link between ambiguity attitudes and ambiguity preferences.

2.2.5 Other factors (ambiguity attitudes-related)

Researchers have empirically found that ambiguity attitudes are affected by several variables other than those that describe an ambiguous situation (those included in the ambiguity profile). These other factors are related to the characteristics of the individual decision maker other than their perception of the ambiguous situation. The following factors are included in Figure 2.1 perceived business context competence, perceived start-up competence, anticipation of being evaluated by others, overconfidence, and averse conditioning. These factors are addressed in turn below.

Business-Context Competence (perceived). Entrepreneurs operating in uncertain environments and who have more industry experience have been shown to demonstrate more accurate, less biased forecasting performance (Cassar, 2014). Heath and Tversky (1991) noted that context-related competence seems to make ambiguity aversion change to ambiguity seeking.

Start-up Competence (perceived). People are less likely to make investment choices in geographically distant locations. An explanation is that people perceive themselves as less knowledgeable about distant investments as compared to local ones (Trautmann et al., 2008). Prior research has expected perceived competence to have an influence on ambiguity attitudes (e.g., Onay et al., 2013). In the context entrepreneurship, we refer to this as start-up competence.

Anticipation of Being Evaluated by Others. An anticipation of being evaluated by others is expected to affect ambiguity preferences because Curley et al. (1986) describes how a decision maker will make a choice that they perceive will be the most justifiable to others. In the context of entrepreneurship, the judgment of co-founders, investors, employees and other stakeholders are anticipated to influence ambiguity attitudes.

Overconfidence. Deligonul et al. (2008) suggest that entrepreneurs tend to dismiss possible future performance states as they enter new markets, and this can contribute to venture failure. Shepherd et al. (2015) have attributed this tendency to entrepreneur overconfidence. This overconfidence is what Camerer et al. (2005) terms "wishful thinking". Hogarth and Karelaia (2012) provide an alternative explanation for this excess entry, namely judgement fallibility. Judgement fallibility would be exogenous to our conceptual model. While these research groups provide theoretical support for their propositions, none has tested these propositions empirically. We have decided to include this variable in the conceptual model and recommend that worthwhile future work could include developing a proposition to test for its relevance.

Averse conditioning. Empirical study suggests that risk aversion conditioning can explain risk avoidance in gambling (Brunborg et al., 2010). Strong evidence supports the key role the amygdala plays in this type of fear learning (Ledoux, 1996). Moreover, the amygdala has a critical role in the context of aversion conditioning to ambiguity—or missing information—which has been done in the field of taste conditioning (St Andre & Reilly, 2007). Thus, it seems possible that negative aversion conditioning from a bad entrepreneurial experience can have a negative (aversion) effect on ambiguity attitudes, although there is no evidence to suggest the same mechanism can have a reverse (seeking) effect from positive entrepreneurial experience.

In Figure 2.1, an arrow is not meant to imply a direct effect on ambiguity attitudes. For instance, Business Context Competence and Start-up Competence might indirectly affect ambiguity attitudes by moderating (1) $\Delta\$$, or the amount of perceived ambiguity in the outcome and/or (2) Δp, the amount of perceived ambiguity in the likelihood. For instance, someone who assesses themselves as competent in navigating an ambiguous gamble might perceive a lesser amount of ambiguity in both the likelihood and possible amount of outcome. This is supported by literature describing how people are both more likely to take an ambiguous bet for which they believe they have greater expertise (Heath & Tversky, 1991) and more likely to take an unambiguous bet over an ambiguous bet (Fox & Tversky, 1995)—at least when small gains are at stake (i.e., in the gain domain).

In sum, researchers have found factors affecting ambiguity attitudes that are related to the characteristics of the decision maker other than their perception of the ambiguous situation. These have been included in Figure 2.1.

2.2.6 Factors not included in the model (risk attitudes-related)

Both risk attitudes (e.g., risk aversion) and ambiguity attitudes (e.g., ambiguity aversion) are associated with risky decision-making; however, ambiguity attitudes is distinct from risk attitudes and is measured separately from risk attitudes. For instance, a person can be risk averse and ambiguity seeking.

Repeatedly, experiments have found no correlation between risk attitudes and ambiguity attitudes (Camerer & Weber, 1992). However, this does not preclude a possibility that factors known to affect risk attitudes might also affect ambiguity attitudes. At the time of writing, we have yet to find literature on a direct link between ambiguity or uncertainty and the following three factors that are prevalently mentioned in literature associated with risk attitudes: business context, affordable loss, and affect. However, neuroscience reveals that there is much overlap in brain activation by factors

affecting risk attitudes and factors affecting ambiguity attitudes (Blankenstein et al., 2017). The impact of any of the three factors on ambiguity attitudes would need to be verified empirically before they could be added to the conceptual model.

Business Context. Business context refers to the attributes of a business situation other than probabilities or outcomes. Schwarzkopf (2006) surveyed 224 business students across situational risk characteristic variables, including how controllable a situation is and how many people are affected by an outcome, and found that business context factors affected participants' risk perceptions of a situation.

Affordable Loss. Affordable loss relates to how much an entrepreneur feels they can afford to lose and whether they feel they have sufficient resources (relative to an aspired level). In a simulation study, March and Shapira (1992) found that the amount of accumulated resources (relative to a perceived "survival point" and/or desired "aspiration level') influence risky choice behavior in decision makers. Dew et al. (2009) rely on behavioral economic theory to predict that individuals who perceive a higher affordable loss are more likely to make the risky choice of pursuing an entrepreneurial career. These researchers also developed propositions related to the affordable loss heuristic that was borne of empirical studies of entrepreneurial expertise (Sarasvathy, 2001). The salience of loss is in accordance to the risk construct proposed in the often-cited book by Yates and Stone (1992). This risk construct is based on three underlying considerations: potential losses, the significance of those losses, and the uncertainty of those losses. Forlani and Mullins (2000) also proposes that new venture risk is framed in terms of potential losses, and not in terms of probabilities, and base this in part on empirical studies by Shapira (1995).

Affect. Emotions affect perceptions of risk in ways that can help explain risk-seeking and risk-aversion (Caplin & Leahy, 2001). Lerner & Keltner (2000) demonstrated that fearful people are more

pessimistic in their estimates of risk and make more risk-averse choices, and angry people are more optimistic in their estimates and make more risk-seeking choices. In a highly-cited book, LeDoux (1996) writes, "While conscious control over emotions is weak, emotions can flood consciousness. This is so because the wiring of the brain at this point in our evolutionary history is such that connections from the emotional systems to the cognitive systems are stronger than connections from the cognitive systems to the emotional systems." One specific fear that appears to be associated with risky decision-making in entrepreneurship is the fear of failure (Kollmann et al., 2017). Moreover, these researchers empirically found a relationship between affordable loss and fear of failure: When nascent entrepreneurs were confronted with financial obstacles (i.e., obstacles related to affordable loss), they had a reduced likelihood of exploiting that business opportunity (i.e., taking a gamble), and this was mediated by fear of failure. This study also found these entrepreneurs to have evaluated a lower perceived magnitude of gain for that business opportunity.

In sum, factors affecting risk attitudes may also affect ambiguity attitudes; however, the impact of any of the three factors above on ambiguity attitudes would need to be verified empirically before they could be added to the conceptual model of Figure 2.1.

2.3 Discussion

The goal of this paper was to theorize about how people behave under condition of ambiguity, a condition that is relevant to the entrepreneurial context. The theoretical contributions of this paper rely on empirical findings in behavioral economics, which has a long history of rigorous experimentation using a validated construct of ambiguity attitudes. While a great deal of empirical study has been done in behavioral economics to study risk attitudes, comparatively less has been done for ambiguity attitudes. This is an important gap because literature reveals that notwithstanding an entrepreneur's attitude to risk, their attitude to ambiguity affects will affect their entrepreneurial

behaviour. The lack of research on ambiguity attitudes in general, and in entrepreneurship specifically, provides a greenfield opportunity for decision making and entrepreneurship research.

Decision sciences and neuroscience have advanced scholarly understanding of ambiguity attitudes, at a deep cognitive level. This understanding is underutilized in entrepreneurship, as evident from our literature review, and developing such an understanding answers a call from entrepreneurship research and practice (Davis et al., 2016; Bacigalupo et al., 2016; OECD & EC, 2015). This paper contributes to theory about attitude to ambiguity at the individual unit of analysis. While the behavioral economics approach to this theorizing has strong merits, it does not preclude alternative approaches, such as an affect-based approach (e.g., Grégoire et al., 2015). Future work could be done to theorize based on other approaches.

2.3.1 Designing experiments in entrepreneurship

Two novel theoretical contributions emerge from this work, and both are helpful in designing experiments that address the above-mentioned gap in entrepreneurship research described by Zhang and Cueto (2017). The first contribution is a conceptual model describing the experimental variables and the relationships between them that should be considered when studying ambiguity attitudes in a context that is representative of entrepreneurship. This contribution has applications in entrepreneurship, particularly in experimental design and survey design. The conceptual model identifies several variables that should be controlled for an experiment to study ambiguity attitudes, namely business context competence (perceived), start-up competence (perceived), averse conditioning, overconfidence, and anticipation of being evaluated by others. For instance, to control for these variables in a study about nascent entrepreneurs, the researcher could restrict their population sample to senior level and graduate entrepreneurship students from the same upper-level class in entrepreneurship so they could be reasonably be anticipated to share a similar level of entrepreneurship training and work experience (i.e., no entrepreneurial experience outside of a

campus business incubator ecosystem). As such, the sample could reasonably be considered homogeneous in both subjects' perceived business context competence and subjects' perceived start-up competence. This choice of population would also help control for subjects' averse conditioning because students such a sample are anticipated to be less likely to yet have had a bad (or good) experience with entrepreneurship. Additionally, sampling students who have followed similar experientially-grounded entrepreneurship training might help additionally control for overconfidence. By virtue of their status as students, all of those in a sample would be reasonably expected to have similar level of anticipation of being evaluated by others. Any anticipation (or fear) of being evaluated could also be controlled (mitigated) by explaining to survey participants that they there are "no wrong answers" and that results shall be anonymized. While there are many good reasons why students are considered representative of nascent entrepreneurs (Hsu et al., 2017), the ability to control for many of the variables influencing ambiguity attitudes is another.

The second contribution is a structure called the ambiguity profile, which is comprised of elements that influence ambiguity attitudes and collectively describe an ambiguous situation as perceived by the decision maker. The ambiguity profile is comprised of those elements (variables) a researcher could choose to manipulate the entrepreneurial condition in an experimental setting.

2.3.2 Interdisciplinary knowledge

Risky decision-making that includes ambiguity is not restricted to entrepreneurship. This conceptual model can be used to facilitate interdisciplinary communication to advance a collective understanding of how people behave under condition of ambiguity. This paper contributes to facilitating interdisciplinary communications by disambiguating some terminology across disciplines. This could contribute to future theory building in at least two other academic disciplines. For one, it could contribute to theory building in the discipline of project management such as new product development (NPD). In new product development (NPD), the term "equivocal uncertainty of

probability distributions" can be used to describe the type of ambiguity described in this paper (Camerer & Weber, 1992; Galbraith, 1974). Project risk management practices developed for NPD could be explored to determine what might be applied to entrepreneurship. Suggestions by Forlani and Mullins (2000) include risk analysis, qualitative and quantitative market research methodologies, and critical assumption planning of Sykes and Dunham (1995). Research in NPD suggests that front-end activity that reduces ambiguity leads to more successful innovation commercialization (Frishammar et al.,2011). In a start-up, the NPD process coincides with the start of the company's operations; in other words, at the founding of a new venture, NPD begins. Therefore, it is likely that at least some of what is known or learned in the context of entrepreneurship might be generalizable to NPD and vice versa.

For another, it could contribute to theory building in the discipline of corporate finance, namely in financial risk management, where ambiguity is called "unknowable risks" (Diebold et al., c2010). Financial forecasting for an innovative new venture requires guessing about the future, where this guessing is based on limited (or no) information. Knowledge gained from empirical work in entrepreneurship could also be useful to researchers in financial risk management. Conversely, knowledge from financial risk management about biases and how to resolve those risks would be relevant to entrepreneurship, and entrepreneurial [corporate] finance in particular.

2.3.3 Future experimental work

Six interesting lines of future experimental research could build on the theoretical contributions of this paper. First, empirical work is encouraged to provide further support for the inclusion of overconfidence in the conceptual model of Figure 2.1. Deligonul et al. (2008) provide an argument that supports including overconfidence; however, an explanation by Hogarth and Karelaia (2012) suggests it should be removed.

Second, experiments could be performed to determine whether any of the factors that are known to influence risk attitudes also influence ambiguity attitudes and should be added to the conceptual model of Figure 2.1.

Third, empirical work is encouraged to better understand the multiple mechanisms mediating or moderating ambiguity attitudes in entrepreneurship. For instance, interaction effects between element of the ambiguity profile are anticipated (e.g., Camerer & Weber, 1992), and above we identify gaps in experimental entrepreneurship to understand some of these anticipated effects. Experiments might be performed to address these gaps by studying the effect of simultaneously manipulating various elements of the ambiguity profile in ways that are representative of ambiguous situations in entrepreneurship. Also, researchers may propose and test for additional factors that might influence ambiguity attitudes, or for additional elements to be added to the ambiguity profile. As mentioned, Figure 2.1 is not necessarily an exhaustive collection of causal variables. For instance, it seems sensible that trust in expert opinion of likelihoods would have an influence on moderating $\boldsymbol{p}$, $\boldsymbol{\$}$, $\Delta\boldsymbol{p}$, and $\Delta\boldsymbol{\$}$. For instance, someone's perceived probability of likelihoods is reasonably anticipated to match that of a trusted expert more closely than that of an untrusted expert.

Fourth, the conceptual model presented here is based on experiments performed at the individual unit of analysis. The elements of the ambiguity profile closely resemble those contributing to Milliken's (1987) "effect uncertainty", or the perceived ambiguity an organizational administrator has regarding an environment's impact on their organization. This suggests that the conceptual model has the potential to be generalized to experimentally study ambiguity attitudes at the level of analysis of the firm.

Fifth, experiments could be performed to study whether this conceptual model is generalizable to ambiguous situations with outcomes that are not financial. For instance, experiments could be

performed to study whether social or environmental outcomes influence ambiguity attitudes in the same way as do financial outcomes. These types of non-financial outcomes are important in social entrepreneurship and sustainable entrepreneurship.

Sixth, further research could explore how ambiguities are tackled by successful start-ups. Specifically, how successful entrepreneurs use their limited resources to reduce ambiguities by gathering information. Lack of information contributes to the ambiguous situation that entrepreneurs face. Regardless of this lack of information, an entrepreneur must make decisions and typically must make those decisions quickly. For instance, in the pursuit of maintaining a positive cash balance, an entrepreneur needs to make many critical financial decisions under conditions of financial ambiguity. The ability to allocate resources to gather information to reduce ambiguity is an important resource allocation problem because an entrepreneur has limited resources (e.g., time; money, and expertise) to deploy. Consequently, which ambiguities the entrepreneur chooses to resolve and how they resolve those ambiguities, given their limited resources, makes for interesting future research questions. Choices between gambles using protocols from experimental research such as pairwise choice might provide information about entrepreneurs' preferences in resolving this ambiguity. Experimental work of this type would help inform our understanding of the entrepreneurial process, particularly resource allocation in entrepreneurship.

To recap, a great deal of empirical literature can be found on decision-making behaviors of those faced with risk and uncertainty. In contrast, relatively little can be found for those faced with ambiguity. This chapter provides a conceptual model of factors affecting attitude to ambiguity. This conceptual model relies on rigorous findings from behavioral economics about ambiguity attitudes. The model includes a novel structure called the ambiguity profile that describes an ambiguous situation as perceived by the decision maker. Next, let us refer to this model and describe the combination of factors typical of a context representative of entrepreneurship. This conceptual model

is useful to designing experiments to study behaviour towards a gamble in a context that is representative of entrepreneurship, or towards an "entrepreneurial gamble".

2.4 Entrepreneurial gamble

An entrepreneur routinely makes risky decisions in an ambiguous context. For instance, in pursuit of a new venture opportunity, an entrepreneur is faced with "entrepreneurial gambles". The concept of an entrepreneurial gamble, and how it can be represented by the elements of the ambiguity profile, is defined here. First, (1) an entrepreneurial gamble has potential for both consequential direct personal gain and personal loss (i.e., element ***$*** of the ambiguity profile) in the same gamble (i.e., element ***d***). For instance, "market segment A could help grow my company but, if it fails, I will be bankrupt." Second, (2) an entrepreneurial gamble often includes a preference between substantial near-term and long-term financial outcomes (i.e., element ***t***). For instance, "should I take this equity offer or wait to see if I get a better one?" Third, (3) an entrepreneurial gamble includes ambiguity originating from non-random sources. For instance, entrepreneurs regularly make decisions whether to pursue an opportunity despite having little information to help inform these decisions. Information such as market size, market growth rate, distribution channels and funding alternatives is typically limited (i.e., incomplete)—at best—and based on conflicting (i.e., insoluble) reports. Ambiguity arising from this incompleteness and/or insolubility of information may be from sources perceived to have non-random variability. For instance, an entrepreneur's trust in a report is anticipated to influence their perception of the characteristics of the ambiguity. (i.e., non-random distributions reflected in the perceived combination of ***p***, Δ***p***, ***$***, and Δ***$***).

2.5 Summary

In sum, an entrepreneurial gamble can be expressed in terms of elements of the ambiguity profile, and no experimental research has looked at ambiguity attitudes towards gambles that have a combination of the characteristics of entrepreneurial gambles.

The next chapter will refer to the entrepreneurial gamble and describe a protocol to measure attitude to ambiguity for a context representative of entrepreneurship, or, in other words, to measure attitude to ambiguity for an entrepreneurial gamble. The next chapter will describe how the ambiguity aversion (or, ambiguity attitudes) protocol is not suitable for the mixed domain of an entrepreneurial gamble. Consequently, ambiguity attitudes towards entrepreneurial gambles may be different that those that have been studied in literature. As such, it is reasonable to anticipate that entrepreneurs may be subject to some yet unexplored ambiguity attitudes.

CONCEPTUAL DEFINITION

Entrepreneurial gamble: an opportunity as perceived by an entrepreneur that is characterized by:

- potential for both consequential direct personal gain and personal loss;
- substantial near-term or long-term financial outcomes, and
- includes ambiguity originating from a non-random source.

Chapter 3
A state measure: Ambiguity Additivity

Notwithstanding an entrepreneur's attitude to risk, their attitude to ambiguity will affect their entrepreneurial behaviour. The objective of this chapter is to describe a protocol to measure attitude to ambiguity for a context representative of entrepreneurship, or, in other words, to measure attitude to ambiguity for an entrepreneurial gamble, which is characterized by the elements of the ambiguity profile of Chapter 2 (conceptual model). This chapter draws from theory of human decision making, specifically behavioural economics, and translates and adapts this theory for entrepreneurship.

Many protocols have been used to quantify attitude to ambiguity, including a widely-used ambiguity aversion (or, "ambiguity attitudes") protocol. As discussed in Chapter 1 (introduction), this protocol has advantages over others in that it provides a state measure, and it can provide insight at a deep psychological level. As discussed in Chapter 2 (conceptual model), in order to make this protocol useful to study attitude to ambiguity for a context that is representative of entrepreneurship, the protocol needs to be able to manipulate the elements of the ambiguity profile that represent the entrepreneurial gamble under study. A suitable protocol had not yet developed that could accommodate for the mixed domain element of an entrepreneurial gamble. This chapter finds a way of providing for this missing element. In the process, this novel protocol has additional desirable features, and has 10 notable features overall.

This chapter is divided into three parts. The first part will describe why and how the protocol was developed and its ten notable features. The second part will describe using the protocol to create a survey instrument for a context representative of entrepreneurship, and describe a survey that is designed using this protocol. This survey instrument helps achieve a second objective of this thesis, namely to measure attitude to ambiguity for a specific context representative of entrepreneurship. The

third section will discuss contributions of this work, implications of the protocol outside of entrepreneurship, proposed future work on the protocol, and use of this protocol in experimental entrepreneurship. Terminology used in this chapter is described in Table 1.1.

3.1 Protocol development and features

The first two features of this protocol came from requirements to address specific gaps described in Chapter 1 (introduction).

1. It is a ***"State"-type*** protocol: This means it is used to measure a dynamic, or situation-specific, attitude to ambiguity described in Chapter 1.2 (prior attempts). Recall from Chapter 1.4 (puzzles) and Chapter 1.2 (prior attempts) that there is a gap in state-type protocols in entrepreneurship, and that filling this gap would provide a contribution to entrepreneurship research. It would also address a gap in entrepreneurship practice, which proposes a conceptual definition of the entrepreneurial mindset that includes dynamic ambiguity (Davis et al., 2016; OECD & EC, 2015).

2. ***The protocol provides psychological insight***: This protocol can be used in cognitive psychology to measure deep psychological constructs associated with ambiguity. Such a protocol would be welcomed by the entrepreneurship community of practice (OECD & EC, 2015), and consequently contributes to filling a gap in entrepreneurship practice.

Searching for a protocol to fit these two requirements began with "beginner's eyes"; in other words, the search was open to interdisciplinary perspectives. Specifically, a broad scope of academic literature was considered, namely decision making (including but not limited to the fields of decision science, behavioural economics, cognitive psychology, ambiguity research, and neuroeconomics), personality research, and entrepreneurship (including but not limited to the fields of entrepreneurial decision making, entrepreneurial characteristics, the entrepreneurial mindset, and new product engineering management). The extensive literature search is fully described in Chapter 1.5

(motivating gap). Chapter 2 (conceptual model) describes how decision making literature provides a robust, widely-used protocol for "ambiguity attitudes" that is based on expected utility and follows a pairwise choice method. This traditional protocol is also used in neuroeconomics to understand neurological mechanisms. Consequently, the ambiguity attitudes protocol provides both of the desired features listed above. However, this traditional protocol does not allow for certain characteristics of an entrepreneurial gamble described Chapter 2.4. Specifically, the traditional protocol does not meet the following two requirements:

3. ***Suitable for the mixed domain***: Recall from Chapter 2.4 that an entrepreneurial gamble is a mixed gamble, one with a potential for both consequential direct personal gain and personal loss in the same gamble, for example, "market segment A could help grow my company but, if it fails, I will be bankrupt."

4. ***Allows for non-random ambiguity***: Recall from Chapter 2.4 that an entrepreneurial gamble can include ambiguity perceived by the entrepreneur to be non-random. For instance, consider an entrepreneur who is faced with the following situation: "market segment A could help grow my company but, if it fails, I will be bankrupt." Precise demand from market segment A, while unknowable, is unlikely to be perceived as completely random. It would be reasonable for some of it to be perceived as epistemic uncertainty and/or agentic uncertainty.

The inability of the traditional protocol to meet these last two requirements led to a research question of this thesis: **might there be a way of measuring ambiguity attitudes in the mixed domain for a context that is representative of entrepreneurship?** To answer this question, theoretical development of a mixed domain construct based on the ambiguity attitudes model of expected utility theory was undertaken, and this is described in Chapter 5.3.1 (theoretical development). A method to operationalize such a mixed domain construct was not available until

recently, with the introduction of a novel approach by Baillon et al. (2018). The adaptation of this approach to an entrepreneurship context (i.e., its ecological verisimilitude to an entrepreneurial gamble) had not previously been attempted, constituting a gap in entrepreneurship. The novel experimental protocol of Baillon et al. (2018) has two features that help to meet the requirements above. For one, their protocol uses a pairwise choice method. Recall from Chapter 1 (introduction) that this method typically limits the nature of ambiguity to aleatory variability. However, the events of Baillon et al. (2018)'s protocol can include any type of ambiguity, including aleatory variability. Baillon et al. (2018)'s protocol only requires events to be mutually exclusive, exhaustive, and nonnull. Because Baillon et al. (2018)'s protocol does not have restrictions on how the set for each event is described, the protocol can be adapted with two more features. First, it does not require the outcomes of a gamble to be symmetric about a reference point (e.g., a gain-loss divide between a gain event and a loss event); in other words, it allows for asymmetry across domains. Second, it does not require that the reference point to be explicitly stated (numeric), the gain-loss divide can be left open to subjective interpretation. These features are summarized:

5. ***Allows for asymmetry of events***: the amount of gain and loss need not be equal. Figure 3.1 illustrates this feature.

6.***Agnostic of objective gain-loss divide***: this feature allows entrepreneurs to perceive the crossover point from their loss domain to their gain domain (and vice-versa) differently. For instance, in the case of potential for either financial gain and loss, the reference need not be zero. To implement this feature, the survey question should describe the gain-loss divide using wording that is at once precise enough to be unequivocally understood and loose enough to allow for subjective interpretation. The gain-loss divide is illustrated in Figure 3.1.

Furthermore, the established protocol for "ambiguity attitudes" follows a traditional pairwise choice method. Unlike the pairwise choice of the traditional method, the pairwise choice method of Baillon et al. (2108)'s protocol is between likelihoods only; in other words, it is indifferent to an individuals' (subjective) utility of possible outcomes of the gamble. It is a series of choices between an ambiguous and unambiguous gamble. This allows for another notable feature:

7. ***Agnostic of objective utility***: this allows entrepreneurs to perceive gain and loss differently from one another. For instance, an entrepreneur's "basket of utility" might include a mix of financial and non-financial items. To implement this feature, the survey question should ideally describe the maximum possible amounts of gain and loss using wording that is at once precise enough to be unequivocally understood and loose enough to allow for subjective interpretation. The intended subjective nature of these maximum amounts of gain and loss is illustrated in Figure 3.1.

