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Bayesian analysis in entrepreneurship decision-making research

Review and future directions

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Abstract

Purpose – The purpose of this paper is to review Bayesian analysis in recent entrepreneurship research to assess how scholars have employed these methods to study the entrepreneurship process. Researchers in other business fields (e.g. management science, marketing, and finance) have increasingly employed Bayesian methods to study issues like decision making. To date, however, Bayesian methods have seen only limited use in entrepreneurship research.

Design/methodology/approach – After providing a general overview of Bayesian methods, this study examines how extant entrepreneurship research published in leading journals has employed Bayesian analysis and highlights topics these studies have investigated most frequently. It next reviews topics that scholars from other business disciplines have investigated using these methods, focusing on issues related to decision making, in particular.

Findings – Only seven articles published in leading management and entrepreneurship journals between 2000 and 2016 employed or discussed Bayesian methods in depth when studying the entrepreneurship process. In addition, some of these studies were conceptual.

Research limitations/implications – This review suggests that Bayesian methods may provide another important tool for researchers to employ when studying decision making in high uncertainty situations or the impact of entrepreneurial experience on decision making over time.

Originality/value – This review demonstrates that Bayesian analysis may be particularly appropriate for entrepreneurship research. By employing these methods, scholars may gain additional insights into entrepreneurial phenomenon by allowing researchers to examine entrepreneurial decision making. Through this review and these recommendations, this study hopes to encourage greater Bayesian analysis usage in future entrepreneurship research.

Keywords Decision making, Entrepreneurship, Methods

Paper type General review

Introduction

Entrepreneurship involves recognizing, analyzing, and exploiting perceived opportunities, which, in turn, lead to product, organization, and industry creation (Brush *et al.*, 2003; Shane and Venkataraman, 2000). To examine this process, entrepreneurship scholars have examined critical research questions such as "how do entrepreneurs make decisions under conditions of uncertainty?" and "how does additional entrepreneurial experience impact decision making?" (Baron and Ensley, 2006; Parker, 2006; Saravarthy and Berglund, 2010).

Similar to most organizational research, when studying these issues empirically, entrepreneurship scholars have primarily employed *p*-value null hypothesis significance testing (pNHST) methods (Dean *et al.*, 2007). Increasingly, however, some organizational

researchers have suggested that methods based on other approaches might help advance the field by incorporating different assumptions and methods into empirical analyses. For example, pNHST-based studies often employ group means as part of their calculations, which may statistically neutralize important differences among individuals or organizations that scholars seek to explain (e.g. Hansen *et al.*, 2004). In addition, researchers cannot employ pNHST methods to compare support for one theoretical model versus another because *p*-values only provide evidence to support or reject the null hypothesis (Andraszewicz *et al.*, 2015). Thus, other methods that overcome these potential limitations may be needed to study critical entrepreneurship issues.

Bayesian analysis represents one such set of methods, and scholars in other business (e.g. management science, marketing, and finance) fields have increasingly employed these methods to study issues like decision making. For example, Allenby *et al.* (2004) found over 50 articles published in top marketing journal that examined Bayesian methods issues during the 1990s. Given its many advantages, Bayesian methods provide another important tool for organizational scholars, in general (Kruschke *et al.*, 2012), and, as we detail below, entrepreneurship researchers, in particular. Most importantly, Bayesian analysis enables scholars to gauge how decision makers update their estimated probabilities of potential outcomes as new data become available, making it a useful method for studying decision making throughout the entrepreneurial process. In addition, Bayesian analysis employs previous results as an input (i.e. "prior beliefs"), and it faces fewer restrictions on sample size than pNHST-based methods (Zyphur and Oswald, 2013).

To date, however, Bayesian methods have seen only limited use in entrepreneurship research, and, as our review below shows, extant research has mostly been conceptual or employed simulated data. Even this limited research, however, has shown the value of employing these methods in studying entrepreneurship processes and topics (Block *et al.*, 2014).

Accordingly, we will discuss how scholars can employ Bayesian methods to study entrepreneurship issues. We first briefly review Bayesian methods, in general, and then examine how researchers have employed these methods in extant entrepreneurship research. We then provide examples of how other business fields have used Bayesian analysis to suggest research areas where entrepreneurship scholars might apply these methods. In doing so, we highlight some of the many advantages these methods have for studying the entrepreneurship process.

Bayesian methods: a brief review

Bayesian methods encompass a set of techniques that differ both philosophically and, in some cases, methodologically from methods relying on the central limit theorem familiar to most organizational scholars. The latter, for example, rely on pNHST and, thus, assume that research outcomes from a particular study reflect what would be obtained, on average, with repeated testing of a relationship (Carlin and Louis, 2009).

Bayesian analysis, in contrast, arose from Reverend Thomas Bayes' research. Bayes, a mathematician and theologian, worked with conditional probability theory in the late 1700s and discovered a basic probability law that came to be known as Bayes' Theorem, represented by the following equation:

$$P(H|E,c) = \frac{P(H|c) \times P(E|H,c)}{P(E|c)}$$

The left-hand term of the equation ($P(H|E, c)$) is the posterior probability, which represents the probability of hypothesis H after considering the effect of evidence (E) on

past experience (c). The term $P(H|c)$ is the a priori probability of H given c alone. Thus, the a priori probability can be viewed as the subjective belief of occurrence of hypothesis H based upon past experience or an "informative priors" based on previous empirical research (Zyphur and Oswald, 2013). The likelihood, represented by the term $P(E|H,c)$, gives the probability of the evidence assuming that the hypothesis H and the background information are true. The term $P(E|c)$ is independent of H and is regarded as a "normalizing" or "scaling" factor (Niedermayer, 2003). Thus, Bayesian analysis provides a method for combining either subjective beliefs or evidence from past research with new data.

Bayes' Theorem provides for a second view of probability in the world of statistics. Two different interpretations have long existed, the first of which uses a classical frequency distribution to describe the probability of the data. Using Bayes' Theorem, in contrast, provides another, more abstract conceptualization – the probability of a hypothesis (corresponding to a theory) given the data. Once known as "inverse probability," Bayesian inference updates the probability estimate for a hypothesis as additional evidence accumulates. Thus, Bayesian inference is explicitly based on the current evidence and prior opinion or evidence, which allows it to be based on multiple sets of evidence (Jaynes, 2003).

