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# To Be or Not to Be: The Entrepreneur in Endogenous Growth Theory

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# To Be or Not to Be: The Entrepreneur in Endogenous Growth Theory*

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**Abstract:** We examine the conceptualization of entrepreneurs in neo-Schumpeterian growth theory, which has reintroduced entrepreneurs into mainstream economics. Specifically, we analyze how neo-Schumpeterians relate to the contradiction between the entrepreneur-centered view of Schumpeter (1934) and the entrepreneurless framework of Schumpeter (1942), with the two frameworks entailing vastly different economic and policy implications. The analysis is based on a review of approximately 750 peer-reviewed articles over the period 1990–2018. The articles were identified using text mining methodology and supervised machine learning. The results show that the literature leans towards Schumpeter (1942); innovation returns are modeled as following an *ex ante* known probability distribution. By assuming that the outcomes of innovation activities are (probabilistically) deterministic, the Schumpeterian entrepreneur becomes redundant. In addition, the literature abstracts from genuine uncertainty, thus evading central issues regarding the economic function of the entrepreneur, especially with respect to disruptive innovations, ownership, and profits. To incorporate genuine uncertainty, the literature needs to adopt a broader conceptual foundation that goes beyond equilibrium modeling.

**Keywords:** creative destruction; economic growth; entrepreneur; innovation; judgment; bibliometric analysis; Knightian uncertainty

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# 1 Introduction

> *What is the problem we wish to solve when we try to construct a rational economic order? […] If we possess all the relevant information, […] and if we command complete knowledge of available means, the problem which remains is purely one of logic. This, however, is emphatically not the economic problem which society faces. And the economic calculus which we have developed to solve this logical problem […] does not yet provide an answer to it.* (Hayek, 1945)

The advent of sustained economic growth that began some two centuries ago has been crucial for the dramatic increase in human welfare compared to earlier periods in the history of our species. Understanding the causes of economic growth is therefore of enormous value. The first generation of modern growth models showed that the accumulation of factors of production could explain only a small part of growth (Solow 1957). This triggered the development of endogenous growth models in the 1980s, which added human capital accumulation and knowledge capital to the models. By assuming that some knowledge was nonrival and nonexcludable, the explanatory power was greatly increased.[1] Nevertheless, the models lacked an agent that combined and applied the new knowledge with other factors of production to generate growth. In short, the models were entrepreneurless.[2]

The first major step to introduce the entrepreneur into mainstream models of aggregate economic growth was neo-Schumpeterian growth theory, which first appeared in the early 1990s.[3] This line of economic inquiry is called "Schumpeterian" because it incorporates the process that Schumpeter (1942) termed "creative destruction", i.e., the process by which new innovations challenge and—if successful—replace existing economic structures, into a new breed of endogenous growth models.

Since its conception in the early 1990s, neo-Schumpeterian growth theory has had a considerable impact on macroeconomic research. Schumpeterian growth models have been applied to a range of economic and policy-related problems, including competition, environmental preservation, and international trade (Acemoglu 2009; Aghion and Howitt 2009; Aghion et al. 2015; Akcigit and Nicholas 2019; Hessels and Naudé 2019).

[1] The seminal articles are Romer (1986, 1990) and Lucas (1988).
[2] Schmitz (1989) is arguably an exception. In his theoretical contribution, he posits that the mechanism that drives growth consists of entrepreneurs who imitate other firms, which results in greater competition, more innovation and a higher rate of growth.
[3] The entrepreneur held a prominent role in economics for a long time. Increased formalization of mainstream theory in the 1930s made the entrepreneur disappear from the dominant paradigm based on general equilibrium theory (Baumol 1968; Barreto 1989; Hebért and Link 2007).

However, Schumpeter took two divergent views on the entrepreneur during his career. In earlier conceptualizations, Schumpeter (1934) considered the entrepreneur to be the *primus motor* of economic growth. Later in life, Schumpeter (1942) distanced himself from his earlier view and predicted that entrepreneurs would become redundant as innovations became routinized and carried out by large corporations. Following Phillips (1971), these two opposing views of innovative activities are customarily referred to as Schumpeter Mark I and Mark II, respectively (e.g., Nelson and Winter 1982; Malerba and Orsenigo 1996).

Hence, creative destruction can be modeled either with the entrepreneur at the center of analysis or with the entrepreneur having a marginal role or being altogether absent. These two conceptualizations have vastly different implications for theory and policy. However, although discussions on entrepreneurial definitions and their implications for research and policy have a long history in related fields, such discussions have been largely absent among neo-Schumpeterian growth theorists.

The aim of this article is to analyze how entrepreneurship is represented and conceptualized in neo-Schumpeterian growth with far reaching implications for theory and policy. We do this by analyzing the content of approximately 750 peer-reviewed articles on neo-Schumpeterian growth published over the period 1990–2018. The articles are identified through text mining of seminal articles and supervised machine learning. The analysis distinguishes between highly influential articles in the field ("core articles"), reviews, and other articles. In addition, two textbooks by seminal authors are analyzed. First, the use of key terminology and references to formative literature are examined quantitatively. Then, a conceptual approach is adopted to identify discussions pertaining to the entrepreneurial function and to categorize these discussions relative to Schumpeter Mark I and II.