The operationalization of my mixed domain construct, described in Chapter 5.3.1 (theoretical development), leads to another feature of this protocol:

8. ***Provides a normative benchmark***: The two events combined constitute a closed set because the two are mutually exclusive, exhaustive, and nonnull. Therefore, the probabilities assigned to each event in would normatively add to one, or be "additive neutral", as described in Chapter 5.3.1 (theoretical development). This additive neutral point is a normative benchmark against which all subjects' measurements can be compared.

Baillon et al. (2018) operationalized their protocol using a three-event partition. Li (2017) also used this protocol. In contrast to theirs, my protocol has been operationalized using a two-event partition, providing a ninth feature:

9. ***Easy as possible to administer***: Compared to the popular three-event partition implementation, my two-event partition implementation requires roughly a third of the time to administer and involves

fewer and less complex numeracy tasks for the participants. This 2-event partition is illustrated in Figure 3.1.

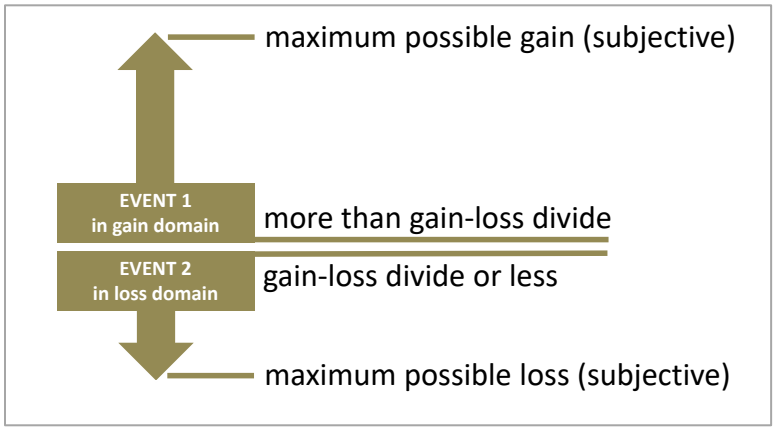
There is a tenth and final feature of the protocol:

10. ***Context is flexible****:* Context that is representative of entrepreneurship, i.e., that represents the characteristics of the entrepreneurial gamble under study, is added by survey question wording. Considerations for survey question wording are described in Appendix A (survey wording) in columns "consideration" and "description".

3.2 The matching-pair probability protocol

The resulting research method is called the "matching-pair probability protocol", and key features are illustrated in Figure 3.1. The following features are illustrated: suitable for the mixed domain, allows for asymmetry of events, agnostic of objective gain-loss divide, agnostic of objective utility, and easy as possible to administer because of 2-event partitioning.

Figure 3.1 Illustration of several features of the "matching-pair probability protocol"



3.3 Survey instrument

The protocol was used to develop a survey instrument to measure attitude to ambiguity for a context that is representative of entrepreneurship. This survey can be found in Appendix B and was

used in the study of Chapter 5 (study) that contributes to establishing the operational validity of the survey, which is described next. Chapter 5.3.1 (theoretical development) also provides a more intuitive label for this measure, namely Ambiguity Additivity.

3.4 Operational validity

Operational validity is supported in four ways. First, face validity (i.e., "do the items measured seem suitable to adequately represent the domain of interest?") is achieved because the protocol preserves the mathematical logic of ambiguity attitudes that prevails in literature. Second, content validity (i.e., "do the items measured seem suitable to adequately measure the domain of interest?") is achieved because the protocol preserves the robust, widely-repeated pairwise choice between ambiguous and precise gambles. Third, item reduction (i.e., "is the scale parsimonious?") is achieved because empirical results find only a low correlation between the two items. These items have a low positive correlation at the Bonferroni-adjusted level, $r(97) = .3467$, $p < .01$. Analysis and interpretation of these results are provided in Appendix G (supplemental statistics: matching probabilities). Low correlation between the items implies at least modest independence, or orthogonality, of the item dimensions. Such orthogonality means the items are not redundant, and this supports parsimony. Fourth, accuracy (i.e., "do the items of the test adequately measure the domain of interest?") is supported by evidence. Specifically, in the study of Chapter 5 (study), participants are found to be highly sub-additive ($M = 0.20$ [8] , $SD = 0.34$ [9], $t(98)= 5.77$ [10], $p < .0001$ [11]), and this can be explained theoretically. Analysis and interpretation of these results are provided in Chapter 5.4.1 (evidence of operational validity).

[8] $M = 0.199798$
[9] $SD = 0.3445131$
[10] $t(98)= 5.7704$
[11] $p < .00005$ (Stata's reporting precision limit)

3.5 Discussion

This work provides three contributions. First, it provides a protocol that can be used in empirical entrepreneurship research. Specifically, this protocol can be used for designing a survey instrument to measure attitude to ambiguity for a context that is representative of entrepreneurship. For example, it has been used to design a survey to study attitude to ambiguity under conditions that includes loss, or ambiguity-related loss aversion. Ambiguity-related loss aversion differs from risk-related loss aversion, which, Chapter 1 (introduction) explains, has been widely studied and referenced. This protocol contributes to entrepreneurship because it enables the study described in Chapter 5 (study), which includes loss aversion for a context that is representative of entrepreneurship. Second, the protocol can be used to assess change in attitude to ambiguity by interventions aimed to help grow the entrepreneurial mindset. This is desired by the entrepreneurship community (Davis et al., 2016; OECD & EC, 2015; Bacigalupo et al., 2016), contributing to entrepreneurship practice. Third, because protocols based on expected utility have been accepted in cognitive psychology, questions designed by this protocol might be used to better understand the mechanism of these interventions at the deep psychological level (e.g., Blankenstein et al. (2017); Huettel et al. (2006)). This is also a contribution to entrepreneurship practice.

This research method has implications in other disciplines. Survey instruments developed using this protocol are agnostic of utility; therefore, this protocol could be used to operationalize an entrepreneurial gamble with outcomes that are non-financial, or a mix of financial and non-financial, making it useful for social entrepreneurship.

Comparison of this protocol to other protocols in Figure 1.1 (prior protocols) reveals that it is more complex to administer than most prior state protocols used in entrepreneurship. Future work could investigate alternative protocols to measure attitude to ambiguity at a deep psychological level. One such exploration is described in Chapter 6, as part of the final objective of this thesis.

3.5.1 Experimental entrepreneurship

Experiments can provide a reliable and cost-effective way to study entrepreneurship compared to field work or secondary data analysis because of the heterogeneity of new ventures. For instance, new ventures vary widely in terms of their industry, scope and scale of resources, level of social capital, and cultural context. Consequently, different new ventures will have different time horizons to outcome and potential amounts to be gained or lost, factors which are known to affect decision-making behaviour. Unless these factors are controlled, they will contribute to measurement error. This challenge could be overcome by analyzing sufficiently large data sets. However, a large sample of entrepreneurs is not always attainable, and secondary data is rarely ideally suited to test a novel hypothesis. Experiments provide a homogenous context in which factors can be controlled and manipulated. Consequently, experiments allow for smaller, more realistic sample sizes, and experiments can be quicker and less expensive than alternatives.

The model described in Chapter 2 (conceptual model) includes the ambiguity profile, which is comprised of the following elements: domain (***d***), magnitude of outcome (***$***), width of the range of outcome (***Δ$***), magnitude of probability (***p***), width of the range of probability (***Δp***), and time horizon (***t***). Note that the elements of the ambiguity profile are objectively defined, as opposed to subjectively perceived. They can be manipulated or controlled by the experimenter. The experimenter assumes that all participants will be exposed to the same objective ambiguity; however, the experimenter does not assume that every participant will perceive the same ambiguity. For instance, groups of participants in the experiment of Chapter 5 (study) will read the same text that unequivocally describes "a LARGE amount of money" they could lose. Because the text is the same, the ambiguity that each participant is exposed to, objectively, is the same. However, each participant will form their own perceptions under this condition of ambiguity, rendering the ambiguity subjective. It is their perception under condition of this ambiguity that the experimenter measures using this protocol.

This protocol could be used to study micro-organizational behaviour under condition of ambiguity. An entrepreneur's initial decision to start a new venture can be made individually. However, Chapter 2 (conceptual model) describes how one's attitude to ambiguity is affected by social factors, namely one's anticipation of being judged by others. Such social factors might affect their initial decision to start a new venture, and their subsequent decisions as their team grows. The influence of these social factors could be investigated through laboratory experiments. For instance, a longitudinal experiment could observe any shift in attitude to ambiguity as an entrepreneurial team grows. Attitude to ambiguity of an individual and a team could be measured. To measure the attitude to ambiguity of a team, the team could collectively perform the experimental task.

Future work could establish laboratory experiments as a tool for empirical entrepreneurship, especially in the study of entrepreneurial decision making.

3.5.2 Operational limitations

A survey developed using this protocol has operational limitations. While it requires subjects to complete a less complex mathematical task than the prior approach by Baillon et al. (2018), it still requires numerosity on the part of the subject. This requirement is anticipated to limit its accessibility across demographics, making it less practical for use across a general population. Future work is recommended to explore ways to make the survey task more cognitively accessible while maintaining the mathematic logic. Alternatively, a non-numerical approach is explored in Chapter 6.

3.5.3 Attitude to ambiguity as a risk assessment

This chapter provides an approach to observing, at a deep psychological level, a dynamic (state) attitude to ambiguity for a context representative of entrepreneurship. This approach uses matching-pair probabilities, which are subjective assessment of likelihoods. Likelihoods comprise what is

commonly known as risk assessments (PMI, 2019). Therefore, an entrepreneur's attitude to ambiguity can be referred to in more generalized terminology as an entrepreneur's risk assessment.

3.6 Summary

This chapter provides a protocol for creating a survey to measure dynamic (or state) attitude to ambiguity, and explains why an entrepreneur's attitude to ambiguity can be referred to in more generalized terminology as an entrepreneur's risk assessment. Surveys created by following the protocol of this chapter are used in Chapter 5 (study) to achieve the second objective of this dissertation, namely to measure attitude to ambiguity for a specific context representative of entrepreneurship, or, in other words, attitude towards entrepreneurial gambles. Before proceeding to the chapter describing the study, the next chapter describes a trait measure that is developed and validated for use in that study.

Chapter 4
A trait Measure: Unpredictability Tolerance

Chapter 1.4 (puzzles) provides reason to believe that personality is important to understanding an entrepreneur's perception of ambiguity. The following section develops and validates a scale for a new measure of trait, specifically, unpredictability tolerance. This measure will be used in the study described in Chapter 5 in order to achieve the second objective of this dissertation: to measure attitude to ambiguity for a specific context representative of entrepreneurship. Thereby, this chapter contributes to a collection of empirical findings from measuring subjective assessment. Specifically, this chapter results in a scale to measure ambiguity tolerance towards entrepreneurial gambles. Terminology used in this chapter is described in Table 1.1.

The definition of tolerance to ambiguity[12] in personality research dates back to Norton (1975) and Budner (1962), researchers who each developed well-known measures of tolerance to ambiguity, define intolerance to ambiguity as a greater tendency to perceive ambiguous information as psychologically threatening. Budner went further to define the tolerance to ambiguity as the tendency to interpret ambiguous situations as desirable. However, many of their survey questions lack relevance to dimensions of ambiguity tolerance associated with entrepreneurial gambles, namely that associated with probability or possible outcome.

4.1 Gaps identified

Literature does not provide an obvious measure of a personality trait of Ambiguity Tolerance for use in the study of entrepreneurial gambling. A recent study by Hillen et al. (2017) reviews well-established scales for measuring Ambiguity Tolerance. They analyzed eighteen (18) validated scales

[12] In personality literature, several terms are used interchangeably to denote "Ambiguity Tolerance", namely "Tolerance to Ambiguity", "Tolerance to Uncertainty", "Intolerance to Ambiguity", "Uncertainty Aversion" and "Ambiguity Aversion". Confusingly, the latter term has also been used in behavioural economics to describe one type of Ambiguity Attitudes (the others being ambiguity-seeking and ambiguity-neutrality).

and identified fourteen (14) sources of ambiguity that are measured across the combination of scales. Most of these sources seem to be irrelevant to the type of ambiguity that characterizes entrepreneurial gambles (e.g., variety, disorder, tentativeness). However, four (4) of these sources of tolerance seem to be relevant to the ambiguity present in entrepreneurial gambles, namely lack of information about outcome (i.e., $\Delta\$$) or probability (i.e., Δp). Specifically, these four sources are tolerance to Incompleteness, Insolubility, Impermanence, and Unpredictability.[13] This research has completed the development and validation of a scale for one of these sources, namely Unpredictability Tolerance.

4.2 Contributions

Despite empirical results that suggest a relationship between Ambiguity Tolerance and attitude to ambiguity (Sherman, 1974)[14], little empirical work has been done to date to study this relationship. Doing so requires combining sufficiently deep knowledge from two disciplines of research, which is challenging in academia and therefore an unlikely occurrence. Specifically, it requires combining a dispositional measure of Ambiguity Tolerance that is widely established in personality research with a situational measure of ambiguity attitudes derived from expected utility theory that is widely established in decision sciences.[15]

Contributions described. Tolerance to ambiguity is important to understanding how an entrepreneur behaves under condition of ambiguity for three important reasons. First, as mentioned, little empirical work has been done to date to study this relationship. Devising a scale to measure Ambiguity Tolerance that has dimensions (factors) that are most relevant to a context representative

[13] Hillen et al. (2017) define "Incompleteness" as "insufficiency, inadequacy of information", "Insolubility" as "resistance to being worked out or explained", "Impermanence" as "instability, evanescence, mutability, changeability, temporariness", and "Unpredictability" as "indeterminacy or randomness of future outcomes".
[14] The scale by Sherman (1974) was not tested for reliability or internal validity, and his work has not been duplicated.
[15] Baillon and Placido (2019) looked at what they call "constant ambiguity aversion" but this was operationalized as situation-specific, not relating to a dispositional personality trait that would be anticipated to remain constant across situations.

of entrepreneurship is contribution to entrepreneurship because it can be used to study this relationship. Second, unlike other variables that are empirically known to affect ambiguity attitudes, measures of Ambiguity Tolerance are both considered to be related to stable traits such as dogmatism and rigidity (MacDonald, 1970) and are proposed to be invariant (Budner, 1962). As a stable psychological construct, Ambiguity Tolerance may be uniquely useful in helping to explain ambiguity preference because correlation with another variable, if one exists, must be in one direction only; in other words, its direction of causation can be clearly established. This makes it a contribution to decision making/ambiguity research generally, and specifically to the study tolerance to ambiguity toward an entrepreneurial gamble, such as the study described in Chapter 5. Third and relatedly, there is a growing body of academic research into the conceptual construct of entrepreneurial mindset, which is proposed to include a dimension of tolerance for ambiguity by both the entrepreneurial community of practice (OECD & EC, 2015) and entrepreneurship academics (e.g., Davis et al., 2016). Consequently, this is a contribution to entrepreneurship research and practice.

4.3 Unpredictability Tolerance (UT) validation

Purpose of this study: This purpose of this experiment is to develop and validate a measure of Unpredictability Tolerance (UT). UT can then be used in the study of Chapter 5, which addresses a research question of this thesis, namely, **can a personality trait help explain attitudes towards ambiguity in an entrepreneurial context?**

Experimental Design and Method: All 75 participants received the same version of questionnaire. [16] [17] Some 36 subjects passed the manipulation check, and their data was retained. The

[16] Participants were comprised of 75 students from two universities in Ontario, Canada. Some 43 were senior undergraduate business students from the University of Waterloo and 32 were graduate business students from Ryerson University.

[17] Other details about the stimulus that might be of interest to the reader: the survey took an average of 10minutes. Both classes were in the evening, and students quietly remained at their desks after class and

method of development and validation of this measure of Unpredictability Tolerance is summarized in Table 4.1.

4.3.1 Results and analysis

An analysis and discussion at each stage of the development and validation is provided in Table 4.1.

completed the paper and pencil survey questionnaire. They were offered healthy snacks and drinks during this time. The topic of the class preceding the survey was business strategy.

Table 4.1 Unpredictability Tolerance scale Development and Validation process

Activity	Methods and Outcomes
	PHASE 1: ITEM DEVELOPMENT
Content validity Do the items adequately measure the domain of interest?	**Method:** Items were drawn from well-established scales. In an effort to develop the most succinct questionnaire, questions are discarded if they were duplicitous, could reasonably have two meanings, or not related to one of the above-mentioned four sources. The questions that are retained are from two well-established scales: Norton (1975), and Greco and Roger (2001). **Outcome:** The resulting scale is comprised of four items to measure the Unpredictability Tolerance (UT) factor. These items are listed in Table 4.2.
	PHASE 2: SCALE DEVELOPMENT
Item reduction Is the scale parsimonious?	**Method:** Administer potential scale items on a sample of the target population. Estimate correlations between scale items, as well as the correlations between each item and sum score of scale items, to answer the following: ● If some items are highly correlated with each other, are some items redundant and should be removed? ● If some items do not correlate satisfactorily to any factors, should these be dropped? ● If some items are often skipped by respondents, should these be dropped? **Outcome:** After item reduction was performed on UT, all four items were retained. In regards to three items of the scale (items 2-4), the factor loadings of each these are roughly equal, which is desirable because this means the factor items are given roughly equal weight, are roughly equally important to the measure. Uniqueness of each item is low, which is desirable because this suggests that each item's variance can be explained by the factor UT. The inter-item correlations are neither excessively high (which would suggest redundancy) or too low (which would suggest low relevance). In regards to the first item of the scale (item 1), Factor Loading was low (0.3565), suggesting relatively low importance to the measure of UT, and its Uniqueness was high (0.8150), suggesting it is not related to UT to the same degree as are the other three items of the four-item scale.[18] A summary of results can be found in Table 4.3. Further work might include creating a new name for an ambiguity tolerance dimension comprised of items 2-4.
	PHASE 3: SCALE EVALUATION
Tests of reliability Are results from the scale consistent?	**Internal consistency** This is an assessment of the degree to which the set of items in the scale co-vary, relative to their sum score. **Method:** This will be performed using Cronbach's alpha (or, "coefficient alpha'). **Outcome:** The four-item scale has a Cronbach's alpha of 0.7702, which is within the range of well-established Ambiguity Tolerance measures[19] and the Big Five Inventory. This was the outcome even when a normalization was applied to correct for any extreme response bias using Likert scale [20] **Predictive validity** An assessment of the degree to which scale scores predict an outcome. **Method:** Multinomial logistical regression of self-reported rating—the dependent variable (predicted outcome)—by UT category (UT < 0: tolerant, UT > 0: intolerant)—the independent variable. **Outcome:** There is a strong, significant association between UT category and predicted outcome (Likelihood-ratio χ^2 (3) = 8.94 [21], $p < .05$ [22]).

[18] This was true also across conditions. For the full dataset of N=123, Factor Loading was low (0.4003) and Uniqueness was high (0.7804).

[19] e.g., Furnham & Ribchester (1995)

[20] The three-item UT measure has a Cronbach's alpha of 0.8295, which is on par or better than well-established Ambiguity Tolerance measures, and on par with those the Big Five Inventory. This was the outcome even when a normalization was applied to correct for any extreme response bias using Likert scale.

Table 4.2 Unpredictability Tolerance (UT) scale items

Item number	Item
1	When the future is uncertain, I generally expect the worst to happen.
2	I like to plan ahead in detail rather than leaving things to chance.
3	I try to have my life and career clearly mapped out.
4	I feel better about myself when I know that I have done all I can to accurately plan my future.

Table 4.3 Unpredictability Tolerance (UT) validation results (*N*=36)

Factor	Item number	Factor loading	Uniqueness	Inter-item correlations			
				1	2	3	4
Unpredictability Tolerance (UT)	1	0.3565	0.8150	1.0			
	2	0.7348	0.4527	0.2391	1.0		
	3	0.8006	0.3457	0.2154	0.6586	1.0	
	4	0.7860	0.3743	0.3671	0.5814	0.6739	1.0
	Cronbach's alpha: 0.7702						

***Note*.** The items in the scale are standardized (mean 0, variance 1).

4.3.2 Discussion

There are two considerations for future work. First, given the uniqueness scores for each item, further work might include creating a new name for the ambiguity tolerance dimension comprised of items 2-4. Second, in this study, a manipulation check tested a subject's interpretation of the ambiguous condition. This was done as an attention check, and roughly half of the subjects passed this attention check. Some 36 observations were retained. While this number is still considered adequate to validate this 4-item scale, an alternative attention check might be designed that adequately tests for attention while allowing for observations to be retained. This could be useful for any scales created to address one or more of the other 14 sources of ambiguity described by Hillen et al. (2017).

4.4 Summary

This chapter provides a survey instrument for measuring a personality trait that is anticipated to be relevant to attitude to ambiguity. This personality trait is unpredictability tolerance, and the survey

[21] Likelihood-ratio χ^2 = 8.9372
[22] p = 0.0301

instrument is in Appendix H (Unpredictability Tolerance survey). Chapter 5 (study) uses this survey to accomplish the second objective of this research, namely to measure attitude to ambiguity for a specific context representative of entrepreneurship.

Chapter 5
A study of state and trait

Now that Chapter 3 (state measure) has provided a way to measure attitude to ambiguity in a context representative of entrepreneurship, this chapter asks what has not been asked before: whether there is an effect of time horizon and potential loss on a decision that is more representative of that made by an entrepreneur, which Chapter 2.4 labels an "entrepreneurial gamble". This question is answered in the study described in this chapter. Thereby, this chapter contributes to a collection of empirical findings to understand subjective assessment. Specifically, this study manipulates items of the ambiguity profile described in Chapter 2 (conceptual model), namely time horizon and amount of potential loss. This study measures loss aversion through the lens of ambiguity, which, as described in Chapter 1 (introduction), is separate and distinct from the lens of risk. Terminology used in this chapter is described in Table 1.1.

Chapter 4 (trait measure) provides reason to believe that personality is also important to understand attitude to ambiguity, but how? A personality trait is expected to be stable across situations, not affected by factors that are known to affect state. This chapter describes a study that addresses both of these questions, or, in other words, addresses the effects on both state and trait. As such, this chapter describes the accomplishment of a second objective of this dissertation, namely to measure attitude to ambiguity for a specific context representative of entrepreneurship.

Chapter 2 (conceptual model) describes how entrepreneurs take risky gambles every day—gambles that are often characterized by financial gain or loss (i.e., "mixed domain" gambles). The financial outcomes of these "entrepreneurial gambles", described in Chapter 2.4, can occur in the near-term or the far-term, and decision making/ambiguity theory suggests that time will matter to gambling behaviours (e.g., Liu and Öncüler, 2017). Theory also suggests that loss will matter to gambling

behaviours (e.g., Du and Budescu, 2005). This chapter considers the effects of both time and amount of potential loss in mixed-domain gambles.

5.1 Gaps identified

There exist gaps in behavioural economics/decision making/ambiguity literature about the effect of time horizon and potential loss that warrant more research to inform attitude to ambiguity in entrepreneurial gambling. Specifically, two gaps have been identified. First, while a great deal of empirical study has been done applying behavioural economics methods to study risk attitudes, comparatively less has been done for ambiguity attitudes[23], and none has been done on entrepreneurial gambles. (Csonka-Peeren & Cozzarin; 2021). For example, prior research has studied the phenomenon of loss aversion (e.g. Abdellaoui et al., 2016; Tversky & Kahneman, 1992); however, this loss aversion research followed the protocol to measure attitude to risk, not attitude to ambiguity. Decision making theory provides robust, neurologically insightful protocols for separately measuring attitude to risk and attitude to ambiguity. Put simply, attitude to risk measures the amount one would be willing to spend (or receive) to play a lottery with known likelihood. In contrast, attitude to ambiguity assumes one is willing to pay an ambiguous ("Knightian") lottery and measures one's assessment of the likelihoods of that lottery. Prior research on loss aversion depends on the amount one would be willing to pay to avoid loss. This amount is related to attitude to risk. Experiments in loss aversion have not looked at the perceived likelihood of losing (regardless of the amount that is willing to be lost), which is related to attitude to ambiguity. Risk-related loss aversion

[23] Extensive literature search has not found overlap between the literature about (1) Attitudes to Ambiguity/Uncertainty (to measure behaviour in a situation) and Ambiguity Aversion/Seeking/Neutrality (behaviours that are measured, e.g., choices that are made using a protocol to measure behaviour in a situation), and (2) Ambiguity/Uncertainty Aversion or Tolerance to Ambiguity/Uncertainty (to measure a personality trait is arguably invariant across situations). However, it is unfortunate (because it is potentially confusing) that some researchers have used Ambiguity Aversion to label the former, while others have used it to label the latter. Chapter 3 (state measure) describes the protocol to create a measure of Attitude to Ambiguity, and in Chapter 5 (study), this measure is relabeled Ambiguity Additivity (my apologies) for a reason that is explained in that chapter.

might be triggered in subjects who take part in this study; however, it is not measured. Instead, this study measures ambiguity-related loss aversion, which, as Chapter 1 (introduction) explains, would be uncorrelated to risk-related loss aversion.

Second, the nature of the ambiguity in those experiments was different from that Chapter 2.4 for entrepreneurial gambles. For instance, the ambiguity in those experiments did not in part arise from a source that was perceived as controllable (e.g., time horizon manipulated with ambiguity arising from random source only)[24].

KEY TAKEAWAY

Attitude to risk measures the amount one would be willing to spend (or receive) to play a lottery with known likelihood. In contrast, **attitude to ambiguity** assumes one is willing to play an ambiguous ("Knightian") lottery and measures one's assessment of the likelihoods of that lottery.

5.2 Contributions

There are reasons why these gaps have not already been addressed in research. A method has not previously been available to study mixed domain gambles using an expected utility approach. One has recently been developed (Baillon et al., 2018), however, its adaptation to an entrepreneurship context (i.e., its ecological verisimilitude to an entrepreneurial gamble) has not previously been done. This brings us to another research question of this thesis, namely, **might there be a way of measuring ambiguity attitudes in the mixed domain in a context that is representative of entrepreneurship?** An additional, fourth, research gap arises related to this question because the international entrepreneurship community has made a call for sensitive tools to measure deep psychological constructs associated with ambiguity (OECD & EC, 2015).