Two competing schools of statistics have developed as a consequence of these differing interpretations of probability. Classical inferential statistics was largely developed in the second quarter of the twentieth century, much of it in reaction to Bayesian probability. The current statistical Bayesian and pNHST perspectives stabilized in the second half of the twentieth century (Gigerenzer *et al.*, 1989). Table I summarizes some similarities and differences between these perspectives (Andraszewicz *et al.*, 2015; Casciaro and Sousa Lobo, 2008; Cyert and DeGroot, 1987; Efron, 2013; Johnson *et al.*, 2015; Kruschke *et al.*, 2012).

	pNHST	Bayesian
Hypothesis testing focus	What is the probability of the observed data, given that a population parameter equals zero? (null hypothesis)	What is the probability a population parameter has a given value, given evidence from the data?
Sample size impact	Large sample sizes increase the statistical power of an analysis, whereas small sample sizes can violate some statistical assumptions	Because analyses can use previous results as priors, small sample sizes in a given study are less problematic than for pNHST-based methods
Role of previous results	Previous results can be used to formulate hypotheses in a current study. Results from a current study can be compared with previous results to see if they are similar or contradictory. Results from a large number of studies can be analyzed employing meta analyses	Previous results from meta analyses and other studies can be used as inputs as prior probabilities
Potential disadvantages and caveats	When testing hypotheses, a model must be specified prior to observing current data to avoid using the data to "fine-tune" the model Researchers cannot employ pNHST methods to compare support for one model against another; *p*-values only provide evidence to support or reject the null hypothesis The null hypothesis is often implausible, given extant scientific evidence In some cases, a very large sample size can result in rejecting a true null hypothesis	When testing hypotheses, a model must be specified prior to observing current data to avoid using the data to "fine-tune" the model Obtaining Bayes factors can be computationally demanding Selection of priors requires skill because employing different priors can have a large impact on results

Table I.
Comparing pNHST
and Bayesian analysis

Renewed interest in Bayesian analysis has arisen, in part, because of the increasing recognition of pNHST's methodological limitations. For example, as noted in Table I, these methods focus on whether research outcomes deviate significantly enough (e.g. at $p < 0.05$) from the null hypothesis, which states that an effect does not exist, for researchers to confidently accept the alternative hypothesis that it does. Thus, pNHST supports hypotheses by contradicting the null (Andraszewicz et al., 2015). In addition, pNHST has methodological limitations, such a threat of rejecting the null, even a true one, as sample size increases (Kruschke et al., 2012). Block et al. (2014) recently provided a useful primer on these and other statistical issues (e.g. the tendency to employ small sample sizes) that make Bayesian analysis particular applicable to entrepreneurship research.

Renewed interest in Bayesian analysis has also arisen from increasing recognition of its methodological advantages for studying issues like decision making. Indeed, we suggest that this direct applicability to decision making makes it particularly relevant for entrepreneurship scholars. In some ways, Bayesian models of decision making resemble other approaches, like pNHST, familiar to many researchers. For example, Bayesian models still assume that decision makers maximize expected utility, based on both a utility function and probabilities. In Bayesian analyses, however, both of these can be, and often are, subjective. A key feature of Bayesian rationality is that decision makers update subjective probability sets based on experience. Indeed, the fact that initial beliefs might be incorrect is often a minimal constraint because Bayesian decision makers should gradually make more qualified decisions as they gather more information (Saravarthy and Berglund, 2010).

Bayesian analysis has been shown to be especially useful when information about past and/or current situations is vague, incomplete, conflicting, and uncertain (Cyert and DeGroot, 1987). Thus, whereas pNHST conceptualizes probability based on the assumption that results are consistent with those from large-sample, repeated testing, Bayesian methods employ probability to quantify uncertainty or degree of belief during decision making (Andraszewicz et al., 2015). Consequently, scholars can employ this analysis to investigate myriad organizational phenomenon, in general (Hansen et al., 2004), and entrepreneurship issues, in particular (Alvarez and Parker, 2009).

To illustrate this application, we provide an exemplar study to highlight how Bayesian methods can be applied to decision making, in general. The example is drawn from a management science study, but both its research question and statistical method have direct applications for entrepreneurship decision-making research.

Bayesian methods: an exemplar study

Lefgren et al. (2015) employed Bayesian methods to investigate how and whether people adjusted strategy decisions in a changing environment. They posited that decision makers are often subject to an "outcome bias," which occurs when people give inordinate weight to their past decisions based on whether an outcome was favorable or unfavorable. For example, research has shown that people often rate a decision as good (poor) when the outcome is favorable (unfavorable), even if a prior evidence demonstrated a high probability of a favorable (an unfavorable) outcome (Baron and Hershey, 1988). Moreover, this bias can also affect future decisions. Thus, outcome bias, like other decision-making biases, causes people to deviate from rational decision making, a topic frequently investigated in entrepreneurship research (e.g. Baron, 1998).

Employing the National Basketball Association (NBA) as a research setting, Lefgren et al. (2015) examined whether and how coaches adjusted their strategies following wins and losses. The authors began with the baseline assumption that coaches would use standard Bayesian updating, namely, they would assume that different game plans would result in various outcomes in different situations, based on a priori probabilities developed from previous experience. Coaches then would choose the plan they thought best

matched the current situation. Once they observed the outcome of the next game, they would use Bayesian updating to determine the posterior probability that they were correct about the situation and then either keep or change their strategy.

Once they developed this baseline model, Lefgren *et al.* (2015) incorporated outcome bias into the model, which showed that under both Bayesian updating and outcome-biased decision making, coaches would be more likely to switch strategies after losses. Under the latter, however, the model predicted that they would often switch strategies even after narrow losses, after both expected and unexpected successes, and when outcomes resulted from factors outside coaches' direct control.