Previous reviews of the literature on neo-Schumpeterian growth (Dinopoulos and Şener 2007; Bogliacino 2014; Shabnam 2014; Block et al. 2017) have taken entrepreneurial concepts as given and have not addressed the fundamentals of the underlying theory. Other studies have challenged the theoretical foundation of neo-Schumpeterian growth theory (Nelson 1997, 1998; Bianchi and Henrekson 2005; Acs and Sanders 2013; Johansson and Malm 2017). However, these studies have been limited in their empirical scope; they have not provided exhaustive evidence on what the literature *does* include.

We contribute to the literature in at least two ways. First, we provide the first large-scale empirical study connecting the conceptions of entrepreneurship in neo-Schumpeterian growth theory to its Schumpeterian antecedents. Second, we position the literature relative to

Schumpeter's work, thus highlighting the limitations of current discussions and pointing to potential areas of future development.

We find that the literature almost exclusively sides with Schumpeter Mark II in that innovative ventures are modeled as processes whose return is determined by an *ex ante* known probability distribution. This modeling of innovative activities renders the entrepreneur—as presented in Schumpeter Mark I—redundant in discussions of neo-Schumpeterian growth. Instead, the neo-Schumpeterian entrepreneur is a routine decision-maker who pursues business opportunities based on exogenous and *ex ante* given parameters. The literature thus abstracts from the role of non-routinized entrepreneurial decision-making under genuine uncertainty, i.e., under non-calculable risk. Genuine uncertainty is likely to be central to understanding the economic role of the entrepreneur, particularly his or her key role in the introduction of disruptive innovations.[4] Furthermore, the current literature does not relate to the key Schumpeter Mark I (1934) concept of "new combinations" when discussing entrepreneurship and innovation.

Our findings highlight a fundamental limitation of the current discourse with far-reaching implications for our understanding of how the economy works and the conduct of economic policy. Given that researchers subscribe to the notion that innovations are, at least partly, associated with genuine uncertainty, this implies that extant models of neo-Schumpeterian growth are also partly insufficient for explaining economic growth, especially in cases where it emanates from the introduction of disruptive innovations.

A potential objection to our examination is that neo-Schumpeterian growth models seek to explain and predict the macroevolution of the economy, and at the aggregate level, it may be fair to abstract from the genuine uncertainty of innovative outcomes at the micro level. However, we argue that a causal understanding is necessary to advance theory to cover previously overlooked empirical phenomena to better explain economic growth. This is likely to be particularly important for economies at the technological frontier, where the relationship between R&D output and economic growth is far from unequivocal and where there are only minor opportunities for improvements to basic institutional quality.

To extend and enrich the discussion beyond routinized innovation, our study suggests that the literature draws insights from extant discussions of genuine uncertainty and its key role in entrepreneurial activity. We believe that the discussion could benefit from incorporating insights into the extensive literature on entrepreneurship that has so far developed parallel to

[4] Schumpeter (1934) used the term "discontinuous" to denote the introduction of innovations transforming industries, whereas the term "disruptive" is mostly used currently.

neo-Schumpeterian growth theory, notably Knight (1921) and the subsequent literature emphasizing the key importance of uncertainty-bearing and judgmental decision-making (e.g., Foss and Klein 2012). By incorporating these aspects, we may gain a deeper understanding of entrepreneurship, innovation, and, ultimately, economic growth as an endogenous process.

The rest of the analysis is organized as follows. Section 2 discusses Schumpeter's two concepts of entrepreneurship. Section 3 presents the study's data and method, and Section 4 presents the results. Section 5 offers a concluding discussion.

## 2 The Schumpeterian entrepreneur

Schumpeter first laid out his theory of the economic function of the entrepreneur in German in 1911, but it took until 1934 before the work was available in English. In Schumpeter (1934), he sets out to identify the causal mechanisms that connect innovative activity to economic growth. He posits that economic growth cannot be adequately explained by increases in factors of production; in his view, long-run growth also involves *change* in the sense that the factors of production are repurposed in new and more valuable ways. Such repurposing of existing resources—the creation of "new combinations"—is carried out by the *entrepreneur*, who, consequently, is conceptualized as the *primus motor* of economic growth.[5] Since economic change is seen as an endogenous process driven by the creativity and actions of individual actors, the ability of the individual entrepreneur becomes central.[6]

Schumpeter (1934) reasoned that new ideas are only economically relevant if they are put to economic use, and the entrepreneur is seen as the primary link between new ideas and their market introduction in the form of valuable commodities. The entrepreneur identifies the potential economic uses of new ideas and realizes their economic value through commercialization, and new firm entry provides an important channel for entrants to introduce radically new ideas and to challenge existing economic structures.

New combinations translate into economic growth through a three-step process. The first step involves the conception of a novel idea, a new combination, which Schumpeter referred to as an *invention*. Once a novel and potentially profitable invention has been identified, the second step consists of identifying its potential economic uses and realizing its economic value by introducing it to the market, which is referred to as carrying out an *innovation*. When an

[5] In a well-known parable, Baumol (1968) has therefore compared leaving out the entrepreneur from the theory of the firm to leaving out the Prince of Denmark from a discussion of Hamlet.

[6] In line with this, Schumpeter (1934) argued that economic development should be confined to changes arising from within the economic system on the initiative of the economic actors and not "forced upon it from without" (p. 63).

economic use of a new combination has been identified, the third step of the process consists of spreading the innovation into the economy, which Schumpeter referred to as *dissemination*.