[24] e.g., Liu and Öncüler (2017)

Contributions described. provides six academic contributions. First, this study extends the empirical coverage of the experimental design space of decision-making, namely by manipulating the elements of time horizon and potential loss in mixed-domain gambles. This work addresses the first gap mentioned above and, consequently, is a contribution to empirical body of knowledge in decision sciences. Second, no previous laboratory research has studied attitude to ambiguity in a context that is characteristic of ambiguity in entrepreneurship, which is fraught with ambiguity resulting not only from aleatory variability but also epistemic uncertainty and agentic uncertainty (e.g., Knight, 1921). As such, this work is both a contribution to entrepreneurship and is welcomed in decision making (e.g., Camerer & Weber, 1992). Third, this study contributes to a growing body of academic work towards measuring a conceptual construct of entrepreneurial mindset, which is proposed by the entrepreneurship community and academics to dynamic reaction to ambiguity (Davis et al., 2016; OECD & EC, 2015) and future-orientation (Lévesque & Stephan, 2019; OECD & EC, 2015). This study addresses the dimension of dynamic reaction to ambiguity by measuring ambiguity attitudes using a new methodology from ambiguity research employed here for a context representative of entrepreneurship and considering the effect of a stable measure unpredictability tolerance (trait). This study addresses the dimension of future-orientation by measuring the effect of manipulating time horizon on ambiguity attitudes. Relatedly, and fourth, this study also helps answer a call from the international entrepreneurship community for sensitive tools to measure deep psychological constructs associated with ambiguity (OECD & EC, 2015). The more reliably and accurately attitudes towards ambiguity can be measured, the more able can be assessing the effectiveness of interventions aimed to help grow an entrepreneurial mindset. Adopting approaches that are acceptable to cognitive neuropsychology will expand the reach of understanding of the mechanism of these interventions at a deep psychological level (e.g., Blankenstein et al., 2017; Huettel et al., 2006).

Fifth, it makes use of a new measurement method from ambiguity research of Baillon et al. (2018) in a new ecological context of entrepreneurship, contributing to validating the generalizability of the measurement for ambiguity academics.

Sixth, measures of ambiguity tolerance[25] are both considered to be related to stable traits such as dogmatism and rigidity (MacDonald, 1970) and are proposed to be invariant (Budner, 1962). As a stable psychological construct, ambiguity tolerance may be uniquely useful in helping to explain attitude to ambiguity because correlation with another variable, if one exists, must be in one direction only; in other words, its direction of causation can be clearly established. Despite empirical results that suggest a relation between ambiguity tolerance and ambiguity attitudes (Sherman, 1974)[26], little empirical work has been done to date to explore this. This makes it a contribution to decision-making/ambiguity research generally.

5.3 Study of the effect of time horizon and potential loss on ambiguity attitudes

Purpose of this study. The contributions of this work address these gaps and two research questions of this thesis. First, **is there an effect of time horizon and potential loss on entrepreneurial gambling?** This study contributes to this answer by conducting an experiment to measure a behaviour towards a gamble, specifically, attitude to ambiguity. This is measured this using a novel method (i.e., Baillon et al., 2018) that is adapted for an entrepreneurial gambling context. Second, **can a personality trait help explain attitudes towards ambiguity in an entrepreneurial**

[25] In personality literature, several terms are used interchangeably to denote "Ambiguity Tolerance", namely "Tolerance to Ambiguity", "Tolerance to Uncertainty", "Uncertainty Aversion", "Intolerance to Ambiguity" and "Ambiguity Aversion". Confusingly, the latter term has also been used in behavioural economics to describe one type of Ambiguity Attitudes (the others being ambiguity-seeking and ambiguity-neutrality).
[26] The scale by Sherman (1974) was not tested for reliability or internal validity, and his work has not been duplicated.

context? This study contributes to this answer by considering the effect of a novel measure of Uncertainty Tolerance, which is further described in Chapter 4 (trait measure).

5.3.1 Theoretical development

For gambling choices made under conditions of partial ambiguity[27], the so-called "α-Maximin Expected Utility function" (α-MEU function) of Ghirardato et al. (2004) has been widely used in empirical work (Heuttel et al., 2006; Hayashi & Wada, 2010). It was derived from "Maxmin Expected Utility with multiple priors" (MEU for short) by Gilboa and Schmeidler (1989), who were motivated to explain the Ellsberg paradox. This form is also widely used empirically (e.g., Blankenstein et al., 2018; Levy et al, 2010; Rustichini et al., 2005, Smith et al., 2002) and referred to in theoretical development (e.g. Du and Budescu, 2005).[28] Simply put, where both probability (***p***) and outcome (***$***) are partially ambiguous, the α-MEU function is interpreted as taking the following form[29]:

$$U_S = (1 - \alpha)\, U_{max} + \alpha\, U_{min} \qquad \textbf{Equation 1}$$

Where

$$U_S = utility\ of\ monetary\ outcome$$

$$U_{max} = maximum\ expected\ value\ of\ utility$$

$$= 0\ for\ experiments\ in\ the\ loss\ domain$$

$$U_{min} = minimum\ expected\ value\ of\ utility$$

$$= 0\ for\ experiments\ in\ the\ gain\ domain$$

[27] Partial ambiguity refers to the situation where the widths Δ***p*** and Δ***$*** are described numerically.

[28] Hayashi and Wada (2010) have proposed what they call a second-order prior model. However, there model has a serious limitation it must obey the "disjointed-set betweeness". Simply put, this condition implies that a decision-maker who was given the choice to do both gambles would not find that choice more preferable to taking only one of the gambles.

[29] In the experiments by Heuttel et al. (2006) and Hayachi and Wada (2010), probability was partially ambiguous (i.e., defined by a range of precise values) and outcome was precise, and so these researchers treated outcomes as subjected to risk aversion using a power function. Unlike the MEU power function, the one they used is unadjusted for ambiguity.

$$\alpha = weight\ placed\ on\ the\ worst\ possible\ utility, 0 \leq \alpha \leq 1$$

Ambiguity Attitudes is taken as the complement of α:

$$Ambiguity\ Attitudes\ is \begin{cases} 'ambiguity\ averse'\ if\ 1-\alpha < 0.5 \\ 'ambiguity\ neutral'\ if\ \alpha = 0.5 \\ 'ambiguity\ seeking'\ if\ 1-\alpha > 0.5 \end{cases}$$

Further,

$$U_{max} = maximum\ expected\ value\ of\ utility = f(\beta^{+})$$

$$U_{min} = minimum\ expected\ value\ of\ utility = f(\beta^{-})$$

Where U_{min} and U_{max} are a function of β^{+}, and β^{-} respectively, where β is a measure of Risk Attitudes. A clear explanation can be found at Huettel et al. (2006, p. 773). Risk-related loss aversion is related to Risk Attitudes. It is a bias wherein $f(\beta^{-})$ is greater than the effect of $f(\beta^{+})$.

Findings of Ambiguity Attitudes in literature are summarized in Table 5.1.

Table 5.1 Findings from literature about effects of domain (i.e., gain, loss) and time horizon (i.e., present, future) on ambiguity attitudes

Reference	Protocol to determine U_S	Experimental condition (under partial ambiguity)		Finding…[30]	…Inferred from finding (RE: Equation 1 & Equation 2)
		Time Horizon	Domain		
Du and Budescu (2005), Study 1	Certainty Equivalent	present	gain [31] $U_{min} = 0$; $U_{max} > 0$	ambiguity averse[32] in the gain domain	$1-\propto_{S'} < 1-\propto$
Onay et al. (2013), Study 1a and Study 2	Pairwise Choice (2 events, 1 choice)	future	gain [33] $U_{min} = 0$; $U_{max} > 0$	ambiguity seeking in the gain domain (i.e., less ambiguity averse than in present)	$1-\propto_{S'} > 1-\propto$
Du and Budescu (2005), Study 1	Certainty Equivalent	present	loss $U_{min} < 0$; $U_{max} = 0$	ambiguity averse in the loss domain[34]	$\propto_S < \propto$
Kunreuther et al. (1995)	Certainty Equivalent	future	loss [35] $U_{min} < 0$; $U_{max} = 0$	ambiguity seeking in the loss domain[36]	$\propto_S > \propto$

Redefining Attitude to Ambiguity as Ambiguity Additivity. The extant model of **Equation 1** assumes probabilistic additivity of the subjective weights, i.e., $(1-\alpha)+\alpha = 1$; the measured value of α is assumed to be probabilistic (i.e., additive). Experiments to date did not allow for testing this assumption. Hitherto experiments were either performed in the gain domain with $U_{min} = 0$ or in the

[30] Includes only findings that were statistically significant.
[31] ***$*** mid; ***p*** mid; Δ***$*** wide and Δ***p*** wide, i.e., as described by Du and Budescu (2005) as "all vague"
[32] Ambiguity averse in the gain domain, i.e., unwilling to pay more than expected value (EV) to pursue potential gain.
[33] ***$*** lo; ***p*** mid; Δ***$*** wide; Δ***p*** wide
[34] Ambiguity seeking in the loss domain: not willing to pay more than expected value (EV) to avoid potential loss.
[35] ***$*** hi; ***p*** very lo; Δ***$*** wide; Δ***p*** wide
[36] Ambiguity seeking in the loss domain: willing to pay more than expected value (EV) to avoid potential loss.

loss domain with $U_{max} = 0$. Consequently, experiments using this traditional protocol, only one subjective probability, either α or $(1 - \alpha)$, was measured and therefore additivity could not be tested.

Theoretical development allows for an experimental protocol with both a non-zero U_{min} and U_{max}. Any measurement based on this new protocol does not assume additivity; in fact, measurements are of the amount of deviation from probabilistic additivity. To describe the model for the new protocol, I rewrite **Equation 1** with α_S and $(1 - \alpha_{S'})$ and consider Baillon et al.'s (2018) Ambiguity Aversion index, which they also label "b", in the mixed domain as a linear combination of **Equation 1** applied to the gain domain (the gain event, E') and to the loss domain (the loss event, which is the complement of the gain event, E). The resulting model for the mixed domain takes the form:

$$U_S = (1 - \alpha_{S'})\, U_{max} + \alpha_S\, U_{min} \qquad \boldsymbol{Equation\ 2}$$

Where

$$U_S = utility\ of\ monetary\ outcome$$

$$U_{max} = expected\ gain\ of the\ best\ possible\ utility, E'$$

$$U_{min} = expected\ loss\ of\ the\ worst\ possible\ utility, E'^{c}$$

$$\alpha_S = weight\ placed\ on\ the\ worst\ possible\ utility, 0 \leq \alpha_S \leq 1$$

$$(1 - \alpha_{S'}) = weight\ placed\ on\ the\ best\ possible\ utility, 0 \leq (1 - \alpha_{S'}) \leq 1$$

To clarify, **Equation 1** summarizes prior theory, where parameter "alpha" is the weight placed on the worst possible utility, on the minimum expected value of utility. Prior theory assumes that alpha and 1-alpha should add to one. For **Equation 2**, I reinterpret alpha in light of Baillon et al. (2018), with two mutually exclusive and exhaustive nonnull events. There are only two events, and so there are only two utilities. Alpha remains defined as the weight placed on the worst possible utility, which

is the utility of the worst possible event [37] In both **Equation 1** and **Equation 2**, alpha is the likelihood of the worst-case scenario; however, in **Equation 2** there are only two scenarios (E' and E'^{c}). Also, alpha of **Equation 2** is not restricted by additivity.

Baillon et al.'s (2018) "b" is taken as the complement of α_S + (1- $\alpha_{S'}$). This is expressed in the following terms:

$$b = 1 - (1 - \alpha_{S'}) - \alpha_S \qquad \textbf{\textit{Equation 3}}$$

It is evident that this measure allows us to consider "b" as a measure of degree of probabilistic additivity (or, conversely, deviation from probabilistic non-additivity). Consequently, for greater clarity, I provide an alternative label for "b", specifically Ambiguity Additivity, and use the following three descriptors:

$$Ambiguity\ Additivity, b, is \begin{cases} 'subadditive' if\ b > 0 \\ 'additive'\ if\ b = 0 \\ 'superadditive' if b < 0 \end{cases}$$

A value for (1-$\alpha_{S'}$), which is unrestricted by additivity, can be inferred relative to the value of neutral (1-α), which is restricted by additivity. Similarly, a value for α_S can be inferred relative to the value of neutral α. Note that the value of a neutral (1-$\alpha_{S'}$) or α is 0.5 for ambiguity that is purely random (i.e., aleatory variability). These inferences are included in Table 5.1 and lead to the following hypotheses:

> **Hypothesis 1a**: In the mixed domain, Maximum [potential] Loss has an effect on Ambiguity Additivity, b.
>
> **Hypothesis 1b**: In the mixed domain, Time Horizon has an effect on Ambiguity Additivity, b.

[37] In the operationalization of Chapter 3.3, this is the event of "making nothing or losing money".

Prior experimental work described in Chapter 2.2 (empirical basis) explains why the effect is anticipated to depend on the combination of Maximum Loss and Time Horizon. However, it is anticipated that no specific, accurate prediction can be made for four reasons. The first three are explained in Chapter 2.4 (entrepreneurial gamble): no experimental research has (1) looked at attitude to ambiguity for a context with a combination of the characteristics of entrepreneurial gambles or (2) explored the experimental design space of the mixed domain or (3) included non-random variability. The fourth, described in Chapter 2.2 (empirical basis), is that interaction effects can be anticipated (i.e., between elements of the ambiguity profile of an entrepreneurial gamble).

To clarify, we cannot infer from this theoretical development and interpretation of ambiguity in the mixed domain that subadditivity in the mixed domain arises from a "distaste for ambiguity", or "aversion" to ambiguity. Subadditivity arises from an under-estimation of the likelihood of the positive event, the negative event, or both. Similarly, we cannot infer that superadditivity arises from "ambiguity loving" or "seeking"; superadditivity arises from an over-estimation of the likelihood of the positive event, the negative event, or both.

KEY TAKEAWAY

In the mixed domain, subadditivity does not necessarily arise from a "distaste for ambiguity"; it arises from an under-estimation of a likelihood. Similarly, superadditivity does not necessarily arise from "ambiguity loving"; it arises from an over-estimation of a likelihood.

Effect of ambiguity tolerance on Ambiguity Additivity, b:

In an individual, dispositional ambiguity tolerance is expected to play a role in these effects. Both Budner (1962) and Mac Donald (1970) assert that highly ambiguity-tolerant individuals will "seek

out ambiguity" and "thrive under this condition". Chapter 4 (trait measure) describes this validated measure of unpredictability tolerance and the following hypothesis is made here:

> **Hypothesis 1c**: Unpredictability Tolerance has an effect on Ambiguity Additivity, b.

Theory does not support a prediction about their relationship.

5.3.2 Experimental design and method

Time horizon and domain is manipulated in 2 (near-term (NT) v. far-term (LT)) x 2 (mixed domain with small potential loss (NL) v. mixed domain with large potential loss (LL)) between-subject experiment. The purpose of this study is to test the effect, if any, of these variables on Ambiguity Additivity. Subjects were randomly assigned to one of four groups, each group receiving a different version of the survey questionnaire. Participants were told that there were no wrong answers.[38] This survey was comprised of Part i and Part iii of a longer survey that is further described in Appendix C (study design).

Ambiguity Additivity. From the surveys, each subject's pair of matching probabilities were measured, and their ambiguity additivity was calculated using the method of Baillon et al. (2018) for calculating Ambiguity Aversion index. This method has been chosen because it allows for partitioning of the mixed gambles into multiple events and for asymmetry in the probabilities across these events (i.e., across Baillon et al.'s (2018) "natural" events). For my survey, the gamble is partitioned into two events: one event of gain outcome, and one event of zero or loss outcome.[39] Chapter 3 (state measure) provides detail of the experimental protocol to measure Ambiguity Additivity, including a sample of the survey instrument.

[38] "No right or wrong answers" was added to control for anticipation of being assessed by others (Kollmann et al., 2017; Curley et al., 1986). Participants were also told that "the right answers are your honest answers" to control for demand effect.

[39] More precisely, two mutually exclusive and exhaustive nonnull events, in accordance to Baillon et al. (2018).

Unpredictability Tolerance (UT). UT was measured with a 4-item scale (each on a 5-point Likert scale) with a Cronbach's alpha of 0.7702, which is within the range of well-established Ambiguity Tolerance measures and the Big Five Inventory. Many items in the existing scales seem to lack relevance to dimensions of ambiguity tolerance associated with entrepreneurial gambles, namely that associated with probability or possible outcome. For this reason, the more concise validated scale for unpredictability tolerance was used for this experiment. Details of UT scale development and validation are described in Chapter 4. Appendix H (Unpredictability Tolerance survey) provides the survey instrument used to measure Unpredictability Tolerance.

ANOVA was used to determine main and interaction effects on Ambiguity Additivity index (a continuous variable) of the (categorically-coded) independent variables of (IVs) of Maximum Loss, Time Horizon, and Unpredictability Tolerance.[40] [41] This analysis controls for any effect of Unpredictability Tolerance (UT) by including this variable in the ANOVA, thereby performing a 3-way (2 ML x 2 TH x 2 UT) ANOVA.

5.3.3 Results and analysis

Some 139 surveys were distributed. A total of 21 (15%) of surveys were disqualified for one of the following reasons: multiple switching points (17 surveys, 12.2% [42]); the participant interpreted every event as impossible (3 surveys, 2%), or a pairwise choice was undecipherable (1 survey, 1%). Some 99 surveys were retained for statistical analysis. Of those in the sample, 96/99 students answered both the question about their age and gender. Based on those responses, the study sample was comprised of participants with an average age of around 21.8 years (*SD* = 1.2 years) and a gender split of 52.6%

[40] Unpredictability Tolerance is included for reasons more extensively discussed in Chapter 4 (trait measure).
[41] Alternatively, IVs could be coded as continuous variables and regression could be used for my analysis instead of ANOVA. Because the manipulations of loss and time horizon are dichotomous, their coding as either continuous or binary is expected to yield similar statistical evidence. Regression has been more popular in the usage of this Baillon et al.'s (2018) method in natural circumstances (e.g., Li, 2017).
[42] This percentage is in keeping with Li (2017), who had 28.6% in rural settings and 4.6% in urban settings.

female. More details about the participants and survey retention are provided in Appendix J (study sample).

The dependent variable, Ambiguity Additivity, or b, (M = 0.20 [43] , SD = 0.34 [44]) is normally distributed and has equal variances across groups. Summary statistics for the dependent variable, is provided in Table 5.2, and interpretation and implications of these results is provided in Chapter 5.4.1.

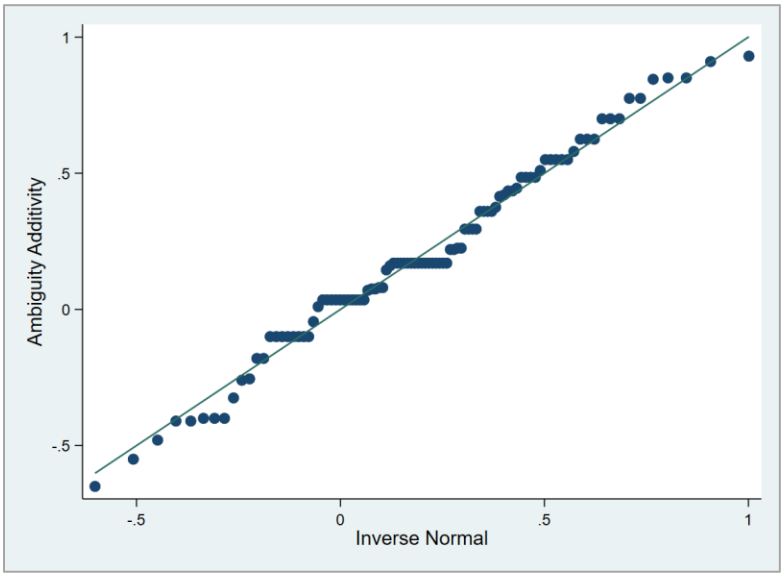
Table 5.2 Summary statistics for variable b

Variable	*N*	*M*	*SD*	*SE*	95% C.I.		min	max
b	99	0.199798	0.3445131	0.0346249	0.1310861	0.2685099	-0.65	0.93

Independence of observations is established. The *Q-Q* plot of Figure 5.1 illustrates the normality of this dependent variable. Appendix D (supplemental statistics: Ambiguity Additivity) provides further details of the tests of these assumptions and summary statistics for the dependent variable.

[43] M = 0.199798
[44] SD = 0.3445131

Figure 5.1 *Q-Q* plot of Ambiguity Additivity (*N*=99)



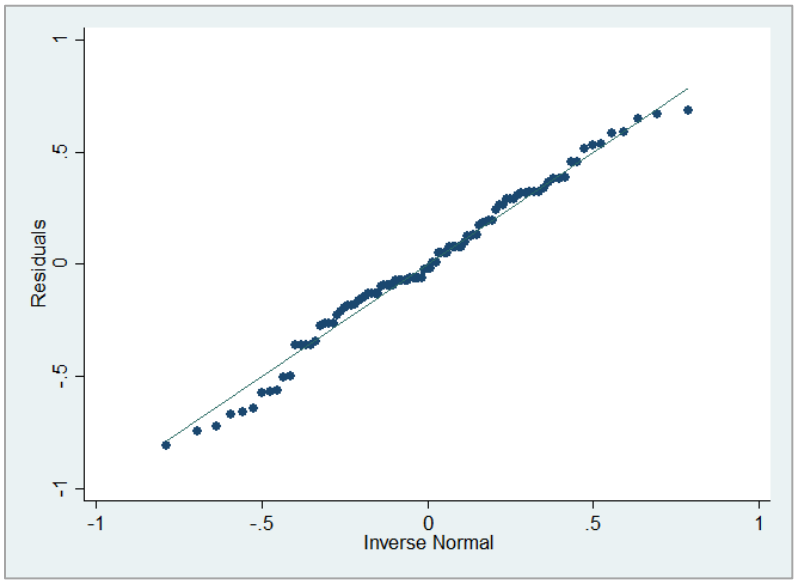
A 3-way (2 x 2 x 2) factorial ANOVA was conducted to compare the main effects of the independent variables (IVs) of Maximum Loss (ML; small- vs large- potential loss) and Time Horizon (TH; near- vs. far-term), Unpredictability Tolerance (UT2CAT; above- vs below- sample average), and the interaction effect between the IVs and the dependent variable (DV), Ambiguity Additivity.

The ANOVA model was developed using a backward elimination approach to stepwise selection. This approach involves performing multiple steps in a stepwise selection process. As a first step, all the candidate IVs are included in the ANOVA. Each successive step repeats the ANOVA having removed the IV (or an interaction with that IV) with the least statistical significance to the model (i.e., with the lowest absolute value of *F*). This repeats until a retained IV that showed evidence of influence for an ANOVA of a previous step no longer shows such evidence. At that point, the last variable removed is added back. Regardless of whether the variable that is added back has an *F* value that meets the statistical test for significance, it is worth keeping because it helps to adjust the model for group differences in that last variable, which is important to the model fit.

Unpredictability Tolerance was removed from the model during backwards regression because there is insufficient evidence[45] of Unpredictability Tolerance having either a main effect or an interaction effect with Maximum Loss or Time Horizon on Ambiguity Additivity. A 2-way (2 x 2) factorial ANCOVA was performed with Unpredictability Tolerance considered as a continuous covariate. Unpredictability Tolerance is not a covariate (p = .3319). In sum, there is **no evidence to support H1c**.

The remainder of the analysis was conducted following 2-way (2x2) factorial ANOVA on the remaining variables of Maximum Loss and Time Horizon. The accuracy of the resulting model is tested using a visual test of the quantiles of its residual. The *Q-Q* plot of the residual is shown in Figure 5.2 and the residual of the model looks normally distributed. The central part of the plot appears to be a straight line and the ends create an overall U-shape, which is indicative of some skewness. While some skewness is indicated, it is not considered excessive.

Figure 5.2 *Q-Q* plot of the residual of the final 2x2 factorial ANOVA model (*N*=99)



[45] E.g. although results suggest a main effect of Unpredictability Tolerance, $F(1,97)=2.82$, $p=.0966$; the residual from that model cannot be considered normal by the criteria of the Shapiro-Wilk W test for normality, $W(98)= 0.97740$, $p=.08940$.

In addition to the visual test, the Shapiro-Wilk *W* test for normality[46] was performed. Results do not provide sufficient evidence to reject that the residual of the model is normally distributed, $W(98)=0.98$ [47], $p=.23$ [48]; in other words, the residuals are assumed to be normally distributed and consequently that the *p*-values of the ANOVA are accurate.

Our analysis of variance yields a no significant main effects of amount of Maximum Loss ($F(1,97)= 0.38$, $p=.54$ [49]) or Time Horizon ($F(1,97) = 0.14$, $p=.70$ [50]). However, the results suggest that there might be a significant interaction effect between these two variables ($F(1, 97)= 3.13$, $p < .1$ [51]). A linear contrast suggests a significant effect of amount of maximum loss for the far-term time horizon.