To test these hypotheses, they employed 20 years' worth of data from the NBA games to see how well the data fit the model's predictions. They operationalized strategy changes as alterations to starting lineups, expected and unexpected successes based on gambling spreads prior to the game, and factors outside coaches' direct control as opponents' free throw percentage during the game. In general, results supported their hypotheses, for example, showing that coaches were 17 percent more likely to keep their starting lineup after a win than after a loss. The data also suggested that coaches swung from self-assurance to second guessing themselves after narrow victories and losses, respectively.

This example highlights some of the benefits of Bayesian relative to the pNHST methods more commonly employed in entrepreneurship research focused on decision making. For example, results can be interpreted as probabilities of outcomes rather than simply accepting or rejecting a null hypothesis employing a pNHST approach. It also highlights the straightforward application of Bayesian methods to decision making.

Of course, we should note that like all statistical methods, Bayesian analysis does include some potential disadvantages and caveats (see again Table I). For example, because Bayesian testing is sensitive to how prior probabilities are specified, this must be done with some care. In addition, as with all statistical approaches, the model must be specified before researchers observe the data to avoid "fine tuning" the hypotheses in advance to better fit the data (Andraszewicz *et al.*, 2015).

Based on this overview, we next briefly review how scholars have employed these methods in extant entrepreneurship research. We then suggest other applications of Bayesian methods to entrepreneurship research in the Future directions section below.

Bayesian analysis in entrepreneurship research

Scholars have often studied entrepreneurship as the process of opportunity identification, evaluation, exploitation, and exit. Entrepreneurs must first discern opportunities based on changing environmental trends, evaluate whether these opportunities are viable, and then assemble resources needed to exploit and profit from them (Shane and Venkataraman, 2000).

Two important dimensions, uncertainty and information asymmetry, remain central to the entrepreneurship process (Venkataraman, 1997). For example, without uncertainty about either individuals' behaviors (i.e. "behavioral uncertainty") or the future state of the world (i.e. "environmental uncertainty"; see Williamson, 1985), entrepreneurs would know *ex ante* both the potential payoffs from and possible downside risks of their efforts (Knight, 1921). In addition, if knowledge were symmetrically distributed in the population, no one would have an advantage in recognizing, evaluating, and/or pursuing opportunities (Shane, 2000). By extension, many sources of competitive advantage (e.g. causal ambiguity and first-mover advantages), which permit entrepreneurs to pursue opportunities without rapid competitive imitation, would not exist (Rumelt, 1987). Thus, uncertainty and information asymmetry are critical for explaining how and why entrepreneurial opportunities develop.

At the same time that these two dimensions generate opportunities, they also create some problems entrepreneurs face in starting and growing their new ventures. For example,

because entrepreneurs will not (e.g. from fear of someone stealing their ideas) or cannot (e.g. because opportunities rely on tacit knowledge) reveal critical information about perceived opportunities, potential stakeholders may refuse to provide them with critical resources needed to exploit these opportunities (Venkataraman, 1997). Indeed, many major theoretical frameworks (e.g. agency theory, transaction cost analysis, and the resource-based view of the firm) and critical constructs (e.g. liabilities of newness) that scholars employ to study entrepreneurial phenomena have uncertainty and/or information asymmetry as foundational assumptions (Lohrke and Landström, 2012).

Thus, both (lack of) information and decisions based on this (lack of) information remain at the heart of the entrepreneurship process. By gathering additional information, however, entrepreneurs can enhance their probability of discovering new opportunities and may be able to reduce (but, obviously, not completely eliminate) uncertainty. Similarly, more information can help stakeholders make more informed decisions about whether or not to invest time, money, and effort into a new venture.

Extant research on entrepreneurs' information usage has focused on the relationship between entrepreneurial experience and decision making, entrepreneurs' decision making heuristics and biases, or what types of information entrepreneurs require before making decisions at different stages of the entrepreneurship process (Shepherd et al., 2015). For example, Baron and Ensley (2006) found that cognitive frameworks essential for opportunity identification varied significantly between experienced and novice entrepreneurs, with the former having richer, more complex, and more business-focused frameworks that the latter. In addition, Choi and Shepherd (2004) found that knowledge of customer demand, technology, and stakeholder support was positively related to entrepreneurs' decisions to exploit opportunities.

Research on stakeholders' information usage has often focused on "signals" that potential investors, suppliers, and customers use to discern new venture viability, given they lack complete information about a startup (Connelly et al., 2011). For example, Hoenig and Henkel (2015) found that venture capitalists employ information about both a venture's team and its previous strategic alliances as important signals affecting investment decisions.

Despite accumulating research, we still know little about how decision making changes over time for entrepreneurs and potential stakeholders (Shepherd et al., 2015). For example, with limited exception (e.g. Parker, 2006, 2013), entrepreneurship studies (primarily employing pNHST methods) have often employed cross-sectional data collection that does not allow tracking changes in decision making over time. Because Bayesian analysis can specifically examine how decision makers employ initial assumptions and then incorporate additional information gathered over time, it would seem particularly applicable to studying the entrepreneurship process.

Method

To review the use of these methods in extant entrepreneurship research, we employed electronic and bibliographic searches of leading entrepreneurship and management journals from 2000 to 2016 for the key words "Bayes" and "Bayesian" (see Table II)[1]. In general, understanding how individuals and teams make decisions is critical to understanding the entrepreneurship process, and extant research, in general, has employed myriad theories and frameworks to study entrepreneurship decision making (Saravarthy and Berglund, 2010).