In describing this process, Schumpeter (1934) was careful to distinguish the role of inventors—actors who conceive new inventions—from those who identify and realize their economic value—*entrepreneurs*. This distinction is essential because it illustrates the assertion that economic change requires, in addition to novel ideas, the ability to commercialize them. This view is commonly referred to as Schumpeter Mark I.

Schumpeter defined innovation more broadly than what is typically referred to by the term in everyday language as well as in economic analysis, where innovation is most commonly thought of as emanating from R&D. However, Schumpeter maintained that this definition was too narrow and argued that innovations did not have to be of scientific origin. Rather, he envisioned innovations as taking five principal forms: the introduction of new products, the introduction of new methods of production, the opening of new markets, the conquest of new sources of supply, and new methods of organizing a firm or industry.

Later in life, Schumpeter (1942) expounded a sharply divergent view of entrepreneurship—customarily referred to as Schumpeter Mark II—in which he argued that the innovative activity of individual entrepreneurs would be gradually phased out and replaced by routinized R&D processes in large corporations.[7] A notable aspect of the thesis is that its primary intent was not to account for the process of creative destruction but rather to provide detail on the virtues of socialism. Schumpeter predicted that increased routinization of innovation would lead to the disappearance of the entrepreneurial class, which, in turn, would pave the way for a structural shift towards socialism in the West.

Innovative activity and creative destruction may thus be modeled either as having the individual entrepreneur at the center of analysis or as a process in which the entrepreneur is marginalized or even completely absent. The choice of conceptualization has far-reaching implications for how one understands the workings of the economic system and the impact of economic policy. Schumpeter Mark II, with its emphasis on large corporations and central planning, lends support to the idea of interventionism and active industrial policy to stimulate economic growth. In contrast, Schumpeter Mark I's focus on individual entrepreneurs and non-routinized innovation speaks in favor of a decentralized market economy.

Although Schumpeter's work has influenced subsequent economic thought, a shortcoming is that it largely abstracts from the roles of risk and uncertainty in economic growth. Therefore,

[7] This prediction turned out to be wrong (Acs and Audretsch 1988; Henrekson and Johansson 2010; Coad et al. 2014; Acs et al. 2017; Parker 2018).

researchers have recently begun to show increasing interest in the work of Knight (1921), who likewise argued that entrepreneurial profit is a product of innovative entrepreneurship. He thereby extended our understanding of profit and, by extension, our understanding of the nature and economic role of entrepreneurship.[8] Importantly, Knight made a distinction between risk and uncertainty: risk is probabilistically quantifiable, while uncertainty is not. Thus, Knight refers to uncertainty as events about which we know so little that we are unable to assign any probabilities. This is customarily termed Knightian uncertainty or genuine uncertainty.[9]

Building on the concepts of risk and uncertainty, Knight stipulated that entrepreneurial actions are inherently uncertain because they involve the creation of new combinations. Therefore, the outcomes of these actions cannot be known *ex ante*. Based on this premise, he argued that entrepreneurial profit cannot persist in competitive markets unless the expected value of innovative activity is also, at least in part, subjective because it would otherwise be absorbed through price adjustments of inputs in the innovation process. Consequently, the qualitative difference between entrepreneurs in the Knightian setting is conceptualized in terms of their ability to subjectively assess the viability of innovative ventures, which Knight referred to as *judgment*.

Given the conception of risk as the outcome of calculable events, Knight was also of the opinion that risk should be seen as an ordinary cost, not as a residual of the returns on innovative activity. Therefore, it should not be understood as part of entrepreneurial profit; entrepreneurial profit should only be seen as the residual returns of innovative activity *given* risk, which he denoted "pure profit". Hence, in the Knightian tradition, entrepreneurial profit refers to the specific payoff from bearing uncertainty associated with the introduction of new ideas and where he saw the pursuit of such profit opportunities as one of the key mechanisms in explaining long-run economic growth.

In contrast to Schumpeter, who asserted that employees could also fulfill the entrepreneurial function, Knight argued that entrepreneurship was inextricably linked to ownership. He based his view on three arguments. First, given that owners hold the ultimate

[8] It is noteworthy that Knight is influenced by Schumpeter; he makes a number of references to Schumpeter (1911). By contrast, Schumpeter does not refer to Knight (1921) in either of his 1934 and 1942 books. One reason could be that Schumpeter believed risk was not part of the entrepreneurial function (1934, p. 137): "The entrepreneur is never the risk bearer … Risk-taking is in no case an element of the entrepreneurial function."

[9] Recently, a third dimension—radical uncertainty— has been added to the distinction between risk and uncertainty (Hébert and Link 2007, p. 346): "Risk refers to the situation where the probability distribution of possible outcomes is calculable and known. Uncertainty refers to a situation where the possible outcomes are identifiable, but the probability distribution of outcomes is not known. Radical uncertainty refers to a situation in which the possible outcomes of a given event are unknown and unknowable." For the purpose of this study, however, it is sufficient to distinguish between risk and uncertainty.

decision-making rights, Knight inferred that owners ultimately decide whether to pursue innovation activities, including any decision to delegate this task. Second, owners are the residual claimants of the return on innovative activity; as their resources are invested, they are the ultimate bearers of uncertainty. Third, given that entrepreneurial activity is inherently uncertain, the value of entrepreneurship is also uncertain; hence, the role of ownership becomes central to understanding entrepreneurial incentives. By virtue of these three arguments, Knight suggested that unlike other factor inputs, remunerations on entrepreneurial activities cannot be determined *ex ante*, not even in a probabilistic sense, due to the inherent uncertainty associated with entrepreneurial activity. Therefore, to foster innovation and establish a "price" on entrepreneurship services in the face of uncertainty, the entrepreneur must hold a residual claim on profits, i.e., be made an owner. Hence, in the Knightian conceptualization, entrepreneurial profit and ownership serve the role of both providing incentives for entrepreneurship and a contractual solution for the pricing of the entrepreneurial function.[10]

Another framework complementary to Schumpeter's view is provided by Kirzner (1973). In contrast to Schumpeter, Kirzner envisioned the role of the entrepreneur as the actor who *restores* equilibrium by identifying existing arbitrage opportunities.[11] Moreover, he described entrepreneurship as a process of alertness and discovery, where entrepreneurs pursue objectively known arbitrage opportunities under competition.