The characteristics of the Ambiguity Additivity observation meets the assumption criteria for the ANOVA method. However, this data is not normal because Ambiguity Additivity is calculated as a linear combination of ordinal (categorical) data. Therefore, the nature of the interaction effect is further investigated by applying two non-parametric tests, namely the Kruskal–Wallis equality-of-populations rank test[52] and the Kolmogorov–Smirnov equality-of-distributions[53] test. Under the criteria of the Kolmogorov-Smirnov test, there is strong evidence to support that in the far-term, values of Ambiguity Additivity for small maximum potential loss are greater than for large maximum

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[46] The Shapiro-Wilk W test for normality (Shapiro and Wilk, 1965) and includes an approximation by Royston (1992, 1993) that makes the test accurate for sample sizes as low as $N=4$.
[47] $W(98)= 0.98285$
[48] $p=.22591$
[49] $p=.5378$
[50] $p=.7048$
[51] $p=.0803$
[52] The Kruskal-Wallis equality-of-populations rank test (Kruskal and Wallis, 1952, 1953) is a based on the Wilcoxon (also called Mann–Whitney) rank sum test (Wilcoxon 1945; Mann & Whitney 1947) with a generalization that allows it to compare more than two samples.
[53] The Kolmogorov–Smirnov equality-of-distributions test (Kolmogorov 1933; Smirnov 1933) is it is fairly powerful for (alternative) hypotheses that involve lumpiness or clustering in the data, such as detecting differences to do with the modes of distributions or variability in ranges of the distributions. This test method is restricted to comparing two samples. The method used for calculating p-values are considered too conservative for small samples ($N < 50$); in other words, for my sample sizes, "real" p-values can be assumed to be "substantially" smaller than those calculated by this test.

potential loss, $p < .05$ [54]. Also, strong evidence is found for a difference between the distributions in the near- and far-term time horizons under condition of large maximum potential loss with both the Kruskal–Wallis test ($\chi^2(1)=4.73$ [55], $p < .05$ [56]) and the Kolmogorov-Smirnov test ($p < .05$ [57]), which finds that values of Ambiguity Additivity for near-term time horizon are greater than for far-term time horizon. In sum, there is an effect of Maximum Loss that goes away in the near-term time horizon and there is an effect of Time Horizon that goes away when maximum potential loss is small. In other words, there is **sufficient evidence to support H1a conditionally** under the far-term time horizon condition but not for the near-term time horizon condition and there is **sufficient evidence to support H1b conditionally** under the condition of large maximum potential loss but not under the condition of small maximum potential loss. This may be due to insufficient sample size to detect the effect across those conditions. This interaction effect is can be seen in Figure 5.3. Specifically, this figure depicts the results of the parametric (ANOVA) test. In sum, there is no significant difference between small and large loss condition in the near term; however, a difference between these conditions is suggested in the far-term. Table 5.3 provides summary statistics of b across Maximum Time and Maximum Loss.

[54] p=.025
[55] $\chi^2(1)$= 4.725
[56] p=0.0297
[57] p=.012

Figure 5.3 Ambiguity Additivity for levels of Maximum Loss over levels of Time Horizon

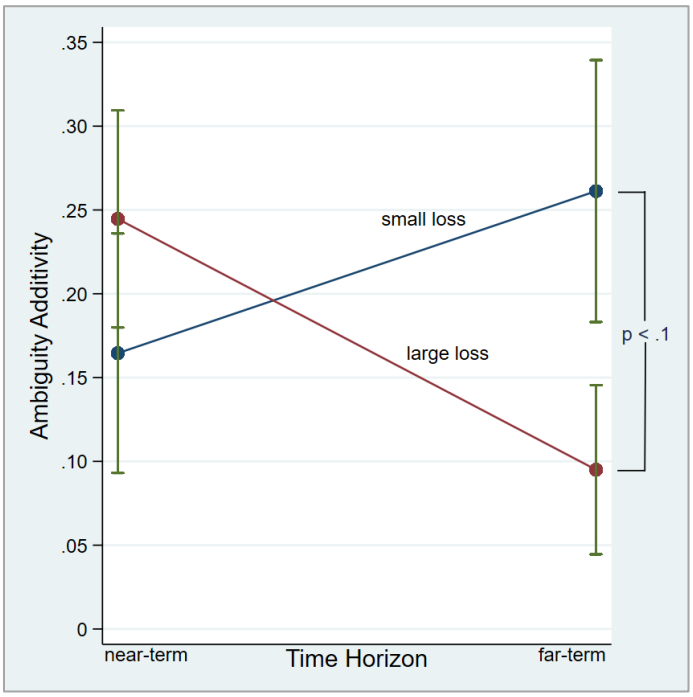


Table 5.3 Summary statistics across Maximum Loss and Time Horizon: mean, standard error of the mean, min, max, n

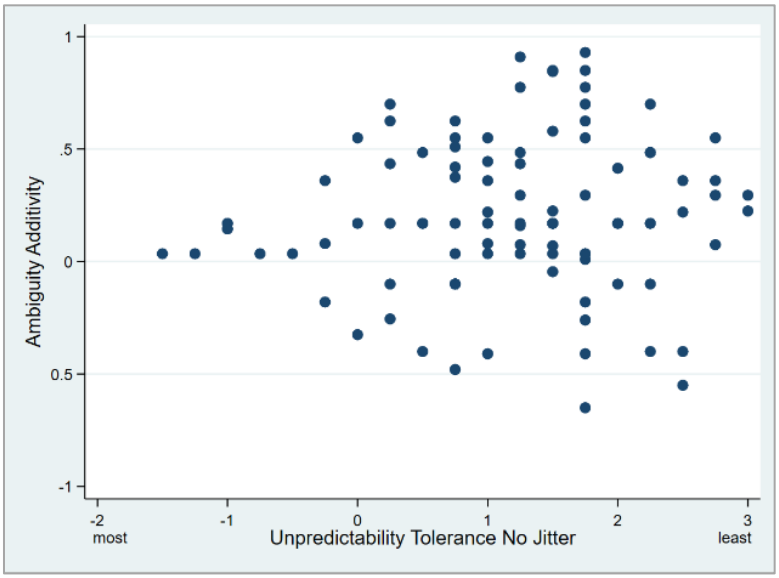
	Time Horizon	
	near-term	**far-term**
Maximum Loss		
small loss		
M	0.16	0.26
SE	0.07	0.08
min	-0.41	-0.55
max	0.85	0.93
n	22	28
large loss		
M	0.24	0.1
SE	0.06	0.05
min	-0.48	-0.65
max	0.78	0.44
n	28	21

For this ANOVA model, the continuous variable of Unpredictability Tolerance, UT [58] ($M = 1.20$ [59], $SD = 0.96$ [60]), was transformed into a binary variable (UT2CAT) with two levels: above- and below-average, where the average is equal to the mean of UT. In posthoc analysis, an interesting relationship between this continuous variable UT and Ambiguity Additivity was observed: Variability of UT appears to be greater for positive UT (i.e., overall "not tolerant") vs. negative UT (i.e., overall "tolerant"). This variability in Ambiguity Additivity across UT is illustrated in the scatterplot of the data of Figure 5.4. When UT is transformed into a three-category variable with three levels: negative-, positive- and zero-score, a test of the population variances between these groups yields an interesting finding. The variability in Ambiguity Additivity across categories of UT is illustrated in the scatterplot of the data of Figure 5.5. Two statistical tests were applied to this 3-level ordinal

[58] The continuous variable UT is considered normally distributed according to the results of visual and statistical tests for normality that are described above.
[59] $M = 1.19898$
[60] $SD = 0.9578482$

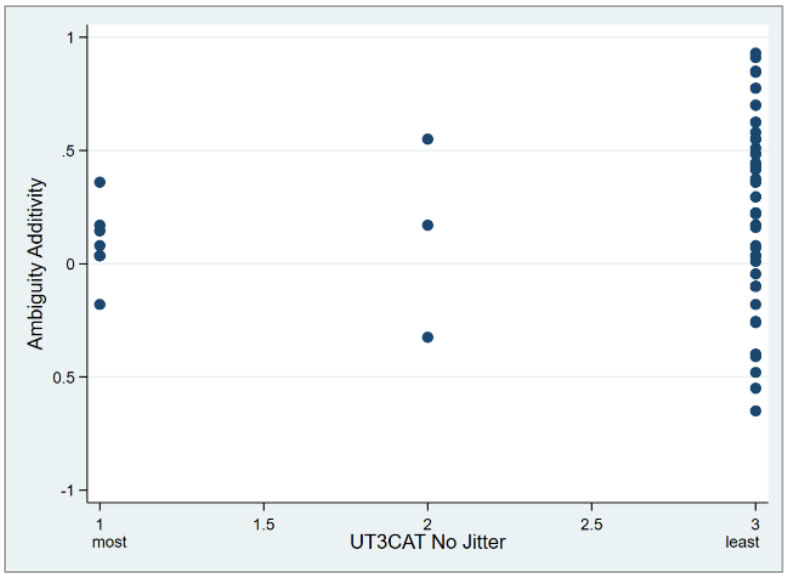
(categorical) variable: Levene's variance-comparison test and Bartlett's test for equal variances. Because this finding was not predicted, this analysis was done at a Bonferroni-adjusted level of significance to .016 [61]. Bartlett's test for equal variance across the three groups might suggest that there is a difference at the Bonferroni level, $\chi^2(2)= 7.11$ [62], p=.029; however, Bartlett's test for equal variances also finds strong support for a difference in variance between the group with most positive (i.e., not tolerant) vs. most negative (i.e., tolerant) at the Bonferroni-adjusted significance level, $\chi^2(1)= 7.28$ [63], $p < .016$ [64], and Levene's variance-comparison test also finds support for this difference, $F(93)= 0.16$ [65], $p < .016$ [66]. In sum, the results of posthoc analysis provide **strong evidence of a difference in variability in Ambiguity Additivity over Unpredictability Tolerance category.**

Figure 5.4 Scatterplot of Ambiguity Additivity over Unpredictability Tolerance (N=99)



[61] 3 levels yields 3 comparisons, resulting in a Bonferroni-adjusted significance level of .05/3 = .0166
[62] $\chi^2(2)= 7.1098$
[63] $\chi^2(1)= 7.2789$
[64] p=0.007
[65] $F(93)= 0.1625$
[66] p=.0098

Figure 5.5 Scatterplot of Ambiguity Additivity over Unpredictability Tolerance category



5.4 Discussion

A novel protocol has been employed to measure attitude to ambiguity the mixed domain, i.e., ambiguity-related loss aversion. This method is different from risk-related loss aversion, which has been widely studied using the protocol to measure attitude to risk. Employing the protocol, I created a survey with a context representative of entrepreneurship. A measurement can be intuitively understood as a measure of the degree of probabilistic additivity. Neutral decision-making under condition of ambiguity implies probabilistic additivity.

While the sample population is ambiguity sub-additive, results indicate an interaction effect between amount of maximum potential loss and time horizon on attitude to ambiguity (i.e., degree of additivity). The most neutral additivity occurs at maximum potential amount of loss in the far-term.

Unpredictability Tolerance does not explain ambiguity additivity (i.e., degree of additivity); however, results indicate that people who are most tolerant of unpredictability are most similar in

their ambiguity additivity (i.e., have the least variability between in their scores). Conversely, those who are least tolerant of unpredictability are the least similar in their ambiguity additivity (i.e., have the most variability between their scores). This finding is supported by Funham and Ribchester (1995), who describe how an individual's need to resolve ambiguity is expected to drive a variety of behaviour, for instance avoiding ambiguous stimuli, seeking clarity, or acting prematurely.

The most neutral additivity is observed under the combined conditions of far-term time horizon and largest amount of potential loss. Neutral additivity implies a balanced perception of the weights of likelihood of success and lack thereof. These results imply that for a DM faced with an entrepreneurial gamble having some ambiguity, their most sum-balanced perception of the weights occurs for a gamble with large potential loss that could occur in the far-term.

Generalizability of the results. Within the scope of my empirical research, I explore *financial* outcomes, although the utility theory that underpins this work is not restricted to financial utility; therefore, my approach and results may be generalizable to entrepreneur gambles with gain and losses that are non-financial, or not entirely financial.

Limitations of the study. There are six limitations of this study. The first arises from the experimental design. While a hypothesized difference was detectable across time condition (re: "Kolmogorov-Smirnov test ($p < .05$), which finds that values of Ambiguity Additivity for near-term time horizon are greater than for far-term time horizon"), a larger sample size may have been able to detect a hypothesized difference across the condition of amount of potential loss.

Five study limitations arise from weaknesses of the survey. First, the survey could have helped control for the amount of ambiguity (e.g., range of likelihood; $\Delta \boldsymbol{p}$). Chapter 2.2.4 describes how range of likelihood (i.e., amount of ambiguity in likelihood) has been found to make a difference in experiments under partial ambiguity. Amount of ambiguity might have been perceived differently

enough between subjects for effects to be undetectable due to error. This difference would contribute to error in the measurement. This could be addressed in future by a change to survey wording to ensure that the interpretation of amount of ambiguity more similar across subjects and/or to control for subjects' interpretation. Second, the protocol used to develop this measure, described in Chapter 3 (state measure), allows the line separating the domain of financial gains and financial losses to be ambiguously defined; it need not be zero. The surveys of this study explicitly defines "zero" as the gain loss divide; however zero is not necessarily the gain-loss divide for every subject. Rewording is recommended for future experiments to allow for subjective perceptions of the gain-loss divide. Third, directing subjects to begin their pairwise choice at 50% may have caused an anchoring effect. While this is a limitation, the effect is anticipated to result in more conservative effect sizes because it would start subjects off (anchors them) at a point that is normatively objective i.e., without bias. Fourth, asking about the likelihood of the loss event before gain event may have caused a priming/framing effect. A future study could randomize the order in which subjects see the two questions to reduce such an effect, if there is any. Fifth, the survey included an illustration similar to that of the matching-pair probability protocol of Figure 3.1, including the illustration of asymmetry of gain and loss events. This visual representation might give the unintended impression that the potential amount of loss is greater than gain. Future work could eliminate any such unintended visual impression. In the case of this study, however, any effect is not anticipated to be deleterious. The phrase "VERY LARGE" (in capital letters) was used to describe the largest amount of gain. The phrase "LARGE" (in capital letters) was used to describe the largest amount of loss. The gain was "VERY LARGE" across all conditions. Only 1/99 subjects did not agree that they could have a "VERY LARGE" gain. Furthermore, this subject's lack of agreement does not imply that the subject misunderstood; it may have been because of their subjective belief that they would not achieve that possible amount of gain (an indication of their risk attitudes).

5.4.1 Evidence of operational validity

Table 5.2 describes a population that is, across all conditions, highly sub-additive ($M = 0.20$ [67] , $SD = 0.34$ [68], $t(98)=5.77$ [69], $p < .0001$ [70]). No experimental study has explicitly looked at the effect on ambiguity attitudes of a combination of characteristics representative of an entrepreneurial context. Furthermore, Chapter 2.2.3 and Chapter 2.2.4 describe how interaction effects between these characteristics (i.e., elements of the ambiguity profile of an entrepreneurial gamble) are possible; therefore, results cannot be predicted directly from prior empirical findings. However, overall sub-additivity is aligned with the phenomenon of ambiguity aversion (e.g., Fox & Tversky, 1995), and this contributes to operational validity.

Recall from Chapter 1.2 that the phenomenon of ambiguity aversion occurs when the ambiguity attitudes of a group of individuals is one of ambiguity aversion (Fox & Tversky, 1995). In other words, it is the overall tendency of a population to choose the unambiguous over the ambiguous when (very small) gains are at stake (i.e., very small potential gain only). Recall from Chapter 3.2 (matching pair probability protocol) that operationalization of the protocol of Chapter 3 involves a series of pairwise choices between an ambiguous and a precise (i.e., unambiguous) gamble. For each matching probability, these choices are in the gain domain and for small gain. Therefore, this tendency is expected from the matching-pair probability protocol. What makes the protocol of Chapter 3 useful is that the strength of this tendency is anticipated to change with the elements and factors described in Chapter 2 (i.e., entrepreneurial context matters). The protocol provides a way to develop a survey that is representative of a particular entrepreneurial gamble, and measure this dynamic attitude to ambiguity.

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[67] $M = 0.199798$
[68] $SD = 0.3445131$
[69] $t(98)= 5.7704$
[70] $p < .00005$ (Stata's reporting precision limit)

While this finding does not provide conclusive validity of the surveys developed following the protocol of Chapter 3, it does provide evidence that contributes to the operational validity of the surveys developed using this protocol. Repeated and replicated experiments making use of this protocol are recommended to continue to test the operational validity of surveys following this protocol.

5.4.2 Impact to risk modeling

Recall from Chapter 5.1 that attitude to risk measures the amount one would be willing to spend (or receive) to play a lottery with known likelihood. In traditional operations research, attitude to risk is incorporated as a discount factor (e.g., Winston & Goldberg (2004)). In contrast, attitude to ambiguity measures one's assessment of the likelihoods of the outcomes of an ambiguous lottery. The impact of attitude to ambiguity on traditional risk modeling in operations research is evident if we compare decision-making under condition of risk to decision-making under condition of ambiguity. For instance, consider a decision having two events (i.e., a binary decision). In this example, the two events have equal and opposite value to the decision-maker: success (valued at 1) and lack of success (valued at -1). Under condition of risk, suppose that the probability of success is 40%. This implies a probability of lack of success to be 60%, and the estimated value will be a negative amount. Under condition of ambiguity, suppose that the decision-maker's risk assessed likelihood of success is 40%, and their assessed likelihood of lack of success is 20%. The estimated value will be a positive amount. In sum, traditional engineering risk modeling does not take attitude to ambiguity into account, and a decision-maker's attitude to ambiguity may result in a very different result than that of traditional engineering risk modeling. A standard methodology for incorporating attitude to ambiguity into engineering modeling is needed and is recommended for future work.

5.4.3 Unassigned likelihoods

Appendix G (supplemental statistics: matching probabilities) describes how, across all groups, pairs of matching probabilities are positivity correlated at only a low level. This low level is not surprizing, given Equation 3 of Chapter 5.3.1 (theoretical development), where b can be interpreted as the amount of likelihood that has not been assigned to either probability of the pair of matching probabilities; in other words, b can be interpreted as the "unassigned likelihood". Obviously, if the unassigned likelihood for each observation were divided into two portions and each portion were added to one of the pairs, there would be strong correlation between the pairs. In sum, any mathematical modeling and statistical analysis of a pair of matching probabilities needs to account for the "three-legged" relationship between matching-pair probabilities and their unassigned likelihood. To this end, subjective binary logic is suggested for future theoretical modeling. Further, to accommodate for the type of ambiguity additivity described in Chapter 5.3.1 as "superadditive", complex number theory (i.e., with both real and imaginary parts) is suggested. This is discussed in more detail in Chapter 7.4 (imagined possibility).

5.5 Summary

This study measured loss aversion through the lens of ambiguity, which, as Chapter 1 (introduction) describes, is separate and distinct from loss aversion through the lens of risk. Theoretical development of this measurement leads to an awareness of ambiguity attitudes as a measure of degree of additivity. Zero additivity implies probabilistic rationality, and as such provides a normative benchmark for probabilistic estimation of likelihoods. In an entrepreneurial scenario with some ambiguity, this measurement is employed to study the effect of time horizon and maximum amount of potential loss on degree of additivity. Findings can be explained by theory and contribute to the validity of the measurement protocol. Literature described in Chapter 4 (trait measure) provides reason to believe that personality is important to attitude to ambiguity, but does not describe in what

way. A personality trait is stable, not expected to be affected by these factors that affect state. Indeed, that is what was found. There was another interesting finding: subjects who are more tolerant of unpredictability have less variability (are more similar) in their scores of ambiguity additivity. Interpretation of additivity and unpredictability tolerance is further explored in the Chapter 7 (overall implications) to proposes to contribute to answering the main inquiry of this dissertation, namely how ambiguity affects an entrepreneur's behaviour.

This chapter describes a study that addresses the effects on both state and trait. As such, this chapter describes the accomplishment of a second objective of this dissertation, namely to measure attitude to ambiguity for a specific context representative of entrepreneurship.

The measure of additivity used for this study is insightful; however, the measure is moderately difficult to administer because of it requires numeracy on the part of the subjects. Decision making literature has long and inadvertently hinted at an easier approach. The next chapter follows clues and explore an alternative approach to measuring attitude to ambiguity, namely one that is affective.

Chapter 6
Towards a psychometric measure of ambiguity attitudes

The prevailing approach to measure attitude to ambiguity is robust and insightful, however, it has operational limitations. As explained in Chapter 3.5.1 (experimental entrepreneurship), the prevailing protocol requires subjects to complete a mathematical task. This requirement of numerosity on the part of the subjects limits its accessibility and practical use across demographics, making it less generalizable across demographics. This chapter describes the quest for an alternative, non-numerical approach. This is the third objective of this dissertation: to explore the possibility of developing a protocol to measure attitude to ambiguity that would be more practical to administer. This chapter describes exploratory work to determine whether an alternative measure of attitude to ambiguity might be developed, one not requiring a numerical task, and specifically whether an affective measure might be developed. Thereby, this chapter contributes to empirical understanding of subjective assessment. Terminology used in this chapter is described in Table 1.1.

6.1 Gaps identified in literature

Gaps in literature became apparent while researching the measurement of ambiguity attitudes using an expected utility approach. Specifically, two gaps are apparent. First, states of fear, hope, optimism and pessimism have long been described in decision making/ambiguity research as associated with ambiguity attitudes, however without empirical evidence. These same descriptive labels have been used to describe the parameters of the so-called "α-Maximin Expected Utility function" (α-MEU) of Ghirardato et al. (2004), which has been widely employed to measure attitudes toward an ambiguous gamble given numerical aspects of the gamble (e.g., Schoemaker, 1989; Viscusi and Chesson, 1999; Gajdos et al., 2008). In brief, the α-MEU model, which takes the form $U_s = (1- \alpha)\ U_{max} + \alpha\ U_{min}$, is used to calculate the parameter 1- α from a subject's subjective utility of the [monetary] outcome (U_s)

of a gamble. The parameter 1- α represents the decision-maker's propensity to underweight the "best expected" utility (U_{max}) and, conversely, to overweight the "worst expected" utility (U_{min}). Further literature review about the form of the α-MEU model and its limitations is available upon request. [71] [72] Assigning descriptive labels such as hope and fear to the parameters 1- α and α, respectively, assumes the labels are correlated to the parameters, however because this assumption is not currently supported by evidence, there is a gap in information to support this assumption.

Second, measures of ambiguity attitudes have been developed for decisions made under conditions of risk and under conditions of partial ambiguity. However, none has been developed for decisions made under conditions of "full ambiguity". A condition of risk is one for which precise numerical values for both probability (***p***) and outcome (***$***) are objectively known. A condition of partial ambiguity occurs where a numerical range is objectively known for ***p*** and/or ***$***. Neither of these are provided under [full] ambiguity, which often occurs in entrepreneurial gambles. Further literature review on the concepts of risk, partial ambiguity and full ambiguity is provided in (Csonka-Peeren & Cozzarin, 2021), and detail about the characteristics of entrepreneurial gambles is given in Chapter 2.4. There are no validated tools for measuring ambiguity attitudes both for a context representative of entrepreneurship, and where ***p*** and ***$*** are not objectively known. One tool proposed recently is demonstrated to be adaptable for ***p*** and ***$*** that are not objectively known (Baillon et al., 2017), but remains to be validated for an entrepreneurial gamble—and this effort is the subject of Chapter 5 (study). However, a gap may still remain: even if the latest method by Baillon et al. (2018) were

[71] Since Hurwicz (1951A), researchers have used the term "optimism" for (1-α) and "pessimism" for α (e.g., Huettel et al., 2006; Gajdos et al., 2008; Pushkarskaya et al., 2015); however, whether this is the appropriate psychological description for this propensity needs to be researched and would be part of this proposed research work.

[72] It was derived from "Maxmin Expected Utility with multiple priors" (MEU for short) by Gilboa and Schmeidler (1989), who were motivated to explain the Ellsberg paradox. This form is also widely used empirically (e.g., Blankenstein et al., 2018; Heuttel et al., 2006; Hayashi and Wada, 2010; Levy et al., 2010; Rustichini et al., 2005; Smith et al., 2002) and referred to in theoretical development (e.g. Du and Budescu, 2005).

validated in an entrepreneurial context, it still requires numerosity on the part of the subject; to assess ambiguity additivity, the subject must choose from a selection of numerical magnitudes the one that best represents their belief about probability. In keeping with Kahneman (2011), in the process of making their selection, deliberate System 2 cognitive processes are activated in their decision-making. System 2 cognitive processes would override automated, System 1 cognitive processes, and consequently may alter their decision-making style. Devising a method by way of self-assessment of state emotions would not require as much deliberate effort as does a likelihood judgement, allowing for System 1 decision-making and thereby providing an alternative method of assessing ambiguity attitudes.

6.2 Gaps identified by the academic community

In addition to the gaps in literature discussed above, two more gaps arise from demands by the entrepreneurial community: First, there is an as-yet unanswered call by the international entrepreneurship community for measurement of the conceptual psychological constructs of the entrepreneurial mindset that is proposed to include those for ambiguity (OECD & EC, 2015). As discussed in Chapter 1.2 (prior attempts), cognitive psychology makes use of well-established expected utility approach to measure ambiguity attitudes that has been useful to help understand the mechanism of bias at a deep psychological level. This approach has not yet been followed to measure ambiguity attitudes toward an entrepreneurial gamble. Second, entrepreneurship encourages the exploration of the nature of affective processes in the engagement of resources, such as information, in entrepreneurship (Grégoire et al., 2015), and specifically encouraging the measurement of state emotions, as opposed to dispositional emotions, during these processes (Cacciotte & Hayton, 2015). No work has been done on states induced when individuals are faced with a gamble, let alone an entrepreneurial gamble.

6.3 Contributions

Although work has been done in the area of emotions and risky decision-making, the aforementioned gaps remain for three reasons: Work to date has been (1) on dispositional emotions[73], not state emotions that are induced by the gamble and/or (2) following a conceptual definition other than that from cognitive behavioural economics[74] and which is targeted to measure attitudes towards risk[75], which is different from ambiguity and/or (3) uses a cognitive behavioural economics approach but is related to risk attitudes and not ambiguity attitudes[76].