Studies examining how entrepreneurs initially identify potential opportunities have examined sources of new opportunities (e.g. environmental changes) and/or how entrepreneurs gather information from their environments to detect potentially attractive opportunities (Eckhardt and Shane, 2003). As shown in Table II, however, only two studies published to date in major entrepreneurship or management journals have used Bayesian analysis to study how entrepreneurs discover new, potentially valuable ideas. First,

Study	Sample	Topic Opportunity sources/recognition	Opportunity evaluation	Opportunity exploitation and exit	Key findings
Arin et al. (2015)	Global Entrepreneurship Monitor and macro-economic data as well as simulated data	Macro-level sources of entrepreneurship			Only four macro-economic trends related to aggregate entrepreneurship. In addition, two of these, inflation and taxation, are controllable, suggesting that governments can influence entrepreneurial activity
Johnson et al. (2015)	60 student teams (n = 360)			Team processes	Team debates and disagreements systematically varied in their impact over time on team performance when writing a business plan
Chwolka and Raith (2012)	Conceptual		Value of business planning	Value of business planning	High-quality planning yields information that may either prompt an entrepreneur to exploit or not exploit an opportunity judged a priori to be unattractive or attractive, respectively
Alvarez and Parker (2009)	Simulated data		Allocation of decision-making authority under uncertainty		Incomplete contract theory may need to be modified because it can explain decision making under risk well, but not under uncertainty
Norton and Moore (2006)	30 entrepreneurs and 23 non-entrepreneurs		Risk-taking propensity		Entrepreneurs did not differ from non-entrepreneurs on risk-taking propensity. Thus, differences in risk assessment, based on information, rather than risk-taking propensity may explain entrepreneurial decision making
Fiet et al. (2005)	Simulated data	Information search			By restricting their opportunity search to domains about which they already have some knowledge, entrepreneurs avoid the impossible situation of unconstrained search and maximize the probability of identifying a viable opportunity
Norton and Moore (2002)	Conceptual		Risk-taking propensity		Entrepreneurs should not differ from non-entrepreneurs on risk-taking propensity. Based on Bayesian probability, the former should assess opportunities and threats differently than the latter

Table II.
Bayesian analysis in recent entrepreneurship research

Fiet *et al.* (2005) employed Bayesian logic to show that entrepreneurs, who restrict their search to areas where they have preexisting knowledge, both maximize the probability and minimize information costs of discovery. Using simulated data, they showed which information sources led to the highest success probabilities, assuming either unlimited resources or a budget constraint for information search.

Second, Arin *et al.* (2015) examined macro-level determinants of entrepreneurship. They found, after correcting for model uncertainty via Bayesian model averaging, that only four of the many macro-level variables often used to explain entrepreneurship actually contribute to startup activity across countries.

Opportunity evaluation examines the decision-making conditions entrepreneurs face and decision processes they employ to make startup decisions (Keh *et al.*, 2002). As noted in Table II, most entrepreneurship studies employing Bayesian analysis, to date, have investigated these topics. For example, Norton and Moore (2006) examined risk-taking propensity and risk assessment. Building on the work of Sitkin and Pablo (1992), they defined propensity as the tendency to take or avoid risk and assessment as the perception of risk inherent in a situation. They hypothesized that entrepreneurs and non-entrepreneurs would not differ on risk-taking propensity, but the former would have more positive assessments than the latter would of an uncertain situation. Using Bayesian logic, they stated how current decisions would be informed by a respondent's industry specific knowledge, which they classified as prior probabilities in their study. Their results supported their hypotheses.

Alvarez and Parker (2009) employed Bayesian analysis to examine the implications of incomplete contract theory (ICT) on decision rights allocation in a new venture. Specifically, ICT predicts that, given the unknown future value of a firm, decision-making authority should reside with the decision maker with the most to gain from the venture. As Alvarez and Parker note, however, the future value of a new venture often remains uncertain for an extended time period, making these claims difficult to allocate *ex ante*. As time passes, however, founders can update their beliefs about a venture's future value based on new information. Employing simulated data, they demonstrated different scenarios for optimally allocating decision-making control within a new venture under ICT assumptions. In addition, they noted that Bayesian analysis allows scholars to study decision making under uncertainty rather than risk because if faced with the latter, all parties involved would be able to compute identical future values for the venture (Cyert and DeGroot, 1987).

Chwolka and Raith (2012) employed Bayesian logic to inform the debate about whether or not entrepreneurs should write business plans prior to launching new ventures. As they noted, to date, empirical evidence has been decidedly mixed on the relationship between writing plans and subsequent venture performance. Employing Bayes' Theorem, they showed how high-quality planning yields information that may prompt an entrepreneur to either exploit or not exploit an opportunity judged a priori to be unattractive or attractive, respectively.

Opportunity exploitation includes the processes related to launching and managing new ventures, whereas opportunity exit involves entrepreneurs' decisions to sell or discontinue their companies. One important aspect of exploitation involves how new venture team members interact and, in turn, how these team processes impact new venture performance (Klotz *et al.*, 2014). Employing a sample of student teams writing business plans, Johnson *et al.* (2015) investigated team processes and found that team debates and disagreements systematically varied in their impact on team outcomes over time. Specifically, two interpersonal process dimensions, task debate and conflict, varied in their impact on team performance during early, middle, and later interactions.

As shown in Table II, despite the importance of exit decisions in entrepreneurial research (DeTienne *et al.*, 2015), to date, no studies published in leading entrepreneurship journals have employed Bayesian analysis to investigate exit topics. Thus, investigating these issues appears to be a useful future research avenue.

Despite the relatively low number of entrepreneurial studies employing Bayesian methods, these results do include some encouraging trends. First, scholars have employed these methods to investigate several topics relevant to the entrepreneurship process. Second, similar to studies from other disciplines, some entrepreneurship scholars have begun using advanced methods, such as employing Markov chain Monte Carlo simulation to test theories with simulated data (e.g. Arin *et al.*, 2015). Based on recent advances in computational power, these simulation methods have allowed Bayesian analysis, in general, to move beyond investigating relatively simple to test more complex models (see Kruschke *et al.* (2012) for additional details).

In sum, we can conclude from this literature review that extant research has underutilized Bayesian analysis to examine critical entrepreneurship issues, especially given its direct applicability to many of the field's most important research questions like the value of previous experience in decision making. Specifically, the review shows that even though entrepreneurship research has occasionally employed Bayesian logic and methods, studies in leading journals have rarely employed Bayesian analysis. It also shows that the majority of the research focus, to date, has been on opportunity evaluation questions related to decision making under uncertainty. These findings coincide with other methods reviews of entrepreneurship research showing that entrepreneurship scholars may lack familiarity with statistical methods from related disciplines, and, as a result they may be slow to adopt these methods (e.g. Dean *et al.*, 2007). They also parallel findings that organizational research scholars, in general, have rarely employed these methods, despite increasing use in related disciplines, such as marketing (Kruschke *et al.*, 2012).