Related to the Knightian and Kirznerian discussions on the nature of entrepreneurial activity, a strand of contemporary research studies the epistemological underpinnings of entrepreneurship by distinguishing between discovered and created business opportunities (e.g., Venkataraman 2003; Alvarez and Barney 2010; Leyden and Link 2015). Discovered opportunities are exogenously existing opportunities whose intrinsic value can be objectively assessed by actors *ex ante*. In contrast, created opportunities are endogenously created by entrepreneurs based on their subjective valuations and cognitive abilities, and the market value of these opportunities is continuously realized by the entrepreneurs through a process of trial-and-error whereby their intrinsic value only becomes manifest *ex post*.

The distinction between discovered and created opportunities provides a framework for understanding both the nature of business opportunities and the entrepreneurial skills needed to pursue them. By applying the concepts of discovered and created business opportunities, it is

[10] Researchers often refer to the function of the Knightian entrepreneur as an actor that "bears uncertainty." However, this definition obscures the fundamental role ascribed to ownership in Knight's framework.
[11] Despite differences in their theoretical approaches, Kirzner explicitly envisioned his entrepreneurial framework as complementary to that of Schumpeter (e.g., Kirzner 2009).

possible to gain insight regarding the position of the neo-Schumpeterian entrepreneur relative to the frameworks of Schumpeter Mark I and II. Specifically, when prospective innovative ventures are assumed to be based on discovered opportunities, i.e., when ventures are modeled as taking calculable risks, theory inadvertently assigns a central role to routinized investments and calculated risk preferences in firms for determining innovation and economic growth, which is in line with Schumpeter Mark II. In contrast, when innovative ventures are assumed to be based on created opportunities, i.e., when opportunities are genuinely uncertain, theory assigns a central role to the non-routinized decision-making of individual entrepreneurs, which is in line with Schumpeter Mark I.[12]

# 3 Method and data

## *3.1 Identifying the population*

We follow Aghion and Howitt (2009) and Acemoglu (2009) and date the conception of neo-Schumpeterian growth theory to 1990 based on the publication of Segerstrom et al. (1990) and Aghion and Howitt (1990). As a result, the empirical focus of the article is confined to peer-reviewed articles dated between 1990 and 2018.

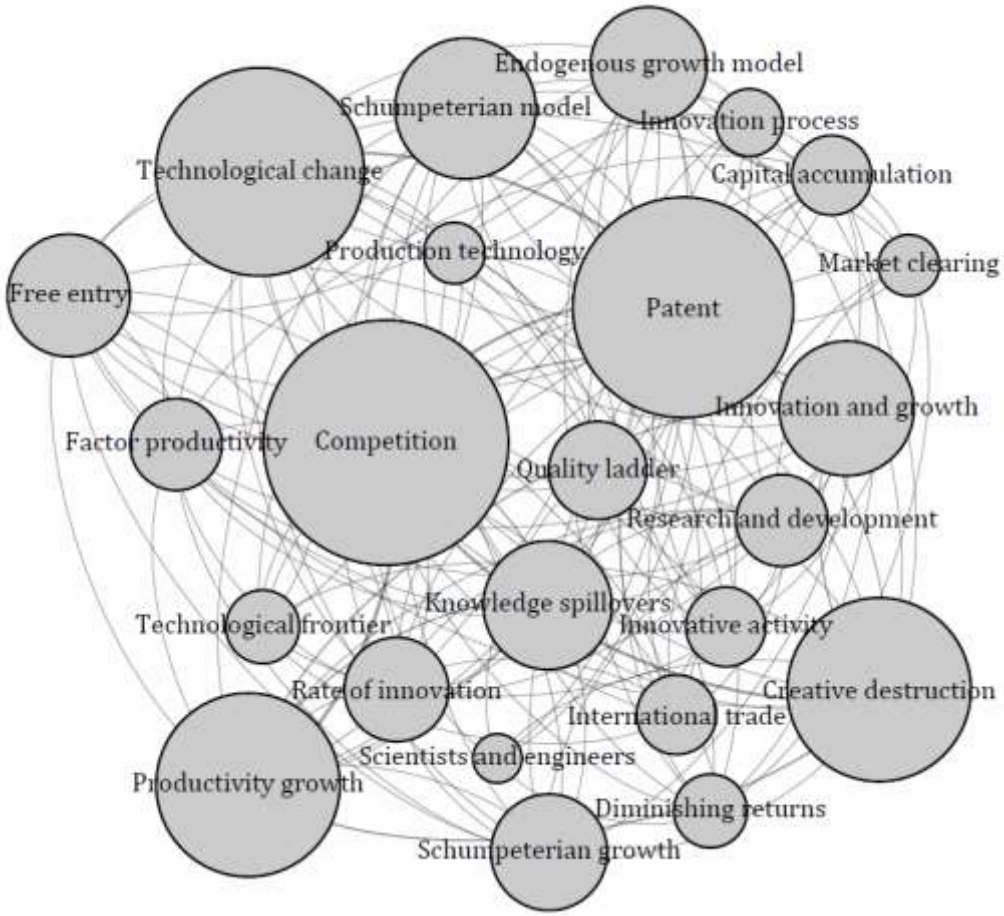
To facilitate the process of identifying the field, a number of influential—or core—articles were reviewed to capture relevant terminology (Cooper 2003; Torraco 2005; Green et al. 2006). Articles were chosen based on the reviews by Acemoglu (2009), Aghion and Howitt (2009), Aghion et al. (2015) and Akcigit and Nicholas (2019). This exercise yielded an initial dataset of 45 publications.[13] Next, the content of these articles was analyzed to capture pervasive terminology across the articles by using text mining tools; see Appendix B.[14] As shown in Figure 1, the most common terms and phrases across the identified core articles are, for example, competition, productivity, and technological change.[15] In contrast, a striking feature of Figure 1 is the absence of the terms entrepreneur and/or entrepreneurship.