Contributions described. The academic contribution of the work described in this chapter is fourfold. First, the approach to developing this new measure provides a complementary perspective on the measure of ambiguity attitudes that does not require numerical values of ***p*** and ***$*** to be objectively known, and the approach proposed in this work explores a new metaphor, namely, one that is psychometric.[77] This would measure a different, complementary construct to the one measured in behavioural economics, and as such would be a contribution to decision making/ambiguity research methodology. Second, the exploratory work described here would help to understand the nature of affective processes, and specifically the state emotions evoked during these processes (Cacciotte & Hayton, 2015), in the engagement of resources in entrepreneurship, such as information preferences (Grégoire et al., 2015). As such, this work is a contribution to entrepreneurship. Third, using a psychometric approach would help answer the call to develop methods to measure the conceptual psychological construct of entrepreneurial mindset. Consequently, this would contribute to a growing body of academic work to measure entrepreneurial mindset. Both the entrepreneurial community and entrepreneurship academics propose that this mindset includes a dimension of

[73] e.g., Kramer & Weber (2011)
[74] e.g., Sitkin & Pablo (1992)
[75] e.g., Lévesque & Schade (2005)
[76] e.g., Podoynitsyna et al. (2012)
[77] Extant measures in behavioural economics require numerosity on the part of the subject; the subjects is expected to compare to a numerical value of percentage.

tolerance for ambiguity (Davis et al., 2016) that is malleable (OECD & EC, 2015). Such is the measure of attitude to ambiguity proposed here. Fourth, addressing the relationships between state variables that have been assumed to be associated with ambiguity attitudes will finally address empirically what has until now simply been assumed.

6.4 Study of affective states elicited by entrepreneurial gambles and their relationship to ambiguity attitudes

Purpose of this study. The contributions of this experimental work address both of these gaps and a research question of this thesis, namely, **might there be a way of measuring ambiguity attitudes psychometrically?** This study contributes to this answer by attempting to develop a measure of a different, complementary construct to the one measured in behavioural economics, specifically on that is psychometric. Referring to Equation 2 of Chapter 5.3.1 (theoretical development): I consider α, the tendency to overweight the worst possible outcome, in terms of fear and state pessimism, and 1-α, the tendency to underweight the best possible outcome, in terms of hope and state optimism. Considered this way, the research question arises: **Can states of hope, fear, optimism and pessimism be used to help characterize ambiguity attitudes?** The purpose of this study is to address these two questions.

6.4.1 Correlational design and method

Subjects all received the same survey to measure their matching-pair probabilities and self-reported Fear, Pessimism, Hope and Optimism towards taking the entrepreneurial gamble under different manipulated conditions described in Chapter 5 (study). [78] This survey is comprised of Part i and Part ii of a longer survey in several parts that is further described in Appendix C (study design), and a survey question is provided in Appendix F (supplemental statistics: ALPHA).

[78] This measure of Affect State uses a 7-point Likert scales to measure the relative self-assessment of each affective state (i.e., each factor).

ALPHA. ALPHA is calculated from the matching probabilities collected from the loss event of ambiguity additivity. Chapter 3 (state measure) provides extensive detail of the experimental protocol to measure ambiguity additivity, including a sample of the survey instrument.

Affective State. A model for Affective State is developed from self-reported Fear, Pessimism, Hope and Optimism. The dataset was divided in two portions of roughly equal number of observations, and the predictor variables were determined through backward elimination approach to stepwise selection using one portion of the data set, then used for the other portion to verify their generalizability to that half. Using those predictor variables, the final model was built using the full data set. Appendix E (Affective State survey) provides the survey instrument used to measure Affective State.

A test of convergent validity is performed between Affective State (a continuous variable) and ALPHA. I did this by exploring whether a model for Affective State can be built that correlates with ALPHA. The model is built using multiple linear regression and tested for convergent validity using Pearson's product-moment correlation.

6.4.2 Results and analysis

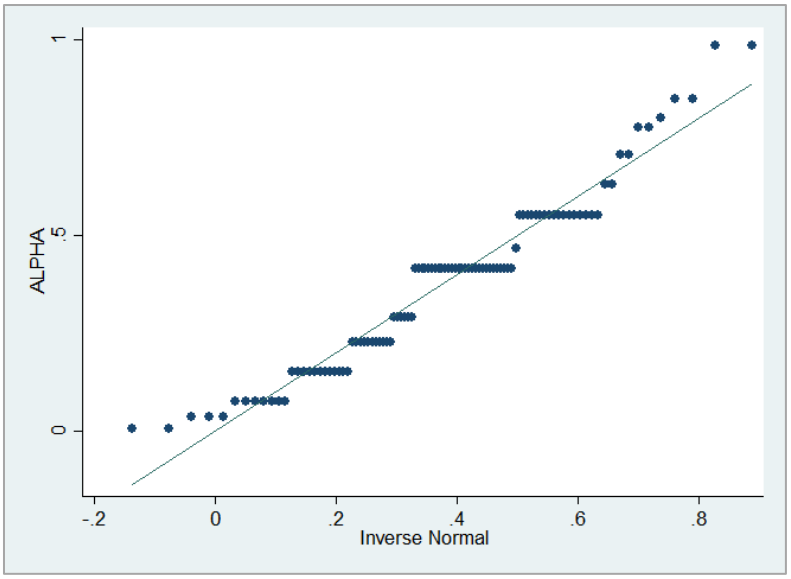
Some 99 observations were retained for statistical analysis. More details about the participants and survey retention are provided in Chapter 5.3.3 and Appendix J (study sample).

The dependent variable, ALPHA ($M = 0.38$ [79], $SD = 0.02$ [80]) has equal variances across groups and independence of observations is established. Appendix F (supplemental statistics: ALPHA) provides further details of the tests of these assumptions and summary statistics for the dependent variable. Because ALPHA is an ordinal (categorical) variable, this variable is not assumed to be normal, and the *Q-Q* (quantiles) plot of Figure 6.1 supports this. Specifically, horizontal lines at the centre of the

[79] $M = 0.3757071$
[80] $SD = 0.0221684$

quantiles plot reveals modes and the S-shape of the ends of the plot indicates kurtosis. However, regression is generally robust to the assumption of normality (and equality of variances). Model accuracy is determined after model development by testing the normality of the model residuals and by comparing predicted vs actual values.

Figure 6.1 *Q-Q* plot of ALPHA (*N*=99)

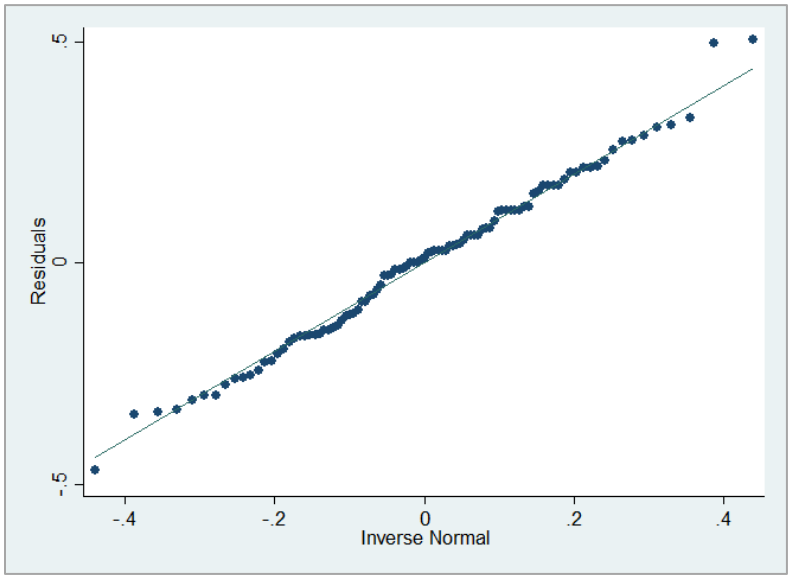


A linear regression model was developed in four stages. First, an initial linear regression model was developed using roughly half of the dataset following a backward elimination approach to stepwise selection. Second, the resulting model was used to predict the other portion of the dataset and this prediction was correlated. Third, the IVs and interactions from the initial model seeded a final model based on the entire data set that was developed following both backward elimination and forward selection. Fourth, predicted values from the final model were used to determine convergent validity.

The accuracy of the resulting model is tested using a visual test of the quantiles of its residual. The *Q-Q* plot of the residual is shown in Figure 6.2 and the residual of the model looks normally

distributed.[81] The central part of the plot appears to be a straight line, and the ends are not indicating skewness or kurtosis.

Figure 6.2 *Q-Q* plot of the residuals of the final regression model (*N*=99)



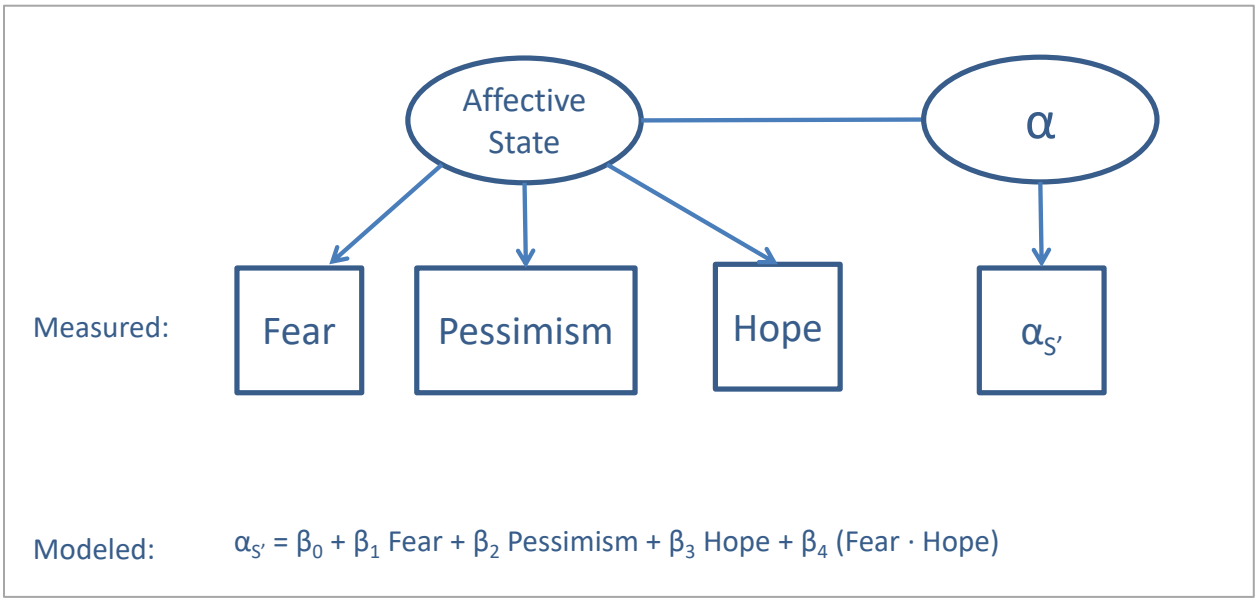
In addition to the visual test, Shapiro-Wilk *W* test for normality[82] was performed. Results do not provide sufficient evidence to reject that the residual of the model is normally distributed, *W*(98)= 0.99 [83], *p*=.79 [84]; in other words, the residuals are assumed to be normally distributed and consequently that the *p*-values of the regression are accurate.

In sum, the final model of Affective State, and its relationship to ALPHA is illustrated in Figure 6.3. Of the four affective states that were measured, namely Fear, Pessimism, Hope, Optimism, only the first three were considered significant predictors of α. Variable α was operationalized as $\alpha_{s'}$, a measure of a subject's subjective probability of the worst possible outcome ('making nothing or

[81] The *Q-Q* plot of normally distributed data should appear roughly as a straight line in its centre, and its ends can deviate somewhat from a straight line. However, how the shape deviates from a straight line is important: a U-shape is indicative of skewness, while an S-shape indicates kurtosis. Skewness of residuals is less acceptable than kurtosis.
[82] The Shapiro-Wilk W test for normality (Shapiro and Wilk, 1965) and includes an approximation by Royston (1992, 1993) that makes the test accurate for sample sizes as low as *N*=4.
[83] *W*(98)= 0.99146
[84] *p*=.78618

losing money') of a set with two possible outcomes. The final model has a correlation between Affective State and α of 0.52.

Figure 6.3 Final model of Affective State, with correlation between Affective State and α of 0.52. (*N*=99)



The array of regression coefficients for the interaction of Fear and Hope, β_4 was further explored using ANOVA, and Fear is a significant factor ($F(1,24)=3.07$, $p < .05$ [85]) in explaining this array of coefficients, suggesting that this array might be collapsed into a simpler term(s) by performing multiple regression on the interaction term and inserting it into this final model. Structural equation modeling is suggested for any future work.

There is a high degree of correlation between measured ALPHA and the model of Affective State, $\rho(97) = 0.52$ [86], $p < .0001$[87], as determined by Pearson's product-moment correlation, and a plot of ALPHA vs Affective State in Figure 6.4 illustrates the positive linear relationship and congruent

[85] p=.0468
[86] $\rho(97) = 0.5178$
[87] $p < .00005$ (Stata's reporting precision limit)

validity. In this plot, the points are symmetrically distributed around a diagonal line, which supports an assumption of linearity. Linearity of the model is also evident from this plot of residuals over predicted values of the model, illustrated in Figure 6.5, where points are symmetrically distributed around a horizontal line centered at zero, with a roughly constant variance. In sum, there is **evidence of congruent validity between this model of Affective State and ALPHA**; in other words, Affective State may provide an alternate measure for 1-α, which has been used in research to determine attitude to ambiguity (i.e., using the protocol of ambiguity attitudes).

Figure 6.4 ALPHA vs Affective State (i.e., predicted ALPHA)

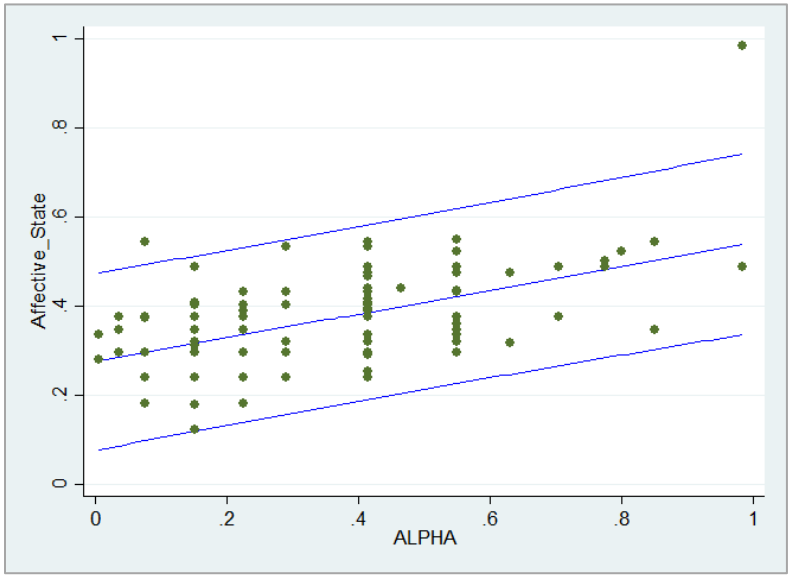
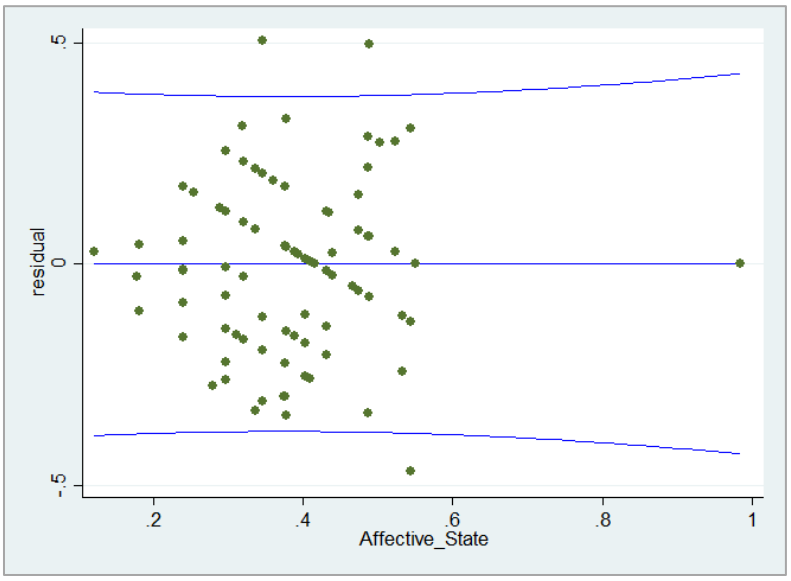


Figure 6.5 Residuals of the final model vs Affective State (i.e., predicted values)



6.4.3 Discussion

Results suggest that there is a way of measuring ambiguity attitudes psychometrically. Pessimism and combinations of fear and hope provide the most significant contributions to this measurement. An interactive effect of fear and hope is not unexpected in literature. Fear, a primary emotion, is known to antagonize hope, a secondary emotion (Jarymowicz & Bar-Tal, 2006).

Pessimism has a small positive significant correlation to attitude to ambiguity, and Optimism is not significant to attitude to ambiguity. This might be a counter-intuitive result because the word optimism is often used to describe investor sentiment in popular media. However, at least two reasons can explain the result: (1) the investor sentiment described in media is referring to risk aversion and not to ambiguity aversion, and (2) investor sentiment of optimism is not operationalized in the same way as this study. Future work might consider expanding the nomological net to include other dimensions that are used to describe investor sentiment.

One of the limitations of this work was sample size. Budget and more time would allow for a replication with a larger sample size.

6.4.3.1 Coping with ambiguity

Entrepreneurs may be able to use their feelings to gauge their degree of neutrality (i.e., additivity), or become more self-aware, when they are making decisions under condition of ambiguity. While an entrepreneur cannot escape their ambiguous environment, this self-awareness may be helpful in coping with ambiguity, in reconsidering their perceptions of ambiguity during decision making. Future work could assess whether and how such self-awareness during financial decision-making results in a greater number of financially sustainable ventures.

It is reasonable to anticipate that the act of self-monitoring emotion would require an inhibition of impulsive behaviour that might be triggered by emotions (e.g., premature decision-making based on feelings of fear). Consequently, this practice of inhibiting impulsive behaviour might in itself help with ambiguous decision-making because gambles involving at least one ambiguous choice (i.e., "ambiguous gambles') activate more portions of the brain responsible for controlling emotions (Krain et al., 2006; Tanaka et al., 2015) such as inhibition of impulsive behaviour (Huettel et al., 2006). In other words, self-monitoring of feelings during ambiguous decision-making may provide some type of synergistic advantage in ambiguous decision-making. Future work might explore this possibility, and any multiplicative effect that can be expected from repeated practice of self-monitoring.

6.5 Summary

This chapter addresses the final objective of this thesis work, namely to explore the possibility of developing a protocol to measure attitude to ambiguity that would be more practical to administer. In addition to its pragmatic potential, it might provide another dimension to understanding an entrepreneur's perception of ambiguity, namely an emotional one. The next chapter describes how the research work of this chapter and previous chapters, together, answer the main inquiry of this dissertation, namely how ambiguity affects an entrepreneur's behaviour. The next chapter also describes how these chapters together address the main purpose of this dissertation, namely to

contribute to our understanding of an entrepreneur's perception of ambiguity. These overall implications and contributions are in addition to the ones described in the preceding chapters.

Chapter 7
Overall implications

In entrepreneurship, ambiguity has largely been ignored, wrongly interpreted as risk alone, or blended with risk. There is a clear difference between risk and ambiguity, and decision making has known this for ages (Camerer & Weber, 1992). Some influential entrepreneurship studies that relied on risk measures alone report null findings (e.g., Burmeister-Lamp et al., 2012) or puzzling findings (e.g., Begley & Boyd, 1987). Chapter 1 (introduction) explains how risk and ambiguity operate separately and unrelatedly on the entrepreneur, and Chapter 1.4 (puzzles) describes why those results might be explained by considering the effect of ambiguity.

KEY TAKEAWAY

Risk and ambiguity operate separately and unrelatedly on the entrepreneur.

In Chapter 3 (state measure), a novel protocol to measure attitude to ambiguity is developed that is based on the traditional, prolific, robust protocol of ambiguity attitudes. In Chapter 5 (study), the measure developed following this novel protocol is given a more intuitive label, ambiguity additivity. The surveys designed following the protocol of Chapter 3 (state measure) allow us to put theory into practice. In this chapter, two risk-management frameworks are proposed, along with an example of how these can be applied in management. Consequently, this chapter draws on theory that is adapted to entrepreneurship in prior chapters, and this chapter contributes by proposing practical strategies to help entrepreneurs cope with ambiguity.

My dissertation work stimulates ideas about overall implications of this work and suggestions about future research in applying the science of decision making to management, specifically entrepreneurship. Future research is suggested in order to extend the main inquiry of this dissertation,

namely how ambiguity affects an entrepreneur's behaviour. Chapter 3.5.3 describes why the measure of ambiguity additivity can be interpreted as a risk assessment. This revelation not only contributes to answering the main research inquiry of this dissertation, namely how ambiguity affects an entrepreneur's behaviour, but also makes evident that the main research inquiry could in future be reframed, **how does ambiguity affect an entrepreneur's risk assessment?** Future research stated using this more generally understood language could facilitate broader cross-disciplinary understanding, knowledge sharing, and diffusion of knowledge.

Specifically, this chapter suggests future research in entrepreneurial cognition, entrepreneurial action, and entrepreneurship practice. In this chapter, a worked example using a prevailing engineering modeling approach is provided to illustrate contributions of this thesis in applied entrepreneurship. This dissertation work also stimulates bold ideas about applying subjective logic and developing a theory of possibility that might provide a new, intuitive engineering representation of attitude to ambiguity.

7.1 Entrepreneurial cognition

First, this work stimulates ideas for research in entrepreneurial cognition. The theoretical development of Chapter 5.3.1 makes evident an intuitive interpretation of the cognitive bias of ambiguity attitudes, namely a measure of additivity under condition of ambiguity. Chapter 3 (state measure) describes the ambiguity additivity protocol, a neurologically sensitive method of measuring a subject's perception of (1) likelihood of achieving success and (2) likelihood of not achieving success. Ambiguity additivity answers to what degree do the subjects likelihoods differ from "neutral additivity". A research questions arises from this: **Can ambiguity additivity help us better understand entrepreneurial cognition?** I propose here that it can. First, however, I propose the "ambiguity sum", derived from ambiguity additivity. Ambiguity sum answers whether the subject's

likelihoods add to one. If so, the subject is sum-balanced in their perspective. Let us consider what ambiguity sum means. “subSum” (likelihoods adding to less than one) can mean three things: underestimating success, underestimating failure (i.e., not achieving success) or underestimating both success or failure. Likewise, “superSum” (likelihoods adding to greater than one) can mean three things: overestimating success, overestimating failure, or overestimating both success or failure. Remember, that any under- or over-estimate is subjective; in other words, no two decision makers are expected to have the same estimate. However, their subjective under- or over-estimation is relevant to understanding how balanced their subjective perspective. In other words, those with an additivity sum closer to one would have a more balanced perception of the likelihoods of achieving success or not. This balance might be important to understanding the relationship between cognition and decision making.

However, ambiguity sum alone will not tell us to which side the balance may be tipped. To do that, I consider the parameters of ambiguity additivity from Chapter 5.3.1 (theoretical development). I call these (1-α’) and α, where (1-α’) is the likelihood of a successful event and α is the likelihood placed on the unsuccessful event. Their ratio provides a measure of weight of the balance of likelihoods of achieving success or not. A ratio of (1-α’)/α= 1 indicates a score that is “ratio-neutral”. It stands to reason that decision makers would be more willing to take an entrepreneurial gamble if they believe the likelihood of achieving success is greater than the likelihood that it will not. For this reason, a ratio of (1-α’)/α > 1 indicates “more action-orientedness” and, conversely, (1-α’)/α < 1 indicates “less action-orientedness”. I call this new measure, derived from ambiguity additivity, the “ambiguity ratio”.

KEY CONCEPTS

***Ambiguity additivity protocol*:** a neurologically sensitive method of measuring a subject's perception of (1) likelihood of achieving success and (2) likelihood of not achieving success

Ambiguity sum answers: Does the subject's likelihoods add to one? If so, the subject is ***sum-balanced*** in their perspective.

Ambiguity ratio answers: Does the subject perceive greater likelihood of achieving success, or not? If the ratio is one, the subject is ***ratio-neutral*** in their perspective.

Scores of the ambiguity sum and ambiguity ratio together provide more insight on ambiguity perspective than ambiguity additivity can, and four distinct groups of scores emerge. An interpretation of the groups is provided in Figure 7.1.

Figure 7.1 Score groups and interpretation of scores from ambiguity sum and ambiguity ratio (both derived from ambiguity additivity)

		Ratio	
		sub (≤ 1)	**super (> 1)**
Sum	**sub (< 1)**	Estimating that achieving success is less likely than not achieving success; underestimating likelihood of achieving success and/or of not achieving success	Estimating that achieving success is more likely than not achieving success; underestimating likelihood of achieving success and/or of not achieving success
	super (> 1)	Estimating that achieving success is less likely than not achieving success; overestimating likelihood of achieving success and/or of not achieving success	Estimating that achieving success is more likely than not achieving success; overestimating likelihood of achieving success and/or of not achieving success

<--- over- ----- 1 ---- under- --->

estimating estimating balanced

Less <---------- Action-orientedness ----------> More neutral

The more reliably and accurately we are able to measure attitude to ambiguity, the more able we will be at assessing the effectiveness of interventions aimed to help grow an entrepreneurial mindset.