To provide guidance in applying Bayesian methods to study important entrepreneurship questions, we next examine examples of how scholars from other organizational sciences have employed these methods for topics related to the entrepreneurship process. This research can suggest other potential applications of Bayesian analysis to important entrepreneurship questions.

Future directions

Our conclusion that extant research has underutilized Bayesian analysis to study entrepreneurial decision making, especially considering its direct applicability to many of the field's most important research questions, suggests several future research directions. To help guide this research, we highlight several future research avenues based on the different stages of the entrepreneurship process. In addition, we highlight exemplar studies from other business fields to illustrate how scholars have investigated topics relevant to these research avenues, to date (see Table III).

Opportunity sources and identification

Entrepreneurial studies investigating opportunity identification have examined how individuals or teams interpret environmental trends to discern potential opportunities. Those focusing on the individual level have examined factors such as creativity, cognitive abilities, entrepreneurial intentions, social network ties, and access to diverse information based on different life experiences (Ardichvili *et al.*, 2003; Shane, 2000). Those examining corporate-level opportunity identification have also studied a firm's overall strategic posture (i.e. "entrepreneurial orientation," Lumpkin and Dess, 1996) and its ability to employ information generated outside the firm (i.e. "absorptive capacity," Cohen and Levinthal, 1990). In general, identifying opportunities remains predicated on gathering information, which involves both uncertainty (e.g. what kind of information to search for) and cost (e.g. how much time and how many resources should be invested; Fiet *et al.*, 2005).

Research employing Bayesian analysis in other fields has focused on two topics applicable to opportunity identification, reactions to environmental changes and use of personal

Research topic	Future research questions	Exemplar Bayesian studies from other disciplines
Opportunity identification		
Identification processes	How do entrepreneurs decide if environmental trends represent viable opportunities? From where and whom should entrepreneurs obtain information?	Grenadier and Malenko (2010); O'Leary (1998)
Network analysis	How can an entrepreneur's personal network help generate ideas that serve as potential entrepreneurial opportunities?	Ansari *et al.* (2011)
Opportunity evaluation		
Decision-making heuristics and biases	How frequently and to what effect do entrepreneurs and investors exhibit certain decision-making tendencies including, in some cases, overconfidence? How biased are entrepreneurs' *post hoc* evaluations of previous decisions? How do entrepreneurs balance intuition with rational decision making when faced with high uncertainty?	Van den Steen (2011); Kaustia and Knüpfer (2008) Lefgren *et al.* (2015) Achtziger and Alós-Ferrer (2014)
Attitudes toward risk and loss aversion	How do risk-seeking and adverse attitudes affect entrepreneurs' and potential investors' decisions about a new venture? How do these attitudes change over time?	Bisière *et al.* (2015); Dillon and Tinsley (2008); Massey and Wu (2005)
Opportunity exploitation		
Liabilities of newness	How do stakeholders update risk assessments about new ventures as more information becomes available, and, in turn, modify their investment decisions? Can companies provide too much information to potential customers, resulting in information overload for the latter?	Saboo and Grewal (2013) Ghose *et al.* (2014)
Network analysis	How do entrepreneur leverage personal networks as a source of funding and other resource support in starting a new venture? How much does the strength of network ties vary and what is the impact of this variance on whether or not an entrepreneur exploits an entrepreneurial opportunity?	Ansari *et al.* (2011) Casciaro and Sousa Lobo (2008)

Table III.
Future research topics in entrepreneurship research employing Bayesian analysis

networks for gathering information. First, Bayesian analysis provides the ability to study how entrepreneurs employ increasing information about environmental shocks to make decisions. For example, drawing from a real options perspective in finance, Grenadier and Malenko (2010) noted that decision makers face uncertainty not only about future shocks, but about the nature (i.e. temporary or permanence) of past shocks. Employing Bayesian logic, they found that the ability to update beliefs provides value to decision makers beyond the oft-cited "option to wait" by providing an "option to learn." These results, therefore, could have direct applicability to studying how entrepreneurs respond to changing environments.

Second, an entrepreneur's personal network also represents a critical part of the opportunity recognition process (Ardichvili *et al.*, 2003). Network participants (e.g. family, friends, and business associates) can help entrepreneurs identify opportunities by facilitating idea generation and pattern recognition among disparate trends (Granovetter, 1973). Thus, findings from employing Bayesian analysis to study networks may be directly applicable to entrepreneurship research. For example, in examining marketing issues, Ansari *et al.* (2011) illustrated how information in one network relationship can be leveraged to predict connectivity in another. Given both the complexity and value of entrepreneurial networks, scholars could also employ this approach to examine how entrepreneurs interact with their network members.

Opportunity evaluation
Studies examining how entrepreneurs evaluate opportunities have examined important decision-making processes under uncertainty and how this decision making can produce outcomes that deviate from rational choice. For example, Baron (1998) posited that entrepreneurs may employ different decision-making biases more or less frequently than non-entrepreneurs when evaluating opportunities. In addition, entrepreneurs' risk/return payoff assessments, based on current information they have, can impact whether or not they decide to exploit opportunities they recognize (McMullen and Shepherd, 2006).

Decision-making biases and heuristics. As noted above, extant entrepreneurship studies employing Bayesian analysis have often studied decision making under uncertainty. This focus parallels research in other fields, but based on findings in these fields, other decision-making issues could also be examined in entrepreneurship. For example, Charness and Levin (2005) examined how heuristic- differed from Bayesian-based decision making. Employing an experimental design, they found that Bayesian updating with expected utility maximization sometimes matched and sometimes contrasted with a "win-stay, lose-shift" heuristic.

In addition, research has employed Bayesian analysis to examine how much confidence decision makers have in their decisions. For example, Kaustia and Knüpfer (2008) found that investors tended to overweight personal experience gained from investing in previous initial public offerings (IPOs) when deciding whether to participate in a current one. Relatedly, Van den Steen (2011) studied decision making by rational agents and found that they can be overconfident about future estimates. He also noted that, somewhat ironically, in trying to update in an optimal way, Bayesian-rational agents increasingly overestimated their decision precision as they received more data.