Once the core terminology across articles was identified, combinations of key terms and auxiliary terminology were selected based on within-article co-occurrences. The resulting search strings were then inserted into *CrossRef*, *Google Scholar*, *Scopus*, and the *Web of Science*. The initial search process yielded a total of 22,838 unique results.[16] All publications

[12] Although not further elaborated in this paper, there exist a number of suggestions to synthesize different views of the entrepreneurial function, e.g., Casson (1982, p. 20), Henrekson and Stenkula (2016, p. 71), Wennekers and Thurik (1989, p. 46–47), and Hebért and Link (1989, p. 47).
[13] A list of surveyed articles is presented in Appendix A.
[14] In this exercise, generic words and phrases have been omitted based on an extensive third-party dictionary.
[15] Similar discussions are also pervasive among lower-ranked terminology.
[16] These results were also cross-referenced against articles that cite core literature.

without a timestamp were excluded due to difficulties in determining their publication date (2,403 observations, 11 percent), and all non-English publications were omitted (2,828 observations, 12 percent).

Figure 1. Co-occurrence of the most common terminology across influential articles on neo-Schumpeterian growth, 1990–2018.




*Note:* Results of co-occurrence analysis of article terminology. The 30 most common phrases and words in neo-Schumpeterian growth articles, measured in terms of article occurrences.[ψ] Articles were selected based on the reviews of Acemoglu (2009), Aghion and Howitt (2009), Aghion et al. (2015) and Akcigit and Nicholas (2019). Search terms were separated from generic macroeconomic terms macroeconomics, such as "steady state" and "general equilibrium". Terminology was stemmed to account for different connotations. Weighted by number of article occurrences.

"Schumpeterian model" encompasses the phrase "Schumpeterian growth model"; "Technological change" encompasses the phrase "Technical change"; "Factor productivity" encompasses the phrase "Total factor productivity".

[ψ] Lower-ranked terminology covers similar discussions.

By applying the above constraints, an initial dataset was obtained consisting of 17,607 papers, including 6,517 peer-reviewed articles (37 percent), 2,506 working papers (14 percent), 1,169 discussion papers (7 percent), 30 policy papers (0.1 percent), 718 doctoral theses (4 percent) and 6,667 works published outside official academic series, such as preliminary drafts and

reports (38 percent). We included unpublished works to account for publication bias (Cooper et al. 1997; Lipsey and Wilson 2001).[17]

Despite efforts to refine the search strings, however, the obtained data were still likely to contain inconsistencies. Specifically, terminology used in neo-Schumpeterian growth is also used in related endogenous growth models as well as in Austrian and evolutionary economics. Therefore, to accurately identify the target literature, all articles were subjected to text analyses using a bag-of-words approach and categorized using a random forest algorithm (e.g., Breiman 2001).[18] This process consisted of manually reviewing a random sample of articles with which to train the algorithm in identifying neo-Schumpeterian articles. Next, in an iterative process, articles identified by the algorithm were manually reviewed and included as training data until the algorithm could not identify any additional entries as belonging to the target population. This strategy yielded a final population of 754 peer-reviewed articles featuring neo-Schumpeterian growth models. A detailed description of the identification process can be found in Appendix B, and a complete list of identified articles is presented in the Online appendix.

### *3.2 Text analysis*

Once the literature was identified, all peer-reviewed articles were manually surveyed to review their coceptualizations of the entrepreneur. Moreover, to characterize the literature, all articles were subjected to a word search for terms related to the work of Schumpeter as well as the complementary work of Knight (1921) and Kirzner (1973). To capture terminology related to all of the above works, articles were searched for the occurrence of the terms "entrepreneur" and "innovation". Next, to capture terminology related to Schumpeterian discussions, articles were also searched for the terms "creative destruction", "new combinations", "invention", "inventor", and "innovator". Moreover, to capture discussions by Knight (1921) and Kirzner (1973), articles were searched for the terms "alertness", "genuine uncertainty", and "judgment".[19] Finally, articles were searched for direct references to Schumpeter (1934, 1942), Knight (1921) and Kirzner (1973). To manage inconsistencies in formulations across texts, all search strings were applied using *n*-gram approximate or "fuzzy" string matching (e.g., Pfeifer et al. 1996).