Entrepreneurial mindset is proposed to include dimensions of dynamic tolerance for ambiguity (Davis et al., 2016; OECD & EC, 2015) such as ambiguity additivity (and its derivatives, ambiguity sum and ambiguity ratio). The ambiguity additivity protocol adopts approaches that are acceptable to cognitive psychology. As such, it allows for interdisciplinary work between entrepreneurship and cognitive psychology to understand of the mechanism of interventions at the deep psychological level (e.g., Blankenstein et al. (2017); Huettel et al. (2006)) and this is welcomed in entrepreneurship practice (OECD & EC, 2015). This would be an improvement over Cooper et al. (1988), which suggests that perceived likelihoods might help explain entrepreneurial success. While their protocol is easier to administer, it has two drawbacks. First, their protocol is not adopted in neuropsychology. Second, it does cannot consider the relationship between probabilities in a pair of matching probabilities, which not only provides likelihood scores but also insight about four score groups.

7.2 Entrepreneurial action

Second, this work suggests that attitude to ambiguity has a role to play in the conceptual model of entrepreneurial action of McMullen and Shepherd (2006). Specifically, entrepreneurs go through periods of action and inaction (Wood et al., 2017). **Can a change in attitude to ambiguity explain an entrepreneurs' shift from inactive to active?** If so, **within what range of attitude to ambiguity will an entrepreneur remain action-oriented?** The following is **proposed**: **An entrepreneur with ambiguity ratio greater than one is more likely to be active** because they perceive greater likelihood of achieving success than not.

The study of Chapter 5 finds a difference in attitude to ambiguity across time when large loss is at stake. Could the effect of time horizon on attitude to ambiguity explain the vacillations of action and inaction in entrepreneurship? For example, an entrepreneur is not anticipated to act if time from action to outcome is perceived as taking too long. (Wood et al., 2019). The following is **proposed:**

Attitude to ambiguity mediates the relationship between time horizon and action. This could be tested in laboratory or lab-in-field.

7.3 Entrepreneurship practice

Third, entrepreneurship educators and entrepreneurial ecosystem coaches could use measures of ambiguity additivity and its derivatives, ambiguity sum and ambiguity ratio, to advise entrepreneurs. Let us consider an entrepreneurship practitioner coaching an entrepreneur (or entrepreneurial team) to cope with ambiguity when evaluating a scenario represented by an entrepreneurial gamble. Following the protocol described Chapter 3 (state measure), the practitioner could measure the entrepreneur (or team)'s parameters of ambiguity additivity towards that gamble. From these parameters, ambiguity sum and ambiguity ratio can be calculated. Recall that the protocol's two events are mutually exclusive, exhaustive, and nonnull. Therefore, underestimation of sum implies an incomplete set, and overestimation of sum implies an exaggerated set. Briefly, an entrepreneur (team) would be well advised to reconsider the completeness of the set for each event in such a way as to mitigate risks. Although underestimation of sum implies an incomplete set, it does not provide information about which of their events has an incomplete set or whether both sets are incomplete. This is done by also considering the ambiguity ratio. Let me explain here how.

7.3.1 Ambiguity risk-management

Four distinct groups of scores emerge from the combination of ambiguity sum and ambiguity ratio. An interpretation of the groups is provided in Figure 7.1.

Briefly, an entrepreneur (team) is advised to reconsider the completeness of a set in such a way as to mitigate risks. For instance, for an entrepreneur (team[88]) in the "subRatio/subSum" quadrant, their

[88] Recall from Chapter 3.5.1 (experimental entrepreneurship) that the experimental task to measure Attitude to Ambiguity can be performed by a collective.

score implies they are underestimating the likelihood of achieving success and/or of not achieving success, and they are estimating that achieving success is less likely than not achieving success.

To help express this in more casual language when giving feedback to entrepreneurs, here I relabel the 2 events the matching-pair probability protocol of Chapter 3.2 to "success" and "failure".[89] An inactive entrepreneur (team) in the "subRatio/subSum" quadrant has three possible reasons for their score: in all three, they think they are going to fail; however, they are also either (1) underestimating their likelihood success; (2) underestimating their likelihood of failure, or (3) underestimating both their likelihoods of success and failure. If they are underestimating their likelihood of failure, advising the entrepreneur (team) to reconsider their failure-event set is not anticipated to change their overall impression that they are going to fail. However, if they are underestimating their success-event set, then advising them to reconsider their success-event set might contribute to increasing their perceived likelihood of success, which I propose results in more action-orientation and a possible shift from inaction to action. A similar analysis of entrepreneurs (team) in each quadrant provides the advice in the Figure 7.2. More explicitly, this framework results from applying a risk management approach to an entrepreneur's risk assessment. The objective of the risk-management is to help an entrepreneur best manage their risk assessment of a situation, or cope with ambiguity. Future research could test **whether this proposed advice can shift an entrepreneur (team) from inactive to active.**

Chapter 5 (study) finds those with high unpredictability tolerance (as measured by Unpredictability Tolerance, UT) have similar ambiguity additivity, regardless of time horizon to outcome or amount of potential loss. This suggests that they are less affected by factors that usually change an entrepreneur's attitude to ambiguity. This may imply that those with high unpredictability tolerance

[89] In the protocol these mutually exclusive events and need to be so labelled, as, for example, "succeeding" and "not succeeding".

are less coachable, and leads to the following **proposition: Given advice, entrepreneurs with high unpredictability tolerance will be less likely to shift between active and inactive.**

Figure 7.2 Risk-Management Advice Framework for individual-level policy in entrepreneurship practice, with casually-worded proposed advice for each ratio/sum quadrant.

		Ratio	
		sub (≤ 1)	**super (> 1)**
Sum	**sub (< 1)**	Overall, you believe you are likely not to succeed but you may be underestimating your likelihood of success --> reconsider your likelihood of success	Overall, you believe you are likely to succeed but you may be underestimating your likelihood of failing --> reconsider your likelihood of failing
	super (> 1)	Overall, you believe you are likely not to succeed but you might be overestimating your likelihood of failing --> reconsider your likelihood of failing	Overall, you believe you are likely to succeed but you may be overestimating your likelihood of success --> reconsider your likelihood of success

<--- over- --- 1 --- under- --> estimating estimating

Less <---------- Action-orientedness ----------> More

7.3.2 Entrepreneurs are sum-balanced sometimes

Findings from Chapter 5 (study) suggest that the most neutral additivity (and therefore, the most balanced sum) is observed under the combined conditions of far-term time horizon and largest amount of potential loss. These results imply that an entrepreneur is most sum-balanced for a gamble with large potential loss that could occur in the far-term. For this type of entrepreneurial gamble, entrepreneurs are anticipated to straddle the line between two ratio/sum quadrants, and their ratio would indicate their action-orientedness.

7.3.3 Ambiguity risk-management strategies

The results of Chapter 6 demonstrate that entrepreneurship is an emotional ride, it creates an emotional workplace for the entrepreneur. These results also suggest that an entrepreneur's affective state is related to their attitude to ambiguity. This leads to questions for future research: **Do entrepreneurs in different quadrants have a different affective experience? Does their affective**

experience contribute to their workplace stress? If so, **does their affective experience contribute to their outcomes within an entrepreneurial ecosystem?**

Entrepreneurial ecosystems connect communities to accelerate entrepreneurship. Chapter 2 (conceptual model) and Chapter 5 (study) explain that attitude to ambiguity changes with elements of an entrepreneurial context. Within an entrepreneurial ecosystem, **what kinds of interventions (e.g., networks and programs) help entrepreneurs change their perceptions and accelerate successful entrepreneurship?**

Let us now consider this from a risk-management perspective. From this perspective, the overall strategy is to mitigate risks for those at greatest risk in each quadrant. For instance, for the entrepreneur (team) in the "subRatio/subSum" quadrant, this means implementing strategies that increases their perception of likelihood of success. Restated more casually, this means providing them with encouragement about their likelihood of success. A similar analysis of entrepreneurs (team) in each quadrant results in the strategies described in Figure 7.3. More explicitly, these frameworks result from applying a risk management approach to entrepreneurs' risk assessment. The objective of the risk-management is to help entrepreneurs best manage their risk assessment of a situation. These strategies are proposed, and future research could test **whether this proposed advice can shift an entrepreneur (team) from inactive to active.**

Figure 7.3 Risk-Management Strategy Framework for population-level policy in entrepreneurship practice, with casually-worded proposed strategies for each ratio/sum quadrant.

		Ratio	
		sub (≤ 1)	**super (> 1)**
Sum	**sub (< 1)**	Some might not think they can do it even if they can. Needs an **encouraging** ecosystem.	Some might be jumping in head first. Needs a **safe** ecosystem.
	super (> 1)	Catastrophizing might be getting the upper hand for some. Needs a **calming** ecosystem.	Some can motivate a team against all odds. Needs a **validating** ecosystem. The most sustainable attitude.

<--- over- ---- 1 ---- under- --> estimating estimating

Less <---------- Action-orientedness ----------> More

To summarize, both sum and ratio are useful to describe distinguish categories of risk-management strategy, and it is proposed here that ratio is an indication of action-orientedness. The following section describes how a risk-management framework can be applied to entrepreneurship management.

7.3.4 Entrepreneurship example

The Director of a university incubator wants to implement a management intervention that could help the largest proportion of entrepreneurs in the incubator become financially self-sustainable (i.e., reach a state of breakeven (**b/e)** or above breakeven (**> b/e)**). The Director also wants to estimate the effect of that intervention. The Director has analyzed the change in venture outcomes of active entrepreneurs over the last 24 months. These (fictional) results reveal that an entrepreneur who is new to the incubator has an even chance of achieving a state of **> b/e**, below breakeven (**< b/e)**, or

remaining at **b/e**. Entrepreneurs who attain **> b/e** tend to remain **> b/e**.[90] Conversely, entrepreneurs who become **< b/e** tend to remain **< b/e**. Not all entrepreneurs were active during this time period: some were stalled, others had stopped. It stands to reason that there can be no success without action. When entrepreneurs restart after a period of inaction (e.g., after stalling to pivot their business model), they have an even chance of achieving a state of **> b/e**, **< b/e**, or **b/e**.[91] These results can be summarized in Table 7.1.

Table 7.1 Fictional likelihoods of active entrepreneurs transitioning from one outcome to another

	> b/e	**b/e**	**< b/e**
> b/e	7/10	1/5	1/10
b/e	1/3	1/3	1/3
< b/e	1/10	1/5	7/10

The Director is aware that ambiguity affects the behaviour of entrepreneurs in the incubator. The Director will rely on the Risk-Management Strategy Framework of Figure 7.3 to choose a management intervention, and has sufficient resources (money, time, expertise) to support one intervention.

To choose an intervention, the Director performs three steps. First, the Director measures the attitude to ambiguity of each entrepreneur using a survey designed according to the protocol of Chapter 3 (state measure). The (fictional) survey results reveal that the entrepreneurs of the incubator are found to have the same probabilities as those from the study described in Chapter 5 (study) and

[90] The likelihood of an entrepreneur remaining in a state of **> b/e** will improve due at least two virtuous cycles: (1) increased access to capital for those who have capital (it is well-known that private lenders are more likely to fund those who do not need it), and (2) increased network support to those who demonstrate success.
[91] These fictional results are grounded in anecdotal personal observations.

analyzed Appendix I (supplemental statistics: Ratio/Sum). These results are summarized in Table Appendix I.5 of Appendix I. The choice of intervention can be represented as an optimization problem with the following parameters:

Objective: to maximize the estimated proportion of entrepreneurs in the incubator who would benefit by an intervention to help them become financially sustainable from operations (**b/e** and **> b/e**), or, conversely, to minimize the proportion that would become unsustainable (**< b/e** and **inactive**).

Constraint: only one management intervention can be implemented.

Given this boundary condition, the objective can be achieved with the following policy:

Policy: for a population, the choice of management intervention is prescribed by the following policy:

$$\delta = \text{Intervention}(\text{quadrant}(\max(P_{ij})))$$

where the P_{ij} are conditional probabilities from Table Appendix I.5 of Appendix I.

Second, the Director determines the quadrant where most of the entrepreneurs' scores fall, i.e.,

$$\max \begin{cases} P(\text{subRatio}|\text{subSum}) = 0.39 \\ P(\text{superRatio}|\text{subSum}) = 0.21 \\ P(\text{subRatio} \mid \text{superSum}) = 0.09 \\ P(\text{superRatio}|\text{superSum}) = 0.04 \end{cases} = P(\text{subRatio}|\text{subSum})$$

Third, the Director chooses the intervention for that quadrant of the Risk-Management Strategy Framework. Specifically, the "encouragement" intervention is chosen for the subRatio/subSum quadrant, i.e.,

$$\delta = \text{Intervention}\ (\text{quadrant}\ (\text{subRatio}/\text{subSum})) = \text{"encouragement"}$$

The Director also wants to estimate the effect of the chosen intervention. Using an appropriate computer model, this is done by simulating the model twice: once without and once with intervention. The computer model is a Markov chain with the following parameters:

States: At any given point in time, each entrepreneur is in one of four (i.e., $L = 4$) mutually exclusive states of the following exhaustive set:

S = {**> b/e**, **b/e**, **< b/e**, **inactive**}

Transition model. Entrepreneurs transition from one state to another, and this can be represented by a state transition matrix that is adjusted for action-orientedness, i.e.,

T_{ijk}: unadjusted state transition matrix

where

ij: transition between state i to j

k: action or inaction

Recall that the Director has determined the (fictional) transition probabilities for active entrepreneurs, and these are included in the unadjusted state transition matrix:

$$\boldsymbol{T} = T_{(3x3)x2} = \{T_{action} | T_{no\ action}\} = \left(\begin{array}{cccc|cccc} .7 & .2 & .1 & 0 & 0 & 0 & 0 & 1 \\ .33 & .33 & .34 & 0 & 0 & 0 & 0 & 1 \\ .1 & .2 & .7 & 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 \end{array}\right)$$

A: adjustment array

$$\boldsymbol{A} = A_{(1x2)} = \{A_{action} | A_{inaction}\}$$

The state transition matrix that is adjusted for action-orientedness is given by the following:

R: adjusted state transition matrix = $\boldsymbol{AT}$

Before intervention, *A* takes on the marginal probabilities from Table Appendix I.5 of Appendix I:

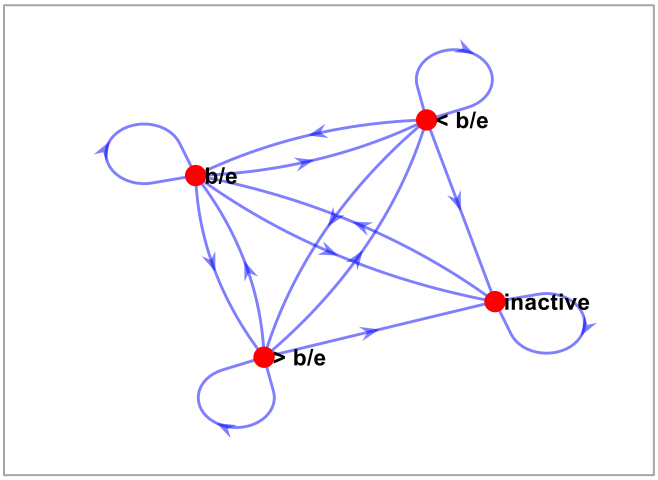
$$\boldsymbol{A}_{before\ \delta} = A_{(1x2)} = \{0.36\ |0.64\}$$

After intervention, *A* is assumed to change in the following way: half of those in quadrant subRatio/subSum are responsive to intervention, and, of these, half are responsive enough to shift from subRatio to superRatio (i.e., to Ambiguity Ratio >1). Recall from the theoretical development in Chapter 7.1 (entrepreneurial cognition) that Ratio is proposed to be an indication of action-orientedness. For this example, let us assume that superRatio (i.e., Ambiguity Ratio > 1) is necessary and sufficient for action. In sum, the "responsiveness rate" is assumed to be 50% * 50% = 25% [92], and using this rate, the elements of *A* after intervention are evaluated and form an array:

$$\boldsymbol{A}_{after\ \delta} = A_{(1x2)} = \{0.46\ |0.54\}$$

A graphical representation of the state transition model is shown in Figure 7.4.

Figure 7.4 Graphical representation of the state transition model



This is an ergodic, stationary system. The long-run proportions, $\boldsymbol{\pi}$, satisfy:

$$\boldsymbol{\pi} = \boldsymbol{\pi}\ \mathbf{R}$$

[92] I.e., after intervention, P(superRatio) = .3636 + (0.5*0.5)*.3939 = .4621

where

$$\sum_{l=1}^{L=4} \boldsymbol{\pi_l} = \mathbf{1}$$

In other words, the long-run proportions satisfy the system of linear equations:

$$\pi_{>b/e} = .36\left(.7\pi_{>b/e} + .33\,\pi_{b/e} + .1\,\pi_{<b/e}\right)$$

$$\pi_{b/e} = .36\left(.2\,\pi_{>b/e} + .33\,\pi_{b/e} + .2\,\pi_{<b/e} + \pi_{inactive}\right)$$

$$\pi_{<b/e} = .36\left(.1\,\pi_{>b/e} + .34\,\pi_{b/e} + .7\right)$$

$$\pi_{>b/e} + \pi_{b/e} + \pi_{<b/e} + \pi_{inactive} = 1$$

The Director calculates the long-run proportions twice: once with $\boldsymbol{A}_{before\ \delta}$ and once with $\boldsymbol{A}_{after\ \delta}$. Results yield $\pi_{>=b/e,\ before\ \delta} = 0.3138$ and $\pi_{>=b/e,\ after\ \delta} = 0.3836$. Based on these results, the Director estimates a 22% increase in the long-run proportion of entrepreneurs who become financially sustainable from this "encouragement" intervention.

7.3.5 Limitations and future work

This example exemplifies one way that the research of this dissertation could be applied to practice. Both practical application and the idealized model of this example are based partially on assumptions. Future work could be done to verify these assumptions and overcome limitations. This future work includes addressing the following:

a) Recall that in this example superRatio (i.e., Ambiguity Ratio > 1) is assumed to be both necessary and sufficient for action. Both parts of this assumption could be explored. While it stands to reason that this ratio should be greater than 1 for action, whether this is a sufficient threshold to pass from inaction to action remains unknown and could be explored empirically. Also, in real-life

situations, other factors will likely influence whether to take action. Recall from Chapter 5.1 (study gaps) and Chapter 5.3.1 (theoretical development) that risk attitudes is related to the anticipated amounts of potential gain or loss; this contrasts with attitude to ambiguity, which is related to the anticipated likelihoods of achieving gain or loss. Future work could include the influence of other factors, such as risk attitudes, on action-orientedness towards an entrepreneurial gamble.

b) For reasons described in Chapter 2.4 (entrepreneurial gamble), an entrepreneurs attitude to ambiguity is anticipated to change as they gain knowledge from experience (i.e., as there is a change in the elements $\Delta \boldsymbol{p}$ and $\Delta \boldsymbol{\$}$ of an entrepreneurial gamble), as time horizon to outcome of the entrepreneurial gamble shortens (i.e., as there is a change in element **t** of an entrepreneurial gamble), and as profits accumulate and might change the perception of the gain-loss reference point (i.e., as there is a change in element ***d*** of an entrepreneurial gamble). Accordingly, Ambiguity Sum and Ambiguity Ratio is anticipated to change with these elements, resulting in a change of optimal management intervention. Future work could include observing change in an entrepreneur's Ambiguity Sum and Ambiguity Ratio with change in elements of an entrepreneurial gamble they take.

c) Related to the last point, a more complex model could be developed to represent an entrepreneur's decision-making over time. This more complex model could take the form of a sequential Markov decision process over multiple sequential entrepreneurial gambles.

d) This example is concerned with helping entrepreneurs achieve success, where success is defined as achieving or exceeding breakeven from operations. However, in real-life, this is not always the only measure of success of an entrepreneurial venture. While breakeven is helpful to sustain operations, the valuation of a venture is helpful to access resources (e.g., cash, expertise) to grow operations. Future work could extend this Markov model to include the valuation of ventures as they

take entrepreneurial gambles (i.e., as the ventures go through iterations), regardless of their state of breakeven. This could be done by adding a "reward" parameter to the Markov model, like that described for a Markov decision process (Winston & Goldberg, 2004). Further, the optimization problem could be redefined with the dual objective of maximizing both a collective valuation and the proportion of entrepreneurs who become financially sustainable from operations.

e) This stationary system is assumed to be able to operate long enough to achieve a steady state objective. Each iteration is analogous to the time horizon of an entrepreneurial gamble. Realistically, the number of iterations (or, entrepreneurial gambles) that can be accomplished within a time period depends on the industry the entrepreneur is attempting to enter. At one extreme are ventures in biotechnology and alternative energy, which typically require long time horizons to realize potential gains (i.e., revenues from operations and/or increase in venture valuation) during iterations of prototype development, require regulatory approvals, and have long sales cycles to institutional customers. At the other extreme are ventures in consumer service, which typically require short (or no) prototype development, require no regulatory approvals, and have short sales cycles to consumers. In this example, the Director should categorize the ventures by typical length of time horizon to outcome for their industry, and analyze each category of venture separately. Future field work should take this categorization into account.

f) In this example, all entrepreneurs took the same survey to determine their attitude to ambiguity (i.e., their matching-pair probabilities, which are then used to calculate Sum and Ratio). However, not all entrepreneurs face entrepreneurial gambles with the same ambiguity profile, and the elements of the ambiguity profile are known to affect attitude to ambiguity. These effects are described in Chapter 2 (conceptual model), and some of these effects relevant to a context that is representative of entrepreneurship are tested empirically in Chapter 5 (study). For instance, biotechnology requires a longer time horizon and has greater maximum potential loss than consumer service. Given the same

survey, the measured attitude to ambiguity of an entrepreneur attempting to enter the biotechnology industry may be the same as one entering the consumer service industry; however, if each were given a survey personalized to an entrepreneurial gamble that they typically face, their measured attitudes are anticipated to be different. This implies that the unadjusted transition matrix could reasonably be different for entrepreneurs entering different industries. Propitiously, the protocol of Chapter 3 (state measure) allows a survey to be created that is customized to an entrepreneurial gamble that best represents that which an entrepreneur is typically faced with in their industry. Machine learning tools might be helpful to classify descriptions of typical entrepreneurial gambles into elements of an ambiguity profile that can be used to create such a customized survey.

g) In this example, the responsiveness rate is assumed to be 25% for those in the subRatio/subSum quadrant who receive the "encouragement" intervention. A pre- and post- intervention study might better quantify this response rate, and similar studies could measure the responsiveness rate of interventions for the other three quadrants, namely subRatio/superSum, superRatio/subSum, and superRatio/superSum.

h) The system is assumed to be ergodic. This implies that any entrepreneur can transition from any state to any other state over the entire time period (all iterations), that there is no mitigating factor that would break the chain for any entrepreneur, that all entrepreneurs are given the same chance as others to continue to participate. This assumption could be verified in future work by observing the "breakeven state" of entrepreneurs in the field as they take entrepreneurial gambles (i.e., as the ventures go through iterations) and testing for differences by demographic group and industry.

i) The empirical results described in Chapter 5 (study) find that those (i.e., the group) with highest measures of the personality trait of unpredictability tolerance (as measured by Unpredictability Tolerance, UT) show significantly less variance in their Ambiguity Sum than those with the lowest.

In other words, those who are more tolerant of unpredictability are more similar to each other in how much consideration they give to "both sides of the coin". Recall from Chapter 4 (trait measure) that personality traits are, by conceptual definition, arguably stable. In other words, theoretically, there is no reason to anticipate that Unpredictability Tolerance would change with a management intervention and, consequently, there is no reason to anticipate that Ambiguity Sum would, either. Therefore, those with higher Unpredictability Tolerance may be less responsive to management interventions that entail reconsidering both sides of the coin. Future work could test this proposition.

7.4 Entrepreneurship and imagined possibility

Fourth, my dissertation research stimulates bold ideas about developing an alternative, intuitive engineering representation of attitude to ambiguity. Recall from Chapter 3 (state measure) that my protocol to measure attitude to ambiguity is dynamic, and recall from Chapter 5.4.3 that ambiguity additivity can be interpreted as the amount of "unassigned likelihood". Suggestions for future work on modeling attitude to ambiguity are twofold. First, subjective binary logic might be a promising means to represent attitude to ambiguity because this logic allows for unassigned likelihoods. Research questions that could intuitively arise from such a model include, **to what extent do entrepreneurs take action based on their assigned likelihood? Based on their un-assigned likelihood?** Second, complex number theory could be applied. Complex number representation allows for a dynamic relationship between real- and non-real mathematical dimensions. The previous chapters have described how attitude to ambiguity is dynamic, and is comprised of both assigned and unassigned likelihoods. Here, I recast the phrase "assigned likelihoods" to "perceived likelihood" and recast "unassigned likelihoods" to "imagined possibilities". This allows me to more intuitively frame a research question: **Could complex number theory provide a dynamic representation of attitude to ambiguity, comprised of both perceived likelihoods and imagined possibilities?** If such a dynamic model were developed, a further research question arises: **In entrepreneurship, what is the**

impact of interventions on the dynamic relationship between perceived likelihoods and imagined possibilities?

Research here could provide materials to build a "cognitive quantum theory" of creatively imagined possibilities and shed light into the "cognitive black hole" of unimagined possibilities. A comparison between results from computer simulation and well-designed experiments could provide a cost-effective way to manipulate factors and contribute to understanding the cognitive nature of perceived likelihoods and imagined possibilities, and their impact in entrepreneurship.

7.5 Summary

This chapter synthesizes risk-management frameworks from the work presented in the preceding chapters of this dissertation. These risk-management frameworks propose an interpretation of attitude to ambiguity, which contributes to understanding an entrepreneur's perception of ambiguity, the purpose of this research. New research questions arise from this synthesis, and from considering implications of this work as a whole. The next chapter summarizes main contributions of this entire dissertation work, outlines a scope for future work, and concludes this dissertation.