Extant research has also employed Bayesian analysis to examine how and whether individuals revise strategies based on past performance when facing high environmental uncertainty. For example, Achtziger and Alós-Ferrer (2014) posited that when making decisions under conditions of uncertainty, decision makers combine intuitive and rational processes. The authors found that when faced with both performance feedback from previous decisions and additional information from the environment, decision makers often relied on the former when making intuitive decisions. In addition, results showed that conflicts between intuitive and rational processes resulted in slower decision making, an outcome that could inform entrepreneurial research on entrepreneurs' heuristic usage (Busenitz and Barney, 1997). As highlighted in detail above, Lefgren *et al.* (2015) employed Bayesian analysis to illustrate basketball coaches' outcome biases, based on how they overestimated the importance that their strategy played in a successful or unsuccessful outcome, especially when margins of victory or defeat were narrow.

Risk perceptions and attitudes. Scholars have frequently examined the role that entrepreneurs' risk perceptions and attitudes have on the entrepreneurship process (Lévesque *et al.*, 2009; Wennberg *et al.*, 2016). Studies in other disciplines have employed Bayesian analysis to examine how decision makers' risk perceptions and attitudes impact subsequent decisions. For example, Dillon and Tinsley (2008) found that people tend to rate near-misses, situations where catastrophe was averted by chance, as successes, and, in turn, they tended to subsequently make riskier decisions following these events. Massey and Wu (2005) found that decision makers were likely to underreact when confronting unstable environments with precise signals and overreact when facing stable ones with noisy signals.

For entrepreneurship research, these findings on opportunity evaluation provide guidance on how Bayesian analysis can be used to study how entrepreneurs and potential

stakeholders employ intuition, heuristics, biases, and risk attitudes when making decisions. In particular, the findings provide additional insight, which coincides with the view in the field that these decision makers do not or cannot always make rational decisions when faced with high uncertainty. In addition, findings suggest important future opportunities to employ Bayesian analysis to examine how entrepreneurs and key stakeholders update their beliefs as more information becomes available about environmental trends.

Opportunity exploitation and exit
Research into opportunity exploitation has examined issues such as where entrepreneurs establish organizational boundaries (Katz and Gartner, 1988) and how they help their new ventures overcome liabilities of newness to encourage key stakeholders to invest in the venture (Stinchcombe, 1965). Other critical research has examined how entrepreneurs assemble the necessary resources to launch their ventures, develop their ventures' competitive advantages, and decide to exit their ventures.

Bayesian research has focused primarily on the role of investor experience has on investing decisions. For example, Saboo and Grewal (2013) studied how information asymmetry impacts company valuation in an IPO. They found that a firm's customer and competitive orientation provide potential investors with additional information about heretofore private companies prior to IPOs, which, in turn, relates positively to a firm's market valuation.

In addition, research has examined interpersonal network development employing Bayesian analysis. As noted above, an entrepreneur's network can be critical for identifying opportunities, but this same network can also facilitate accumulating resources necessary to exploit opportunities (Larson, 1992). In examining networks, Casciaro and Sousa Lobo (2008) hypothesized that the extent to which one person liked another (i.e. the level of interpersonal affect) would impact whether or not the former sought out the latter to be part of his/her network for accomplishing a task. Results indicated that affect significantly impacted this tendency even more than whether the person building the network perceived a person as competent in his/her job abilities.

In sum, this review shows that research in other disciplines has increasingly employed Bayesian analysis to study issues relevant to the entrepreneurship process. Examining topics familiar to entrepreneurship researchers, it illustrates how future studies can employ Bayesian analysis to study decision-making processes in entrepreneurship contexts.

Conclusion
This study reviewed Bayesian methods use in extant entrepreneurship research. In general, we found that these studies have infrequently employed Bayesian methods, despite the direct applicability of Bayesian methods to entrepreneurship topics and research situations (e.g. decision making under uncertainty). Specifically, only seven studies employed Bayesian logic or methods from 2000 to 2017. As a result, we highlighted additional topics where scholars could employ these methods in future research and provided examples from other organizational research illustrating applications of these methods to entrepreneurship research.

This review also demonstrates that this analysis may be particularly appropriate for entrepreneurship research, given the importance of both uncertainty and information asymmetry to the entrepreneurship process. By employing Bayesian methods, scholars may gain additional insight into entrepreneurial phenomenon by allowing researchers to examine entrepreneurial decision making. We hope that through this review and these recommendations, we help encourage greater Bayesian analysis usage in future entrepreneurship research.

Note

1. Because we evaluated research from high-quality journals from 2000 to 2015, we employed Fried's (2003) ranking of high-quality entrepreneurship outlets. We added *Strategic Entrepreneurship Journal* to the list because it began publication after 2003 and quickly achieved high-quality status.

References

Achtziger, A. and Alós-Ferrer, C. (2014), "Fast or rational? A response-times study of Bayesian updating", *Management Science*, Vol. 60 No. 4, pp. 923-938.

Allenby, G., Bakken, D. and Rossi, P. (2004), "The HB revolution: how Bayesian methods have changed the face of marketing research", *Marketing Research*, Vol. 16 No. 2, pp. 20-25.

Alvarez, S. and Parker, S. (2009), "Emerging firms and the allocation of control rights: a Bayesian approach", *Academy of Management Review*, Vol. 34 No. 2, pp. 209-227.

Andraszewicz, S., Scheibehenne, B., Rieskamp, J., Grasman, R., Verhagen, J. and Wagenmakers, E.-J. (2015), "An introduction to Bayesian hypothesis testing for management research", *Journal of Management*, Vol. 41 No. 2, pp. 521-543.

Ansari, A., Koenigsberg, O. and Stahl, F. (2011), "Modeling multiple relationships in social networks", *Journal of Marketing Research*, Vol. 48 No. 4, pp. 713-728.

Ardichvili, A., Cardozo, R. and Ray, S. (2003), "A theory of entrepreneurial opportunity identification and development", *Journal of Business Venturing*, Vol. 18 No. 1, pp. 105-124.

Arin, K., Huang, V., Minniti, M., Nandialath, A. and Reich, O. (2015), "Revisiting the determinants of entrepreneurship: a Bayesian approach", *Journal of Management*, Vol. 41 No. 2, pp. 607-631.