[17] To ensure text legibility, all articles were processed using text recognition algorithms, so-called Optical Character Recognition (OCR).

[18] Bag-of-words refers to the process of decomposing texts and counting the number of instances of each distinct word represented within them.

[19] Results for "genuine uncertainty" also encompass the terms "radical uncertainty" and "Knightian uncertainty". Searches for terminology related to Schumpeter (1934, 1942), Knight (1921) and Kirzner (1973) are restricted to text bodies to capture only explicit mentions of these concepts. In practice, this does not affect the results.

# 4 Results

In this section, the use of entrepreneurship constructs in neo-Schumpeterian growth research is analyzed and positioned relative to Schumpeter Mark I and Mark II. First, article contents are surveyed for terminology use and literature references related to Schumpeter (1934, 1942) and the complementary frameworks of Knight (1921) and Kirzner (1973). Then, theoretical conceptualizations of the entrepreneur and his/her roles in innovative activity are qualitatively reviewed across articles.

## *4.1 Descriptive results*

Table 1 presents the use of Schumpeterian terminology related to Schumpeter (1934, 1942) as well as the complementary frameworks of Knight (1921) and Kirzner (1973). In addition, the table reports the number and share of articles that include direct citations to Schumpeter (1934, 1942), Knight (1921) and Kirzner (1973). In an effort to capture seminal discussions in the literature, the results are presented across the categories "core articles", "review articles", "textbooks", and "other articles".

The table reports that 31 percent of all articles mention the term "entrepreneur", whereas almost all include the term "innovation".[20] Rather than using the term "entrepreneur", the literature is found to use the term "innovator", which is represented in almost half of all articles.[21] This usage is likely to result from the terminology used in early papers, such as Aghion and Howitt (1992), to signify actors that pursue innovative activity. Notably, the term "entrepreneur" does not appear in any of the seminal articles of Segerstrom et al. (1990), Aghion and Howitt (1992), and Grossman and Helpman (1993), and it was not until later that the term appeared in the overall literature. Early contributions are represented around the genesis of the literature, such as Boyer (1991) or Cheng and Dinopoulos (1992).[22] However, it would take until the mid-2000s for the first emergence of this term in an article that spurred a significant number of subsequent studies (i.e., Aghion et al. 2005).

The concepts of "invention" and "inventor", which are central in Schumpeter Mark I, are found in approximately one-third versus one-fourth of all articles. In this case, it could also be noted that the early articles as well as the review articles exclude these terms. Moreover, the few references made to "new combinations" use the term only to position the presented discussions relative to Schumpeterian terminology, whereas none apply the concept to the

[20] The remaining articles use the term "technology" rather than "innovation" to discuss innovative growth.
[21] The two terms are weakly complementary; approximately 20 percent of the articles use both "entrepreneur" and "innovator".
[22] A single statement on "firms or entrepreneurs" is also made by Grossman and Helpman (1994). However, this statement is not expanded upon.

analysis (Stein 1997; Olsson 2000, 2005; Albaladejo and Martínez-García 2015; Murakami 2017).[23]

Table 1. The number and share (%) of peer-reviewed articles and textbooks that include direct citations and terminology related to Schumpeter Mark I and II, Knight (1921), and Kirzner (1973), 1990–2018.

| | (1) Core articles | | (2) Review articles and textbooks | | (3) Other articles | | (4) Total | |
|---|---|---|---|---|---|---|---|---|
| | Number | Share | Number | Share | Number | Share | Number | Share |
| *Key terminology* | | | | | | | | |
| Creative destruction | 22 | 49 | 4 | 100 | 328 | 43 | 354 | 44 |
| Entrepreneur | 15 | 33 | 3 | 75 | 233 | 30 | 251 | 31 |
| Innovation | 45 | 100 | 4 | 100 | 706 | 93 | 755 | 94 |
| Innovator | 28 | 62 | 2 | 50 | 364 | 48 | 394 | 49 |
| Invention | 18 | 40 | 2 | 50 | 252 | 33 | 272 | 34 |
| Inventor | 17 | 38 | 2 | 50 | 190 | 25 | 209 | 26 |
| New combination | 1 | 2 | 0 | 0 | 12 | 2 | 13 | 2 |
| Uncertainty | 17 | 38 | 2 | 50 | 200 | 26 | 219 | 27 |
| Risk | 23 | 51 | 3 | 75 | 385 | 51 | 411 | 51 |
| Genuine uncertainty | 0 | 0 | 0 | 0 | 9 | 1 | 9 | 1 |
| Judgment | 0 | 0 | 0 | 0 | 6 | 0.8 | 6 | 1 |
| Alertness | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Literature references* | | | | | | | | |
| Schumpeter (1934) | 0 | 0 | 2 | 50 | 48 | 6 | 50 | 6 |
| Schumpeter (1942) | 4 | 9 | 2 | 50 | 49 | 6 | 55 | 7 |
| Knight (1921) | 0 | 0 | 0 | 0 | 2 | 0.2 | 2 | 0.2 |
| Kirzner (1973) | 0 | 0 | 0 | 0 | 1 | 0.1 | 1 | 0.1 |
| Total | 45 | 6 | 4 | 0.5 | 754 | 94 | 803 | - |

*Note*: The category "genuine uncertainty" also encompasses the terms "Knightian uncertainty", "true uncertainty" and "radical uncertainty". See Appendix A for "Core articles". "Review articles" are Aghion et al. (2015) and Akcigit et al. (2019). "Textbooks" are Acemoglu (2009) and Aghion and Howitt (2009). "Other articles" are presented in the online appendix. The terms "entrepreneur" and "innovator" are weakly complementary: approximately 20 percent of articles use both terms.