Chapter 8
Conclusion

The purpose of this dissertation was to contribute to our understanding of an entrepreneur's perception of ambiguity, and specifically of their risk assessment in entrepreneurship. The main research enquiry was: **How does ambiguity affect an entrepreneur's behaviour?** The broad research design entailed completing the three research objectives and obtaining answers to the five research questions that guided this work. The research methodology for each of the objectives has been described in detail in Appendix K (research program).

8.1 Main contributions

In pursuing the main research enquiry, this work provides three main contributions. First, it translates and adapts theory from human decision making, and specifically behavioural economics, for entrepreneurship. Objective 1 was to develop a protocol to measure attitude to ambiguity for a context representative of entrepreneurship. The function of this was to help answer the main research enquiry through empirical study, which, as described in Chapter 1 (introduction) was lacking. Main contributions begin in Chapter 2 (conceptual model), which describes a novel conceptual model of ambiguity attitudes in an entrepreneurship context, and includes a novel profile of ambiguity. This model was used to develop a way to measure of ambiguity attitudes at a deep psychological level and for a context that is representative of entrepreneurship, detailed in Chapter 3 (state measure). Fortuitously, decision making had previously operationalized attitude to ambiguity as attitude to subjective ambiguity or Knightian uncertainty, which is representative of the riskiness in entrepreneurship. These works were used as a starting point to develop a protocol to measure attitude to ambiguity in a context that is representative of entrepreneurship and as the basis upon which to attempt to address the limitations of this traditional protocol for an entrepreneurship context. These

limitations are described in Chapter 3 (state measure), and one of those limitations is addressed by answering the first research question: **Might there be a way of measuring ambiguity attitudes in the mixed domain in a context that is representative of entrepreneurship?** In short, there is. Specifically, I develop a pragmatic protocol to measure attitude to ambiguity in a context that is representative of entrepreneurship that has ten features, including providing a way to measure ambiguity attitudes in the mixed domain. This measure is called "ambiguity additivity", and is described in Chapter 3.

Completing Objective 1 required translating the terminology and measures used within and across academic domains. A summary of the terminology across domains is described in Table 1.1 (terminology) and a summary of protocols from prior research described in Figure 1.1 (prior protocols). These tables serve as a reference, and offer a bridge of understanding between decision making and entrepreneurship literatures that can be crossed to mutually inform one another.

Second, this thesis contributes to empirical research. Specifically, this thesis presents findings from two experimental studies I performed to measure subjective assessment in numerical and non-numerical ways. Objective 2 was to use this protocol to measure attitude to ambiguity for a specific context representative of entrepreneurship. Chapter 2 (conceptual model) describes how the variables of time horizon and potential loss characterize typical decisions in the context representative of entrepreneurship. Studying the effect of these variables helps answer the main research inquiry by providing empirical insight to how ambiguity affects an entrepreneur's behaviour. Specifically, this answers the second research question: **Is there an effect of time horizon and potential loss on ambiguity attitudes in an entrepreneurial context?** The study is described in Chapter 5 (study), and results revealed an interaction effect of loss and time horizon on attitude to ambiguity. This study looks at the phenomena of loss aversion from a different dimension than previously studied, namely the dimension of attitude to ambiguity. This provides fresh insights to future decision making

research on loss aversion, and helps entrepreneurship researchers understand loss aversion from the context of entrepreneurship. The answer to the second research question of this dissertation was also anticipated to be influenced by personality. Therefore, under objective 2, a third research question arose: **can a personality trait help explain attitudes towards ambiguity in entrepreneurial gambling?** Using a measure developed in Chapter 4 (trait measure), my study also addresses this third research question. Chapter 4 (trait measure) describes a systematic methodology to develop a measure of tolerance to ambiguity from sources found in context representative of entrepreneurship. (The phrase tolerance to ambiguity is used here to denote a stable trait. This is in contrast to dynamic attitude to ambiguity, or dynamic state. The distinction between trait and state is described at length in Chapter 1.2 (prior attempts)). A measure of unpredictability tolerance was developed following this methodology, and was validated. This methodology can be used in future research to develop other personality (trait) measures that are relevant to tolerance to ambiguity. Results of my study indicated that attitude to ambiguity is not influenced by unpredictability tolerance; however, those with a with a similar unpredictability tolerance (trait) are similar in their attitude to ambiguity (state) across loss and time. Chapter 7 (overall implications) describes how this might influence how entrepreneurs cope with ambiguity.

Third, this research work draws on the first contribution, adapted theory, to propose practical strategies to help entrepreneurs cope with ambiguity. The implications of ambiguity additivity measure are considered in the Chapter 7 (overall implications), and this leads to a novel derivatives of ambiguity additivity, namely, the “ambiguity sum” and “ambiguity ratio”. An interpretation of ambiguity sum and ambiguity ratio together provide insights into helping entrepreneur cope with ambiguity, and this is summarized in two frameworks, the “ambiguity risk-management advice framework” and the “ambiguity risk-management strategy framework”, provided in Chapter 7

(overall implications), which can be used in entrepreneurship practice to help entrepreneurs cope with ambiguity.

Objective 3 was to explore the possibility of developing a protocol to measure attitude to ambiguity that would be more practical to administer. The function of this objective was to suggest a simpler means for future research to continue to answer the main research inquiry. To this end, this dissertation answers a fourth research question, **might there be a way of measuring ambiguity attitudes psychometrically?** Literature suggests that there is and led me to a fifth research question of this dissertation, specifically, **can states of hope, fear, optimism and pessimism be used to help characterize ambiguity attitudes?** These states have been assumed to be associated with ambiguity attitudes in decision making literature but this has never been explored. Hence, I carried out an empirical exploration, described in Chapter 6, and my results suggest that there might be an alternative way to measure ambiguity attitudes, answering the fourth question. Specifically, my results suggest that pessimism, fear and hope should be included in this measure, answering the fifth question of this dissertation. This not only provides a new metaphor for exploring ambiguity attitudes, namely, one that is psychometric, but it also suggests a measure that may be easier to administer, and self-administer, than others.

8.2 Scope for future work

Two main areas are recommended for future work. A first area is the continuation of research into attitude to ambiguity in entrepreneurship. Specifically, addressing research questions about the influence of attitude to ambiguity on action-orientation, in theory and practice. For reasons explained in Chapter 2.3.1 (designing experiments) and Chapter 3.5.1 (experimental entrepreneurship), experimental work is anticipated to be efficient and effective for this type of work. Repeated and

replicated experiments making use of the protocol of Chapter 3 are recommended to continue to test operational validity.

A second area of work arises from validating the proposed management interventions of the risk-management frameworks proposed in Chapter 7 (overall implications). Specifically, this involves testing whether such interventions help more entrepreneurs become successful. An engineering model of the type included in the worked example of Chapter 7.3.4 (entrepreneurship example) could be helpful to estimate the change from an intervention and to compare estimated to actual change observed in field work. Chapter 7 (overall implications) provides research questions that arise from my dissertation work, and Chapter 7.3.5 provides detailed recommendations for future work specific to validation and modeling. These recommendations include (1) more complex modeling using a sequential Markov decision process over multiple sequential entrepreneurial gambles and including a "reward" parameter, and (2) machine learning to classify entrepreneurial gambles in a way that can be used to offer personalized management interventions to accelerate successful entrepreneurship.

8.3 Conclusions of the thesis

In sum, the purpose of this dissertation was to contribute to our understanding of an entrepreneur's perception of ambiguity, which this thesis makes evident is an entrepreneur's risk assessment that is measurement of attitude to ambiguity. Theory and empirical findings suggest that attitude to ambiguity is a missing puzzle piece in empirical entrepreneurship and relevant to branches of entrepreneurial decision making such as entrepreneurial cognition and entrepreneurial action. This thesis developed and operationalized a novel protocol to measure state attitude to ambiguity (i.e., ambiguity additivity and its derivatives, ambiguity sum and ambiguity ratio) and personality trait (i.e., unpredictability tolerance). With these measurement instruments, future research can better observe to what extent an entrepreneur's condition of ambiguity affects their risk assessment. Interpretation of

these measures led to proposed frameworks (i.e., ambiguity risk-management advice framework, ambiguity risk-management strategy framework) for advancing entrepreneurship practice. Investigation into an alternative, non-numerical measurement instrument suggests that a measure of attitude to ambiguity that is easier to administer might be developed. Continued research can help us better understand an entrepreneur's behaviour under condition of Knightian uncertainty, and specifically their risk assessment in entrepreneurship—a promising area for future research.

Chapter 9

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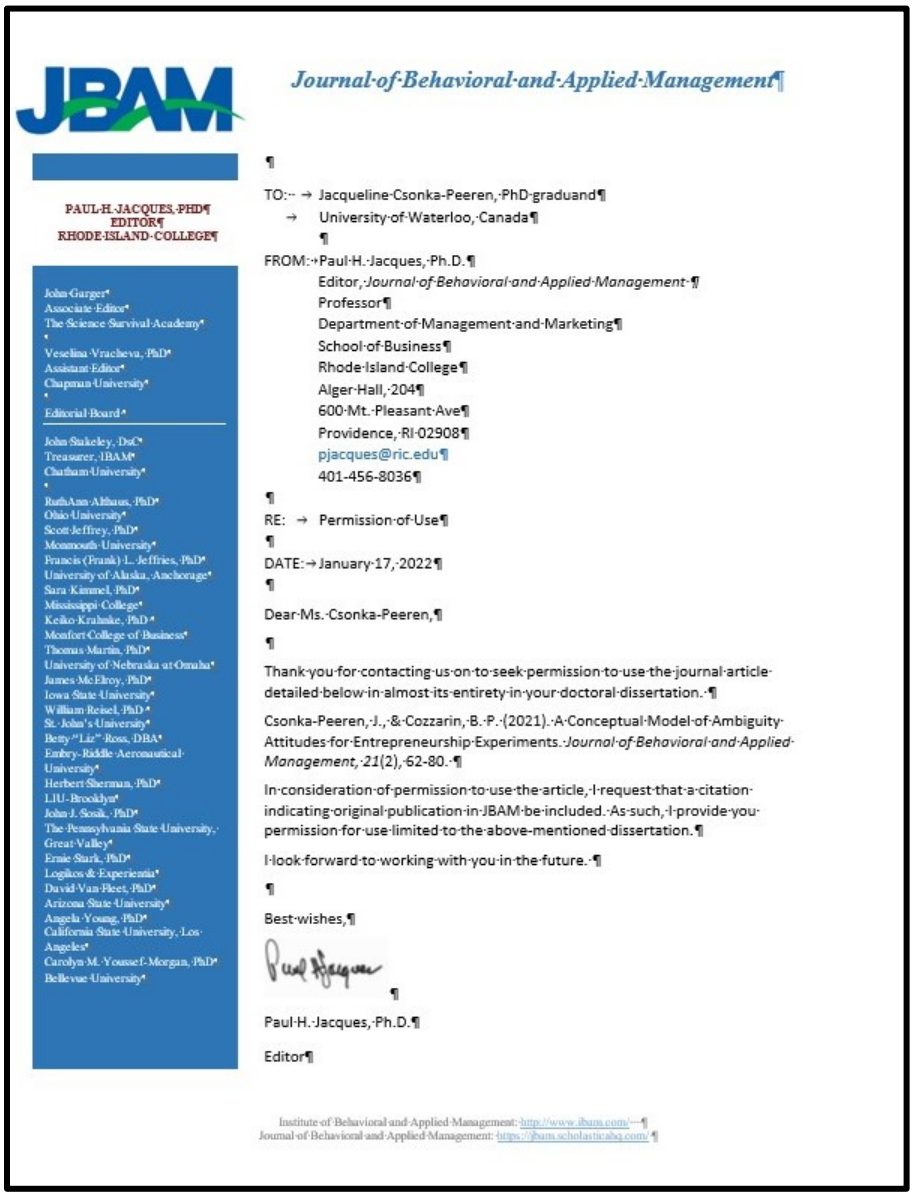

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Appendix A

Attitude to Ambiguity survey wording

Survey wording adds context to a survey instrument designed following the protocol of Chapter 3 (state measure). Table Appendix A.1 describes the wording considerations, the survey wording used in the survey instrument used in Chapter 5 (study), and what could be changed to wording for future use of that instrument.

Table Appendix A.1 Wording considerations for a survey to measure attitude to ambiguity

Consideration	Description	Survey wording for this study	Survey wording for future studies
Ecological Validity	• ”A property of paradigms that correspond to common everyday decisions and evoke naturalistic intensity. Such paradigms capture the dynamic integration of moment-to-moment information, can be consequential, binding, and may have higher emotional intensity.” (Camerer & Mobbs, 2017)	• The wording is obscure, abstracted from a real scenario, unlike any choice they would have had to make before. Therefore, it is anticipated that they do not bring preconceived notions to their choice, which helps control for several variables that are known to affect ambiguity attitudes (although this does mean they affect vagueness attitudes) such as “Perceived Business Context Competence” and “Perceived Startup Competence”.	
		• No numerical values are provided for several reasons. First, it does not reflect real-life, where ambiguities are not presented numerically. Second, providing a numerical value might create “anchoring bias” in a participant (Tversky & Kahneman,1974).	
		• Ambiguous means missing information (Camerer & Weber, 1992); in this case all information other than the gain-loss divide reference point of Zero is missing. The protocol described in Chapter 3 allows the reference point separating the domain of gains and losses to be ambiguously defined; in the case of financial gains and losses, it need not be zero.	• If I were to redo this experiment, I would not explicitly define the gain-loss divide as "zero", I would reword to allow each subject their own subjective interpretation of their gain-loss divide.
		• With wording that is open to subjective interpretation, even the researcher cannot know the exact outcome or probabilities (which creates an authentically ambiguous situation).	

Consideration	Description	Survey wording for this study	Survey wording for future studies
		• The protocol described in Chapter 3 allows the possible amount of gain and loss ambiguously. The possible amount of gain and loss are described using survey question wording that is both precise and open to some subjective interpretation. E.g., "an opportunity to make what YOU consider to be a VERY LARGE amount of money"; "this large amount to pay would be more money than you can easily afford, EVEN if you asked friends and family to help you pay it"	
Realism	• Impacts difference in hypothetical vs real results	• The word "imagine" is used to try to elicit realism. • "We review evidence of similarity and differences in hypothetical and real mental processes. In many cases, hypothetical choice tasks give an incomplete picture of brain circuitry that is active during real choice." (Camerer & Mobbs, 2017). This is one reason Camerer and Mobbs endow their participants with cash and are told that at the end of experiment they will perform a similar gamble to the hypothetical one of the experiment and that their choices in that gamble depends on their survey answers. For an entrepreneurial gamble, an ethical way of providing incentive (for gain or loss) as piquant as those in the entrepreneurial gamble under study was not formulated; instead, subject recruitment was based on participants' interest in contributing to research to advance entrepreneurship and their goodwill. In case a participant's interest or goodwill waned during the experiment, they were given multiple opportunities to easily withdraw from participating, even anonymously.	
Affective Realism	• "The degree to which a laboratory stimulus evokes the same emotion it would evoke in its natural setting. For example, a picture of an angry face might capture our attention more than a neutral face, yet an angry person actually staring at us might evoke even more emotions and behaviours including extreme fear, flight or fight, and visual search for a threat source." (Camerer & Mobbs, 2017)	• Adding dramatic wording to try to elicit the same emotions as real-life. E.g., "more money than you can easily afford, EVEN if you asked friends and family to help you pay it"	

Consideration	Description	Survey wording for this study	Survey wording for future studies
Directionality	• "Positive verbal probability phrases make listeners focus on the occurrence of an uncertain event, while negative verbal probability phrases make listeners focus on the non-occurrence of that event." (Honda & Yamagishi, 2017)	• E.g., "You come across an opportunity to make…". This is an example of positive verbal probability phrase because it tells them what will happen, not what will be avoided. Gets listeners to focus on the occurrence of being successful, i.e., the gain event. • E.g., "you would immediately need to pay (in other words, lose)...if the opportunity were completely UNsuccessful…" This is an example of positive verbal probability phrase because it tells them what will happen, not what will be avoided. Gets listeners to focus on the occurrence of being UNsuccessful, i.e., the loss event.	
Demand effect	• Participants give the response that they think is desired of them	• E.g., "There are no wrong answers." • At the start and partway through the survey, participants were verbally reminded that "there are no wrong answers. The right answers are your honest answers."	
Framing effects / Reference point	• Phrases may elicit unintended affect (Honda & Yamagishi, 2017)	• Gambling has negative connotations and can elicit unintended affective reaction. E.g., "opportunity" instead of "entrepreneurial gamble"	
	• In a mixed gamble, message framing effects can influence whether a subject perceives gain or loss. (Tversky &Kahneman, 2010).	• Adding a comprehension question to make sure that the possible amount of gain and loss was perceived as intended. Also, the first question about one event might have a framing effect on a subject that affects their answer to the second question about the other event. In this case, there are two questions, one for gain event and one for the loss event. The order of the two questions could be randomly presented.	• Presenting the loss event question first may have had a framing effect, affecting answers to the gain event question. If I were to redo this experiment, I could randomize the order that subjects saw the two questions.
	• In a mixed gamble, message framing effects can influence the reference point between gain and loss.	• The reference point was explicitly set to Zero, although this may have compromised ecological validity (described above). E.g., "'making money" means the possibility of MAKING MORE than zero (this does not include zero). MAKING MONEY is illustrated by the darker area in the figure…"; "MAKING NOTHING OR LOSING MONEY is illustrated by the darker area in this figure…"	
Priming effect (this can include	• Participants answer to one question is affected by something happening earlier in the experiment	• Placing any questions that might be perceived as normative nearer to the of the survey. E.g., Trait questionnaire comes after State questionnaire.	

Consideration	Description	Survey wording for this study	Survey wording for future studies
Framing / Reference point effects)		• Adding comprehension questions to test whether a participant is perceiving the possible amount of gain and loss as intended	
Anchoring effect	• Participant's perception is affected (anchored) by prior information	• Directing subjects to a pairwise choice at 50% may have caused an anchoring effect. While this is a limitation, the effect is anticipated to result in more conservative effect sizes because it would starts subjects off (anchor them) at a point that is normatively objective i.e., without bias.	

Appendix B

Attitude to ambiguity sample survey

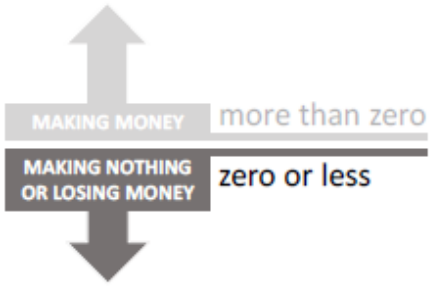
The following pages provide a sample of a question that was used in the study described in Chapter 5 to measure attitude to ambiguity, which in that chapter is also called ambiguity additivity. The whitespace in the question is intentional, to focus the participants' attention.

Imagine that you have just graduated and are a full-time entrepreneur. You come across an opportunity to make what YOU consider to be a VERY LARGE amount of money within the next five (5) years. There is a large upfront investment and, regardless of the outcome of the opportunity, five (5) years from now you would immediately need to pay (in other words, lose) what YOU consider to be a LARGE amount of money. If the opportunity were completely UNsuccessful, this large amount to pay would be more money than you can easily afford, EVEN if you asked friends and family to help you pay it.

This opportunity has a level of risk and uncertainty that YOU consider typical, with one big difference. Compared to typical opportunities, your sales ability is more important to the success of this particular opportunity. "Sales ability" means your ability to build and grow a highly effective sales team or your ability to hire the right person to do that for you.

Think about your odds of ending up making nothing or losing money after 5 years if you pursue this opportunity. MAKING NOTHING OR LOSING MONEY is illustrated by the darker area in this figure:

Now, let's say you were offered a lottery ticket for $50 with the SAME odds as what you believe are the odds of ending up MAKING NOTHING OR LOSING MONEY after 5 years if you pursue this opportunity. Below, you will be asked to indicate whether you would prefer to play a real-life lottery to win $50 with those odds, or to play it with KNOWN odds. On each row, you indicate your preference by placing a check (√) closer to your preference.



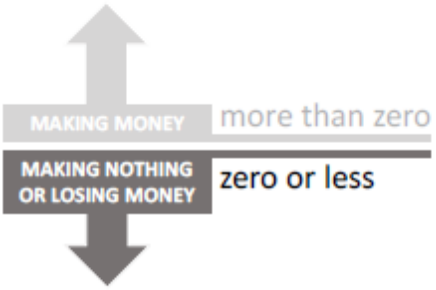
This table provides two examples. Notice where the checks (√) are placed and refer to the figure above if you need to:

	I prefer to play a REAL-LIFE lottery to win $50 with:...	(Check (√) one on each row)		I prefer to play a REAL-LIFE lottery to win $50 with these KNOWN odds:...
Example 1	...the SAME odds as MAKING NOTHING OR LOSING MONEY or	(√)	( )	...odds of 0% (no chance).
Example 2	...the SAME odds as MAKING NOTHING OR LOSING MONEY or	( )	(√)	...odds of 100% (a guaranteed win).

If you DO NOT understand these examples, please check here (√): ___ (If you DO understand, leave it blank.)

(continued): As a reminder, MAKING NOTHING OR LOSING MONEY is illustrated by the darker area in the figure to the right.

Think again about your odds of ending up MAKING NOTHING OR LOSING MONEY after 5 years if you take this opportunity. If you think the odds are really bad, start at **Question A and work down** the list. If you think the odds are really good, start at **Question P and work up** the list. If you think the odds are somewhere in the middle, start at **Question H and work up and down the list.** Please answer all 16 questions below.



If you DO NOT understand these instructions, please check here (√): ___ (If you DO understand, leave it blank.)

Please answer with 16 checks (√), one on each row:				
	I prefer to play a REAL-LIFE lottery to win $50 with:...	(Check (√) one on each row)		I prefer to play a REAL-LIFE lottery to win $50 with these KNOWN odds:...
Question A	...the SAME odds as MAKING NOTHING OR LOSING MONEY or	( )	( )	...odds of 1% (1 in 100 chance).
Question B	...the SAME odds as MAKING NOTHING OR LOSING MONEY or	( )	( )	...odds of 2% (1 in 50 chance).
Question C	...the SAME odds as MAKING NOTHING OR LOSING MONEY or	( )	( )	...odds of 5% (1 in 20 chance).
Question D	...the SAME odds as MAKING NOTHING OR LOSING MONEY or	( )	( )	...odds of 10% (1 in 10 chance).
Question E	...the SAME odds as MAKING N OTHING OR LOSING MONEY or	( )	( )	...odds of 20% (1 in 5 chance).
Question F	...the SAME odds as MAKING NOTHING OR LOSING MONEY or	( )	( )	...odds of 25% (1 in 4 chance).
Question G	...the SAME odds as MAKING NOTHING OR LOSING MONEY or	( )	( )	...odds of 33% (1 in 3 chance).
Question H	...the SAME odds as MAKING NOTHING OR LOSING MONEY or	( )	( )	...odds of 50% (1 in 2 chance).
Question I	...the SAME odds as MAKING NOTHING OR LOSING MONEY or	( )	( )	...odds of 60% (3 out of 5 chances).
Question J	...the SAME odds as MAKING NOTHING OR LOSING MONEY or	( )	( )	...odds of 66% (2 out of 3 chances).
Question K	...the SAME odds as MAKING NOTHING OR LOSING MONEY or	( )	( )	...odds of 75% (3 out of 4 chances).
Question L	...the SAME odds as MAKING NOTHING OR LOSING MONEY or	( )	( )	...odds of 80% (4 out of 5 chances).
Question M	...the SAME odds as MAKING NOTHING OR LOSING MONEY or	( )	( )	...odds of 90% (9 out of 10 chances).
Question N	...the SAME odds as MAKING NOTHING OR LOSING MONEY or	( )	( )	...odds of 95% (19 out of 20 chances).
Question O	...the SAME odds as MAKING NOTHING OR LOSING MONEY or	( )	( )	...odds of 98% (49 out of 50 chances).
Question P	...the SAME odds as MAKING NOTHING OR LOSING MONEY or	( )	( )	...odds of at least 99% (99 out of 100 chances or better).

On the previous page, did you answer all 16 questions **A-P** above by putting a check (**√**) on each row? If not, please go back and do so now…thank you!…Now you are more than halfway through this survey! 😊

Now, think about your odds of ending up making money after 5 years if you pursue this opportunity. For the set of 16 questions below (5A- 5P), "making money" means the possibility of MAKING MORE than zero (this does not include zero).

MAKING MONEY is illustrated by the darker area in the figure to the right.

Think again about your odds of ending up making money after 5 years if you take this opportunity. If you think the odds are really bad, start at **Question A and work down** the list. If you think the odds are really good, start at **Question P and work up** the list. If you think the odds are somewhere in the middle, start at **Question H and work up and down the list**. Please answer all 16 questions below.