Baron, J. and Hershey, J. (1988), "Outcome bias in decision evaluation", *Journal of Personality and Social Psychology*, Vol. 54 No. 2, pp. 569-579.

Baron, R. (1998), "Cognitive mechanisms in entrepreneurship: why and when entrepreneurs think differently than other people", *Journal of Business Venturing*, Vol. 13 No. 4, pp. 275-294.

Baron, R. and Ensley, M. (2006), "Opportunity recognition as the detection of meaningful patterns: evidence from comparisons of novice and experienced entrepreneurs", *Management Science*, Vol. 52 No. 9, pp. 1331-1344.

Bisière, C., Décamps, J.-P. and Lovo, S. (2015), "Risk attitude, beliefs updating, and the information content of trades: an experiment", *Management Science*, Vol. 61 No. 6, pp. 1378-1397.

Block, J., Miller, D. and Wagner, D. (2014), "Bayesian methods in family business research", *Journal of Family Business Strategy*, Vol. 5 No. 1, pp. 97-104.

Brush, C., Duhaime, I., Gartner, W., Stewart, A., Katz, J., Hitt, M., Alvarez, S., Meyer, G. and Venkataraman, S. (2003), "Doctoral education in the field of entrepreneurship", *Journal of Management*, Vol. 29 No. 3, pp. 309-331.

Busenitz, L. and Barney, J. (1997), "Differences between entrepreneurs and managers in large organizations: biases and heuristics in strategic decision-making", *Journal of Business Venturing*, Vol. 12 No. 1, pp. 9-30.

Carlin, B. and Louis, T. (2009), *Bayesian Methods for Data Analysis*, 3rd ed., Chapman & Hall/CRC, Boca Raton, FL.

Casciaro, T. and Sousa Lobo, M. (2008), "When competence is irrelevant: the role of interpersonal affect in task-related ties", *Administrative Science Quarterly*, Vol. 53 No. 4, pp. 655-684.

Charness, G. and Levin, D. (2005), "When optimal choices feel wrong: a laboratory study of Bayesian updating, complexity, and affect", *American Economic Review*, Vol. 95 No. 4, pp. 1300-1309.

Choi, Y. and Shepherd, D. (2004), "Entrepreneurs' decisions to exploit opportunities", *Journal of Management*, Vol. 30 No. 3, pp. 377-395.

Chwolka, A. and Raith, M. (2012), "The value of business planning before start-up: a decision-theoretical perspective", *Journal of Business Venturing*, Vol. 27 No. 3, pp. 385-399.

Cohen, W. and Levinthal, D. (1990), "Absorptive capacity: a new perspective on learning and innovation", *Administrative Science Quarterly*, Vol. 35 No. 1, pp. 128-152.

Connelly, B., Certo, S., Ireland, R. and Reutzel, C. (2011), "Signaling theory: a review and assessment", *Journal of Management*, Vol. 37 No. 1, pp. 39-67.

Cyert, R. and DeGroot, M. (1987), *Bayesian Analysis and Uncertainty in Economic Theory*, Rowman and Littlefield, Totowa, NJ.

Dean, M., Shook, C. and Payne, G. (2007), "The past, present, and future of entrepreneurship research: data analytic trends and training", *Entrepreneurship: Theory & Practice*, Vol. 31 No. 4, pp. 601-618.

DeTienne, D., McKelvie, A. and Chandler, G. (2015), "Making sense of entrepreneurial exit strategies. A typology and test", *Journal of Business Venturing*, Vol. 30 No. 2, pp. 255-272.

Dillon, R. and Tinsley, C. (2008), "How near-misses influence decision making under risk: a missed opportunity for learning", *Management Science*, Vol. 54 No. 8, pp. 1425-1440.

Eckhardt, J. and Shane, S. (2003), "Opportunities and entrepreneurship", *Journal of Management*, Vol. 29 No. 3, pp. 333-349.

Efron, B. (2013), "A 250-year argument: belief, behavior, and the bootstrap", *Bulletin of the American Mathematical Society*, Vol. 50 No. 1, pp. 129-146.

Fiet, J., Piskounov, A. and Patel, P. (2005), "Still searching (systematically) for entrepreneurial discoveries", *Small Business Economics*, Vol. 25 No. 5, pp. 489-504.

Fried, V. (2003), "Defining a forum for entrepreneurship scholars", *Journal of Business Venturing*, Vol. 18 No. 1, pp. 1-11.

Ghose, A., Ipeirotis, P. and Li, B. (2014), "Examining impact of ranking on consumer behavior and search engine revenue", *Management Science*, Vol. 60 No. 7, pp. 1632-1654.

Gigerenzer, G., Swijtink, Z., Porter, T., Daston, L., Beatty, J. and Kruger, L. (1989), *The Empire of Chance: How Probability Changed Science and Everyday Life*, Cambridge University Press, Cambridge.

Granovetter, M. (1973), "The strength of weak ties", *American Journal of Sociology*, Vol. 78 No. 6, pp. 1360-1380.

Grenadier, S. and Malenko, A. (2010), "A Bayesian approach to real options: the case of distinguishing between temporary and permanent shocks", *Journal of Finance*, Vol. 65 No. 5, pp. 1949-1986.

Hansen, M., Perry, L. and Reese, C. (2004), "A Bayesian operationalization of the resource-based view", *Strategic Management Journal*, Vol. 25 No. 13, pp. 1279-1295.

Hoenig, D. and Henkel, J. (2015), "Quality signals? The role of patents, alliances, and team experience in venture capital financing", *Research Policy*, Vol. 44 No. 5, pp. 1049-1064.

Jaynes, E. (2003), *Probability Theory: The Logic of Science*, Cambridge University Press, Cambridge.

Johnson, A., van de Schoot, R., Delmar, F. and Crano, W. (2015), "Social influence interpretation of interpersonal processes and team performance over time using Bayesian model selection", *Journal of Management*, Vol. 41 No. 2, pp. 574-606.

Katz, J. and Gartner, W. (1988), "Properties of emerging organizations", *Academy of Management Review*, Vol. 13 No. 3, pp. 429-441.