Next, by studying references to Schumpeter (1934) and (1942) [Schumpeter Mark I and Mark II], the results in Table 1 again suggest that the literature primarily relies on the work of Schumpeter Mark II. The two works are cited in 6 versus 7 percent of articles, respectively.[24]

[23] Curiously, prominent articles published in top economics journals that are contemporary with neo-Schumpeterian growth discussions have actually taken steps to introduce new combinations in models of economic growth (e.g., Weitzman 1998). However, these propositions have seemingly not been implemented in the neo-Schumpeterian tradition.

[24] The relatively low share of articles that cite any of Schumpeter's works is notable because it suggests that the literature is only weakly reliant on the original Schumpeterian literature.

Moreover, no core articles make a single reference to Schumpeter (1934), including the early articles of Aghion and Howitt (1992), Segerstrom et al. (1990) Grossman and Helpman (1993). This strengthens the conjecture that neo-Schumpeterian growth theory is primarily oriented towards Schumpeter Mark II.

There are three observations that stand out in Table 1. First, given the large difference in the share of articles that include the term "innovation" compared to the terms "entrepreneur" and "innovator", the focus of neo-Schumpeterian analyses is primarily innovation per se and not the actor(s) who conduct(s) it. This implies reliance on Schumpeter Mark II rather than Schumpeter Mark I. Since the latter views the entrepreneur as the *persona causa of* innovative growth, the exclusion of these terms indicates that Schumpeter Mark I is not applied.

Second, turning to the frameworks of Knight (1921) and Kirzner (1973), the literature frequently refers to the concepts of "risk" and "uncertainty". These terms are also central to Knight (1921). However, a qualitative analysis suggests that these terms are used interchangeably rather than denoting two separate constructs. Similarly, only approximately one percent of all articles include discussions using the key Knightian concepts "genuine uncertainty", "Knightian uncertainty", "radical uncertainty", "true uncertainty", and "judgment", and no articles include the Kirzernian concept of "alertness". Finally, Knight (1921) is cited in only two articles.[25] Kirzner (1973) is cited in one single article, Sanders and Weitzel (2012), who also apply this framework in their modeling. Given the small number of occurrences, these observations strongly suggest that the overall neo-Schumpeterian literature to date has not incorporated insights from Knight (1921) or Kirzner (1973).[26]

### *4.2 Conceptual analysis*

By examining the prevalence of key terms and references related to formative literature on entrepreneurship, the analysis in Section 4.1 offers a preliminary understanding of the orientation of neo-Schumpeterian analyses relative to Schumpeter Mark I and Mark II. We will now proceed to a qualitative assessment of the literature by reviewing the boundaries of entrepreneurial conceptualizations across articles.

[25] These are Cantner et al. (2009) and Heertje (1995). Cantner et al. only mention Knight (1921) as a seminal contribution. Heertje explicitly recognizes limitations in its theoretical neo-Schumpeterian framework with respect to the omission of genuine uncertainty.

[26] In line with Kirzner (1973) the literature includes some discussions on entrepreneurial opportunity. However, most of these discussions are not clearly positioned relatively to the entrepreneur and its role in identifying opportunities, but rather the emergence of business opportunities as a result of, for example, recessions (e.g., Aghion and Saint-Paul 1998; Caballero and Hammour 2005; Aghion et al. 2009; Pardo 2016). Upon examination, two articles are found to include notions of business opportunities that are comparable to the Kirznerian formulation (Olsson 2005; Sanders and Weitzel 2012).

In reviewing the literature, two common elements were identified that have implications for the neo-Schumpeterian articles' orientation relative to Schumpeter Mark I and Mark II: the nature of innovative activity and the role of the entrepreneur in identifying the economic uses of novel ideas and the realization of their economic value. First, the entrepreneurial function in neo-Schumpeterian growth theory is modeled as the pursuit of R&D investments in search of *ex ante* calculable monopoly rents (e.g., Aghion et al. 2015). The entrepreneur is thus conceptualized as a decision-making agent in an intermediate sector firm that is responsible for allocating firm resources between two activities: production and R&D. This conceptualization is silent about the role the entrepreneur within the firm, i.e., whether the role can be fulfilled by a manager or whether it refers to the owner(s) of a firm. A second common element of the literature is the conceptualization of innovative outcomes. Throughout the literature, it is assumed that returns on innovative investments follow an *ex ante* and objectively known probability distribution. The expected costs and returns of innovations are objectively calculable, and the value and economic uses of innovations are known once a new product or technology has been developed. Hence, the innovation concept is reminiscent of the concept of discovered opportunities.[27]

By assuming that innovations can be objectively valued and by depicting the entrepreneur as an actor whose economic function is to invest in calculable outcomes, the role of the neo-Schumpeterian entrepreneur is relegated to the role of a routine decision-maker in pursuit of discoverable business opportunities. This implies that neo-Schumpeterian economic modeling closely resembles the entrepreneurless growth process of Schumpeter Mark II rather than the entrepreneur-centered view of Schumpeter Mark I. Nevertheless, the current framework may still be suitable for describing incremental quality improvements of established products or services where the potential payoffs on investments are partly or wholly calculable, i.e., what neo-Schumpeterians commonly refer to as "quality ladders".[28]

Moreover, when the profitability of R&D investments is modeled as being exogenously determined once they are undertaken, the innovative process becomes of subordinate interest, which explains why the literature does not elaborate on the different stages of economic development: invention, innovation, and dissemination, i.e., the processes that connect the conception of a new idea to its subsequent market introduction and dissemination in the

[27] In a supplementary analysis, we find zero occurrences of the terms "discovered opportunities" and "created opportunities".