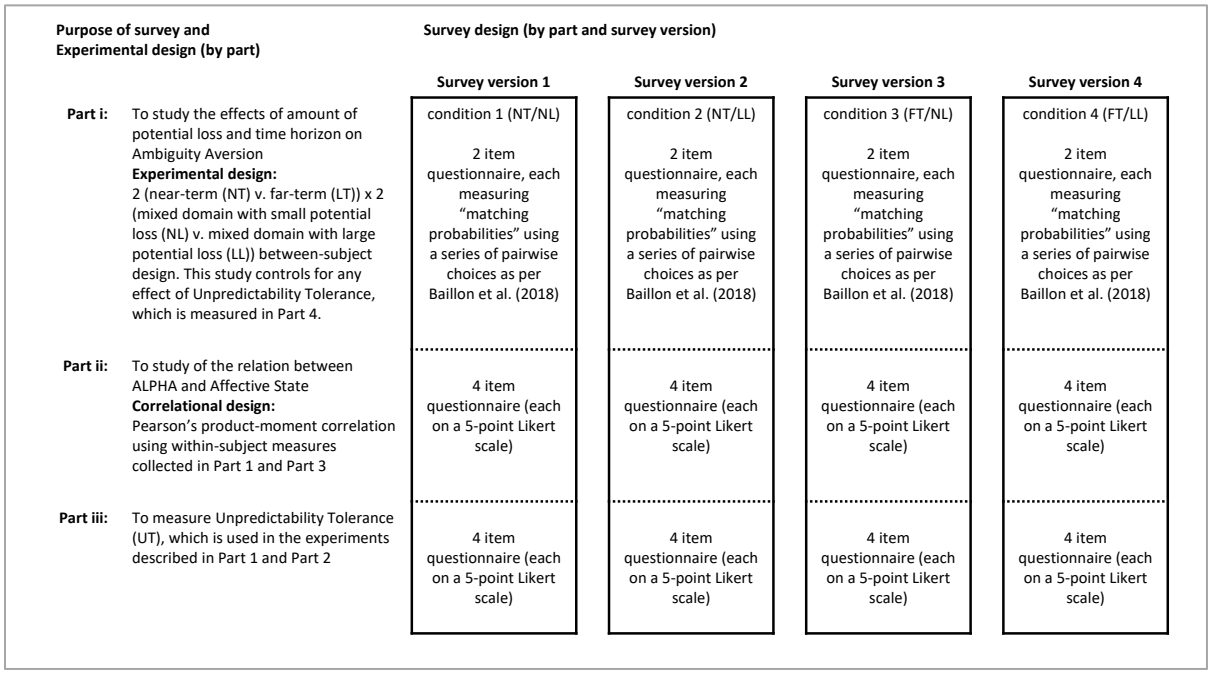
Please answer with 16 checks (V), one on each row:				
	I prefer to play a REAL-LIFE lottery to win $50 with:...	(Check (V) one on each row)		I prefer to play a REAL-LIFE lottery to win $50 with these KNOWN odds:...
Question A	...the SAME odds as MAKING MONEY or	( )	( )	...odds of 1% (1 in 100 chance).
Question B	...the SAME odds as MAKING MONEY or	( )	( )	...odds of 2% (1 in 50 chance).
Question C	...the SAME odds as MAKING MONEY or	( )	( )	...odds of 5% (1 in 20 chance).
Question D	...the SAME odds as MAKING MONEY or	( )	( )	...odds of 10% (1 in 10 chance).
Question E	...the SAME odds as MAKING MONEY or	( )	( )	...odds of 20% (1 in 5 chance).
Question F	...the SAME odds as MAKING MONEY or	( )	( )	...odds of 25% (1 in 4 chance).
Question G	...the SAME odds as MAKING MONEY or	( )	( )	...odds of 33% (1 in 3 chance).
Question H	...the SAME odds as MAKING MONEY or	( )	( )	...odds of 50% (1 in 2 chance).
Question I	...the SAME odds as MAKING MONEY or	( )	( )	...odds of 60% (3 out of 5 chances).
Question J	...the SAME odds as MAKING MONEY or	( )	( )	...odds of 66% (2 out of 3 chances).
Question K	...the SAME odds as MAKING MONEY or	( )	( )	...odds of 75% (3 out of 4 chances).
Question L	...the SAME odds as MAKING MONEY or	( )	( )	...odds of 80% (4 out of 5 chances).
Question M	...the SAME odds as MAKING MONEY or	( )	( )	...odds of 90% (9 out of 10 chances).
Question N	...the SAME odds as MAKING MONEY or	( )	( )	...odds of 95% (19 out of 20 chances).
Question O	...the SAME odds as MAKING MONEY or	( )	( )	...odds of 98% (49 out of 50 chances).
Question P	...the SAME odds as MAKING MONEY or	( )	( )	...odds of at least 99% (99 out of 100 chances or better).

On the previous page, did you answer all 16 questions **A-P** by putting a check (**√**) on each row? If not, please go back and do so now…thank you again!

Appendix C
Study design

There are four versions on the survey, and two contain 3 parts and the other two contain 4 parts. The purpose and design of each part is illustrated in Figure Appendix C.1. Together, they provide data required for the study described in Chapter 5.

Figure Appendix C.1 Illustration of survey design for the studies



Appendix D

Supplemental statistics: Ambiguity Additivity

Testing ANOVA assumptions for Ambiguity Additivity:

We test the three assumptions for ANOVA, namely that (1) the observations are independent; (1) the dependent variable (DV), namely Ambiguity Additivity, is normally distributed, and (2) the population variances are equal across the groups.

Independence of observations is established in a couple of ways. For one, three classrooms were surveyed and statistical tests showed that classroom had no effect. For another, the experimental protocol controlled for independence of the observations within a classroom in two ways: First, participants in each of the classrooms were assigned to one of the four groups randomly. Second, participants were told that the survey they received would be different from that of any neighbour.

The DV can be assumed to be normally distributed as a result of a visual test and a statistical test. An illustration of the quantiles in a *Q-Q* plot, where the quantiles of the DV are plotted against those of the normal distribution, is shown in Figure 5.1 of Chapter 5 (study). This figure reveals that the centre of the scatter plot is roughly a straight line. The ends of the data (the quantiles at the tails of the distribution, indicating the length of the tails) can deviate from the straight line and the data can still be considered normal (Howell, 2010). In addition to the visual test, the Shapiro-Wilk *W* test for normality[93] was performed. Results did not provide sufficient evidence to reject that the DV is normally distributed, $W(98)=0.98$ [94], $p=.49$ [95]; in other words, the statistical test provides additional validation of the assumption that the DV is normally distributed.

[93] The Shapiro-Wilk W test for normality (Shapiro and Wilk, 1965) and includes an approximation by Royston (1992, 1993) that makes the test accurate for sample sizes as low as $N=4$.
[94] $W(98)= 0.98759$
[95] $p=.48571$

Note: because it is outside of the inner fence[96], one point was considered as a potential outlier. However, no reason can be found to consider the respondent's answers unreasonable, and their answers also in line with predictions.

The population variances are considered equal across the groups. Two statistical tests were used: Levene's variance-comparison test and Bartlett's test for equal variances.[97] Results of the Levene's variance comparison test indicate that there is not sufficient evidence to reject equality of variances across the groups of Maximum Loss ($F(97)= 1.54$ [98], $p= 0.14$ [99]), Time Horizon, $F(97)=0.91$ [100], $p=.75$ [101], and Unpredictability Tolerance, $F(96)=0.66$ [102], $p=.16$ [103]; in other words, the IV are considered to have equal variances across the groups.

For completeness, Table Appendix D.2 presents the summary statistics for UT. ANCOVA was performed and UT was not found to be a covariate.

Table Appendix D.2 Summary statistics for variable UT, not found to be a covariate

Variable	*N*	*M*	*SD*	*SE*	95% C.I.		min	max
UT	98	1.19898	0.9578482	0.0967573	1.006943	1.391016	-1.5	3

[96] Inner fence is the range Q1-1.5*Q1 to Q3+1.5*Q3.
[97] While Bartlett's test for equality of variance (Bartlett, 1937) assumes normality of the sample, Levene's test statistic (Levene, 1960) is robust under nonnormality.
[98] $F(97)= 1.5391$
[99] $p=.1373$
[100] $F(97)= 0.9132$
[101] $p=.7523$
[102] $F(96)= 0.6556$
[103] $p=.1574$

Appendix E

Affective State survey

The following survey questions were used in the exploratory study described in Chapter 6 to measure affective states.

Imagine that you have decided to pursue this opportunity and rate how that makes you feel:

	lowest level	low level	moderate level	high level	highest level
Fear (anxious concern)	( )	( )	( )	( )	( )
Hope (desire accompanied by expectation of or belief in fulfillment)	( )	( )	( )	( )	( )
Optimism (to anticipate the best possible outcome)	( )	( )	( )	( )	( )
Pessimism (to expect the worst possible outcome)	( )	( )	( )	( )	( )

Appendix F
Supplemental statistics: ALPHA

Testing assumptions of linear regression for ALPHA:

Prior to performing multiple linear regression, the three initial assumptions for regression are tested, namely that (1) the observations are independent; (2) the dependent variable (DV), namely ALPHA, is normally distributed, and (3) the population variances are equal across the groups.

Independence of observations is established in a couple of ways. For one, three classrooms were surveyed and statistical tests showed that classroom had no effect. For another, the experimental protocol controlled for independence of the observations within a classroom in two ways: First, participants in each of the classrooms were assigned to one of the four groups randomly. Second, participants were told that the survey they received would be different from that of any neighbour.

Because ALPHA is an ordinal (categorical) ordinal variable, the DV is not assumed to be normally distributed. A quantiles plot of ALPHA, shown in Figure 6.1 of Chapter 6, reveals modes and some kurtosis. As expected, the Shapiro-Wilk *W* test for normality[104] provides strong evidence to reject that the DV is normally distributed, $W(98)= 0.97$ [105], $p < .05$[106]. Summary statistics for the dependent variable, ALPHA, are presented in Table Appendix F.3.

Bartlett's test for equal variances provides no evidence of a difference in variance across the IVs. The highest test statistic is across groups for Pessimism, $\chi^2(4)=7.58$ [107], $p=0.11$ [108]; however, not only does this test statistic provide sufficient support to accept that that the variances are equal across Pessimism, but also linear regression is rather robust to unequal variances and normality of the DV.

[104] The Shapiro-Wilk W test for normality (Shapiro and Wilk, 1965) and includes an approximation by Royston (1992, 1993) that makes the test accurate for sample sizes as low as N=4.
[105] $W(98)= 0.97431$
[106] $p=.04963$
[107] $\chi^2(4)=7.5808$
[108] $p=.108$

Table Appendix F.3 Summary statistics for variable ALPHA

Variable	*N*	*M*	*SD*	*SE*	95% C.I.		min	max
ALPHA	99	0.3757071	0.2205732	0.0221684	.3317145	.4196996	.005	.985

Appendix G

Supplemental statistics: matching probabilities

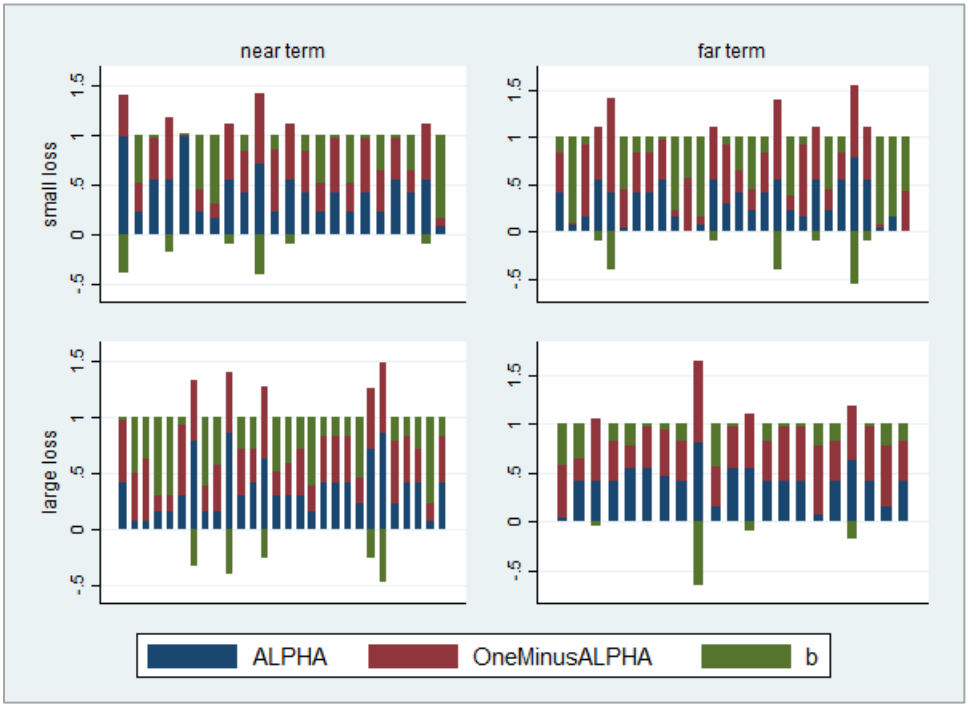
Post-hoc correlation testing was performed between pairs of matching probabilities across all groups, and the results are summarized in Table Appendix G.4. Correlation was tested by the Pearson product-moment correlation coefficient. Across all groups, pairs of matching probabilities have a low positive correlation at the Bonferroni-adjusted level, $r(97) = .3467$, $p < .01$. This result supports operational validity of the survey instrument. Specifically, it supports that item reduction (i.e., "is the scale parsimonious?") is achieved because the empirical results find only a low correlation between the two items. Low correlation between the items implies at least modest independence, or orthogonality, of the item dimensions. Such orthogonality means the items are not redundant, and this supports parsimony. A detailed description of operational validity of the survey instrument is provided in Chapter 3.4 (operational validity).

Effect size is an important consideration in statistical analysis (e.g., Cohen, 1988). To detect a low correlation of this effect size at a .01 significance level (i.e., a chance of Type 1 error, or false positive) with power of .8 (i.e., with a chance of Type II error, or false negative, of .2), a minimum sample size of 79 is required for parametric data. This minimum sample size is less than the total sample size for this study, or 99; therefore, the results supporting operational validity have a high power. In contrast, this minimum sample size is much larger than the group sizes, which vary from 22 to 28. A sample size of 28 would have a power of only 30% of detecting this low correlation, or a chance of false negative of 70%. Therefore, results for each group are not considered conclusive enough to interpret. Figure Appendix G.2 illustrates the relationship between each pair of matching probabilities and their measure of b for each group.

Table Appendix G.4 Correlations between pairs of matching probabilities for each group and across all groups

	group				
	all groups	**small/near**	**large/near**	**small/far**	**large/far**
n	99	22	28	28	21
r	0.3467*	0.2047	0.5996*	0.4498	-0.02
p	.0004	.3609	.0007	.0163	.9315

Figure Appendix G.2 Matching probabilities for each observation



Appendix H

Unpredictability Tolerance survey

The following survey was used in the study Chapter 5 to measure Unpredictability Tolerance. A description of the scale validation is provided in Chapter 4 (trait measure).

For each statement, put a check mark (**√**) in the column that best represents your first reaction.

	YES! always	YES, often	yes	? unsure	no, sometimes	NO	NO! never
When the future is uncertain, I generally expect the worst to happen.	( )	( )	( )	( )	( )	( )	( )
I like to plan ahead in detail rather than leaving things to chance.	( )	( )	( )	( )	( )	( )	( )
I try to have my life and career clearly mapped out.	( )	( )	( )	( )	( )	( )	( )
I feel better about myself when I know that I have done all I can to accurately plan my future.	( )	( )	( )	( )	( )	( )	( )

Appendix I
Supplemental statistics: Ratio/Sum

The proposed risk-management frameworks of Chapter 7 (overall implications) describe how classifying observations by their ratio/sum combination might be useful in entrepreneurship. This section describes the analysis done on the empirical data collected for the study of Chapter 5 to classify the attitude to ambiguity scores by their ratio/sum combination. Results of this classification are used in the worked example of Chapter 7.3.4 (entrepreneurship example). For the study of Chapter 5, surveys were developed by following the matching-pair probability protocol of Chapter 3 (state measure). Consequently, the surveys use a pair of matching probabilities to operationalize attitude to ambiguity. Each survey observation is comprised of a pair of matching probabilities. These can provide information in two distinct ways: by their sum and by their ratio.

$$\text{Ambiguity Sum} = (1 - \alpha_{S'}) + \alpha_S$$

$$\text{Ambiguity Ratio} = (1 - \alpha_{S'}) \,/\, \alpha_S$$

Both Ambiguity Sum and Ambiguity Ratio are used to classify attitude to ambiguity observations by their ratio/sum combination in the following ways:

Sum. Ambiguity Sum observations are divided into 3 categories to create the ordinal variable "Sum". One category is for Ambiguity Sum observations that are approximately equal to 1, another is for those greater than that, and another is for those less than that. For this analysis, a margin of +/- 0.1 was added around 1 to allow for margin of error in the method of measuring matching probabilities (or, the instrument error).[109]

[109] Each probability in a pair of matching probabilities is subject to instrument error due to the width of the intervals between pairwise choices. Propagation error can affect Ambiguity Sum by as much as sqrt(2)*((.50-.34)/2), or approximately 0.1. Future work could reduce this error by narrowing the intervals that are currently widest.

$$Sum\ is \begin{cases} 'subSum'\ if\ \text{Ambiguity Sum} < 1 - \text{ margin of measurement error} \\ 'balancedSum'\ if\ \text{Ambiguity Sum} = 1 \pm \text{ margin of measurement error} \\ 'superSum'\ if \text{Ambiguity Sum} > 1 + \text{ margin of measurement error} \end{cases}$$

Ratio. Ambiguity Ratio observations are classified into 2 categories to create the ordinal binary variable "Ratio". One category is for Ambiguity Ratio observations greater than 1, and the other for those less than or equal to one. Ratio is less affected by the instrument measurement error, and is not accounted for here.[110]

$$Ratio\ is \begin{cases} 'subRatio'\ if\ \text{Ambiguity Ratio} < 1 \text{ or Ambiguity Ratio} = 1 \\ 'superRatio'\ if \text{Ambiguity Ratio} > 1 \end{cases}$$

A full contingency table of Ratio and Sum scores is provided in Table Appendix I.5.

[110] Because of the ordinal nature of each probability in a pair of matching probabilities, it is assumed that the accuracy of Ambiguity Ratio is not significantly affected by the instrument error due to the width of the intervals between pairwise choices. This assumption could be tested in future work, and a trade-off is anticipated between increased subject fatigue by additional length to complete the survey and decreased measurement error due to finer intervals.

Table Appendix I.5 Contingency table for across Ratio and Sum: frequency, row percentage, and cell percentage

	Ratio		**TOTAL**
	sub (≤ 1)	**super** (>)	
Sum			
sub (≤ 0.9)			
n	39	21	60
% (row)	61.90	58.33	60.61
% (col)	39.39	21.21	60.61
balanced (0.9 - 1.1)			
n	15	11	26
% (row)	23.81	30.56	26.26
% (col)	15.15	11.11	26.26
super (> 1.1)			
n	9	4	13
% (row)	14.29	11.11	13.13
% (col)	9.09	4.04	13.13
TOTAL			
n	63	36	99
% (row)	100.00	100.00	100.00
% (col)	63.64	36.36	100.00

Appendix J
Study sample

The studies described in Chapter 5 and Chapter 6 were performed with the study described in Appendix C (study design). My study has research ethics board approval from both the University of Waterloo Research Ethics Committee (ORE #31905) and Ryerson Research Ethics Board (REB #2018-411) through their coordinated Tri-Council Policy Statement for Ethical Conduct for Research.

Participants were comprised of 139 senior undergraduate business students from the Ted Rogers School of Management at Ryerson University in Toronto, Canada. Much has been done to describe the benefits of sampling student population. In addition, research into how ambiguity affects behaviour of students who are trained have skills but not yet too experienced has wide impact for two reasons. Firstly, these factors that are known to affect attitude to ambiguity (re: Chapter 2—conceptual model) and, secondly, every entrepreneur starts out as "nascent".

"No right or wrong answers" was added to control for anticipation of being assessed by others (Kollmann et al., 2017; Curley et al., 1986). Participants were also told that "the right answers are your honest answers" to control for demand effect.

Other details about the stimulus that might be of interest to the reader: the survey took approximately 15 minutes. Students were recruited from four sections of the same core course for senior undergraduate students. All four sections were in the daytime. Four versions of the survey were distributed and reasonable care was taken to ensure that students in close proximity to each other did not receive the same version. Students were told they would not receive the same survey as their neighbors and, as mentioned above, that "there are no wrong answers" and "the right answers are their honest answers". They were offered healthy snacks and drinks while they completed their survey. The topic of the class preceding the survey was business strategy.

Appendix K

Research program

The detail below summarizes this research program, including the research questions and their relationship to the research objectives, contributions and where they are situated, the location of a description of the motivating literature and research methodology, and proposed research questions / next steps.

Overarching research question (i.e., main research inquiry): how does ambiguity affect an entrepreneur's behaviour?

Research purpose: Contribute to our understanding of an entrepreneur's perception of ambiguity

3 Research objectives:

OBJECTIVE 1) Develop a protocol to measure attitude to ambiguity for a context representative of entrepreneurship

• (RQ1) **Might there be a way of measuring ambiguity attitudes in the mixed domain in a context that is representative of entrepreneurship?**

• ***Research methodology***: Chapter 1 (introduction) & Chapter 3 (state measure)

• ***Literature revealing gap(s)***: Chapter 1 (introduction), Chapter 2 (conceptual model) & Chapter 5 (study)

• ***Contributions***: conceptual model for designing experiments for entrepreneurship, protocol for measuring attitude to ambiguity for a context representative of entrepreneurship, ambiguity ratio

This is a contribution to…	*...as described in…*	*…and leads to this future work discussed in Chapter 7 (overall implications)*
• Entrepreneurial cognition	Chapter 1 (introduction) & Chapter 7 (overall implications)	**• Can attitudes to ambiguity help us to better understand entrepreneurial cognition?**
• Entrepreneurial action / practice	Chapter 7 (overall implications)	**• Can change in attitude to ambiguity (i.e., change in perception) explain an entrepreneurs' shift from inactive to active?** (first need to understand: What model for action-orientedness to use? And, what factors (ambiguity-related) are expected to CHANGE action-orientedness?) **Can the advice from the Ambiguity Risk-Management Framework shift an entrepreneur from inactive to active?** • If so, **within what range of attitude to ambiguity will entrepreneurs remain more action oriented? Can the strategies of the Ambiguity Risk-Management Strategy Framework result in keeping entrepreneurs within their ecosystem active?** **• Next step:** validation and engineering modeling.
• Entrepreneurship practice / education	Chapter 1 (introduction) & Chapter 3 (state measure)	• Generalize the research question**, how does ambiguity affect an entrepreneur's risk assessment?** **• What kinds of interventions (e.g., networks and programs) help entrepreneurs change their perceptions and accelerate entrepreneurship?**
• Decision making	Chapter 1 (introduction) & Chapter 5 (study)	**• Next step**: Possible interdisciplinary RQ

OBJECTIVE 2) Following protocol, measure attitude to ambiguity for a specific context representative of entrepreneurship

• (RQ2) **Is there an effect of time horizon and potential loss on ambiguity attitudes in an entrepreneurial context?**

• ***Research methodology***: Chapter 5 (study)

• ***Literature revealing gap(s)***: Chapter 1 (introduction) & Chapter 5 (study)

• ***Contributions***: findings re: phenomenon of loss aversion from the perspective of attitude to ambiguity; phenomenon of loss aversion from the perspective of attitude to ambiguity in a specific context representative of entrepreneurship; generalizability of decision making's ambiguity attitudes protocol

This is a contribution to…	*...as described in…*	*…and leads to this future work discussed in Chapter 7 (overall implications)*
• **Entrepreneurial action**	Chapter 7 (overall implications)	• **Proposition:** An entrepreneur with ambiguity ratio greater than one is more likely to be active. • **Proposition:** Attitude to ambiguity mediates the relationship between time horizon and action.
• **Decision making**	Chapter 5 (study)	• **Next step**: Possible interdisciplinary RQ

• (RQ3) **Can a personality trait help explain attitudes towards ambiguity in an entrepreneurial context?**

• ***Research methodology***: Chapter 4 (trait measure)

• ***Literature revealing gap(s)***: Chapter 1 (introduction) and Chapter 4 (trait measure)

• ***Contributions***: protocol for developing a measure a personality disposition (trait) relevant to specific sources of ambiguity; a validated measure of unpredictability tolerance; findings re: relationship between Unpredictability Tolerance and attitude to ambiguity in specific context representative of entrepreneurship

This is a contribution to…	*...as described in…*	*…and leads to this future work discussed in Chapter 7 (overall implications)*
• **Entrepreneurship practice**	Chapter 1 (introduction) & Chapter 4 (trait measure)	• **Proposition:** Entrepreneurs with high Unpredictability Tolerance will be less likely to shift between active and inactive.
• **Entrepreneurial personality**	Chapter 1 (introduction)	• **Could other useful measures of ambiguity tolerance be developed to understand attitude under condition of other sources of ambiguity, other than predictability? E.g., ambiguity due to complexity**
• **Decision making**	Chapter 4 (trait measure)	• **Next step**: Possible interdisciplinary RQ

OBJECTIVE 3) Explore the possibility of developing a protocol to measure attitude to ambiguity that would be more practical to administer

• (RQ4) **Might there be a way of measuring ambiguity attitudes psychometrically?**

• (RQ5) **Specifically, can states of hope, fear, optimism, and pessimism be used to help characterize ambiguity attitudes?**

• ***Research methodology***: Chapter 6

• ***Literature revealing gap(s)***: Chapter 6

• ***Contributions***: findings: maybe an easier method exists; new metaphor to encourage interdisciplinary shared meaning

This is a contribution to…	*...as described in…*	*…and leads to this future work discussed in Chapter 7 (overall implications)*
• **Entrepreneurship practice**	Chapter 6	• (RQ4--CONTINUED) **Might there be a way of measuring ambiguity attitudes psychometrically?**
		• **Next step**: Repeat with larger sample size
		• **Next step**: Consider expanding the nomological net to include other dimensions
		• **Next step**: Consider non-linear modeling (e.g., ambiguity ratio)
	Chapter 6 & Chapter 7 (overall implications)	• **Do entrepreneurs in each quadrant of the Ambiguity Risk-Management framework have a different affective experience?**
		• **Does their affective experience contribute to their workplace stress?**
		• **Does their affective experience contribute to their outcomes within an entrepreneurial ecosystem?**
• **Decision making**		• **Next step**: Possible interdisciplinary RQ