Kaustia, M. and Knüpfer, S. (2008), "Do investors overweight personal experience? Evidence from IPO subscriptions", *Journal of Finance*, Vol. 63 No. 6, pp. 2679-2702.

Keh, H.T., Foo, M.D. and Lim, B.C. (2002), "Opportunity evaluation under risky conditions: the cognitive processes of entrepreneurs", *Entrepreneurship: Theory & Practice*, Vol. 2 No. 2, pp. 125-148.

Klotz, A., Hmieleski, K., Bradley, B. and Busenitz, L. (2014), "New venture teams: a review of the literature and roadmap for future research", *Journal of Management*, Vol. 40 No. 1, pp. 226-255.

Knight, F. (1921), *Risk, Uncertainty and Profit*, Houghton Mifflin, New York, NY.

Kruschke, J., Aguinis, H. and Joo, H. (2012), "The time has come: Bayesian methods for data analysis in the organizational sciences", *Organizational Research Methods*, Vol. 15 No. 4, pp. 722-752.

Larson, A. (1992), "Network dyads in entrepreneurial settings: a study of the governance of exchange relationships", *Administrative Science Quarterly*, Vol. 37 No. 1, pp. 76-104.

Lefgren, L., Platt, B. and Price, J. (2015), "Sticking with what (barely) worked: a test of outcome bias", *Management Science*, Vol. 61 No. 5, pp. 1121-1136.

Lévesque, M., Minniti, M. and Shepherd, D. (2009), "Entrepreneurs' decisions on timing of entry: learning from participation and from the experiences of others", *Entrepreneurship: Theory & Practice*, Vol. 33 No. 3, pp. 547-570.

Lohrke, F. and Landström, H. (2012), "Examining the intellectual roots of entrepreneurship research", in Landström, H. and Lohrke, F. (Eds), *Historical Foundations of Entrepreneurship Research*, Edward Elgar Publishers, Cheltenham, pp. xiii-xxvi.

Lumpkin, G. and Dess, G. (1996), "Clarifying the entrepreneurial orientation construct and linking it to performance", *Academy of Management Review*, Vol. 21 No. 1, pp. 135-172.

McMullen, J. and Shepherd, D. (2006), "Entrepreneurial action and the role of uncertainty in the theory of the entrepreneur", *Academy of Management Review*, Vol. 31 No. 1, pp. 132-152.

Massey, C. and Wu, G. (2005), "Detecting regime shifts: the causes of under- and overreaction", *Management Science*, Vol. 51 No. 6, pp. 932-947.

Niedermayer, D. (2003), "An introduction to Bayesian networks and their contemporary applications", available at: www.niedermayer.ca/papers/bayesian (accessed July 26, 2013).

Norton, W. Jr and Moore, W. (2002), "Entrepreneurial risk: have we been asking the wrong questions?", *Small Business Economics*, Vol. 18 No. 4, pp. 281-287.

Norton, W. Jr and Moore, W. (2006), "The influence of entrepreneurial risk assessment on venture loss or growth decisions", *Small Business Economics*, Vol. 26 No. 3, pp. 215-226.

O'Leary, D. (1998), "Knowledge acquisition from multiple experts: an empirical study", *Management Science*, Vol. 8 No. 8, pp. 1049-1058.

Parker, S. (2006), "Learning about the unknown: how fast do entrepreneurs adjust their beliefs", *Journal of Business Venturing*, Vol. 21 No. 1, pp. 1-26.

Parker, S. (2013), "Do serial entrepreneurs run successively better-performing businesses?", *Journal of Business Venturing*, Vol. 28 No. 5, pp. 652-666.

Rumelt, R. (1987), "Theory, strategy, and entrepreneurship", in Teece, D. (Ed.), *The Competitive Challenge: Strategies for Industrial Innovation and Renewal*, Ballinger, Cambridge, MA., pp. 137-158.

Saboo, A. and Grewal, R. (2013), "Stock market reactions to customer and competitor orientations: the case of initial public offerings", *Marketing Science*, Vol. 32 No. 1, pp. 70-88.

Saravarthy, S. and Berglund, H. (2010), "On the relevance of decision-making in entrepreneurial decision-making", in Landström, H. and Lohrke, F. (Eds), *Historical Foundations of Entrepreneurship Research*, Edward Elgar Publishers, Cheltenham, pp. 163-182.

Shane, S. (2000), "Prior knowledge and the discovery of entrepreneurial opportunities", *Organization Science*, Vol. 11 No. 4, pp. 448-469.

Shane, S. and Venkataraman, S. (2000), "The promise of entrepreneurship as a field of research", *Academy of Management Review*, Vol. 25 No. 1, pp. 217-226.

Shepherd, D., Williams, T. and Patzelt, H. (2015), "Thinking about entrepreneurial decision making: review and research agenda", *Journal of Management*, Vol. 41 No. 1, pp. 11-46.

Sitkin, S. and Pablo, A. (1992), "Reconceptualizing the determinants of risk behavior", *Academy of Management Review*, Vol. 17 No. 1, pp. 9-38.

Stinchcombe, A. (1965), "Social structure and organizations", in March, J. (Ed.), *Handbook of Organizations*, Rand McNally, Chicago, IL, pp. 142-193.

Van den Steen, E. (2011), "Overconfidence by Bayesian rational agents", *Management Science*, Vol. 57 No. 5, pp. 884-896.

Venkataraman, S. (1997), "The distinctive domain of entrepreneurship research", in Katz, J. and Brockhaus, R. (Eds), *Advances in Entrepreneurship, Firm Emergence and Growth*, JAI Press, Greenwich, CT, pp. 119-138.

Wennberg, K., Delmar, F. and McKelvie, A. (2016), "Variable risk preferences in new firm growth and survival", *Journal of Business Venturing*, Vol. 31 No. 4, pp. 408-427.

Williamson, O. (1985), *The Economic Institutions of Capitalism*, Free Press, New York, NY.

Zyphur, M. and Oswald, F. (2013), "Bayesian estimation and inference: a user's guide", *Journal of Management*, Vol. 41, pp. 390-420.

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