[28] These types of incremental innovations, that can be understood as taking place once a scientific paradigm has been established, have also been referred to as "puzzle-solving" or "mopping-up" operations (Olsson 2000; Olsson 2005).

economy. This constitutes yet another departure from Schumpeter Mark I.[29] Likewise, discussions of different types of innovations and their relative importance are largely absent.

Hence, the neo-Schumpeterian framework in its current stage of development is likely to be *ineffective* in capturing innovation and entrepreneurship in cases where innovative outcomes are non-routinized and non-calculable, i.e., in cases where they are characterized by Knightian uncertainty. In turn, Knightian uncertainty is likely central to forming an understanding of the antecedents of disruptive innovations and entrepreneurship. To the extent that researchers subscribe to the notion that disruptive innovations and high-impact entrepreneurship are important for explaining modern economic development, this implies a need for a different conceptualization of innovation-driven growth.

A model of endogenous growth under genuine uncertainty must incorporate the fact that many—perhaps most—innovations do not have objectively known outcomes against which their costs can be weighed. Entrepreneurs do not know the value of an idea until after its realization. Instead, its pursuit is determined by the *subjective* valuations and judgment-based decisions of individual entrepreneurs. Hence, given genuine uncertainty, entrepreneurs cannot rely on objective knowledge on the final economic uses of ideas or of their expected economic value. They must retain an active role in identifying the economic uses of innovations and appropriating their economic value, as the entrepreneur of Schumpeter Mark I. In contrast to neo-Schumpeterian growth models, this implies that the focus of analysis is directed towards the process of invention, innovation, and dissemination.

At the same time, introducing incalculability and subjectivity into the economic models does *not* imply that innovative outcomes are driven solely by chance and subjectivity. Rather, Knight (1921) stresses the central role of the knowledge, experience, and innate abilities of entrepreneurs in the selection and outcome of disruptive innovations, i.e., what he refers to as "judgment". For example, it is likely that the tacit knowledge gained from past experiences of creating and exploiting innovations is a core element of entrepreneurial acumen. Superior judgment may explain why some entrepreneurs consistently retain a competitive advantage over time (Alvarez and Busenitz 2001; Alvarez and Barney 2010). Moreover, performance and profits may derive from the ability of founding entrepreneurs to build efficient organizational structures that are capable of sustaining competitive advantages through continuous innovation and adaption to changed circumstances (cf. Alvarez and Busenitz 2001). In line with Knight

[29] Taking stock of Schumpeter (1934), recent literature elaborates on the actors with different but complementary competencies required to generate rapid economic development, e.g., Johansson (2010); Elert and Henrekson (2020).

(1921), these high-impact entrepreneurs also illustrate that ownership is intertwined with entrepreneurship and that remuneration to entrepreneurs—pure profit—emerges from bearing uncertainty as a residual claimant. In contrast, in the absence of uncertainty, ownership itself is unnecessary because any actor can simply contractually compose the required control over assets and obtain the foreseen returns (Foss et al. 2021). Finally, genuine uncertainty may also help to explain the failure of previously successful entrepreneurs because they can never fully anticipate the value of a novel idea.

Despite criticism from related fields, a notable finding is that the conceptual limitations of the neo-Schumpeterian entrepreneur have not been addressed so far within the literature. In fact, during the literature review process, no instances of critical discussions related to the entrepreneurial construct were identified. At the same time, recent neo-Schumpeterian work explicitly acknowledges the disparity between core measures of R&D (patent output) and economic growth (Aghion et al. 2019). This may signal an increasing awareness in the literature that its workhorse models are currently lacking key determinants. Therefore, the recent models constitute a significant step towards a more realistic conceptualization of the economy. In effect, neo-Schumpeterian growth models have reintroduced the entrepreneur to the core of mainstream economics, and the neo-Schumpeterian literature has contributed to an increased focus on economic history to further our understanding of how institutions and policy facilitate or impede creative destruction (Acemoglu and Robinson 2012).

A potential objection to our examination is that neo-Schumpeterian growth models seek to explain and predict the macroevolution of the economy, and at the aggregate level, it may be fair to abstract from the genuine uncertainty of innovative outcomes at the micro level. Although the validity of this assertion is debatable per se, this line of reasoning is also likely to be flawed in at least two respects. First, given that economics seeks to explain the *causes* of economic growth, a deeper causal understanding is necessary. Second, economists aspire to provide reliable policy advice. In turn, the adequacy and precision of policy proposals hinges on a good causal understanding of the growth process and its microeconomic foundations. The above points are likely to be particularly relevant for economies at the technological frontier, such as the U.S. and Western Europe, where the causality between R&D output and economic growth is already marginal (Aghion et al. 2019) and where there are only marginal opportunities for improvements to basic institutional quality, such as enabling free entry, securing property rights, or increasing accessibility to higher education.

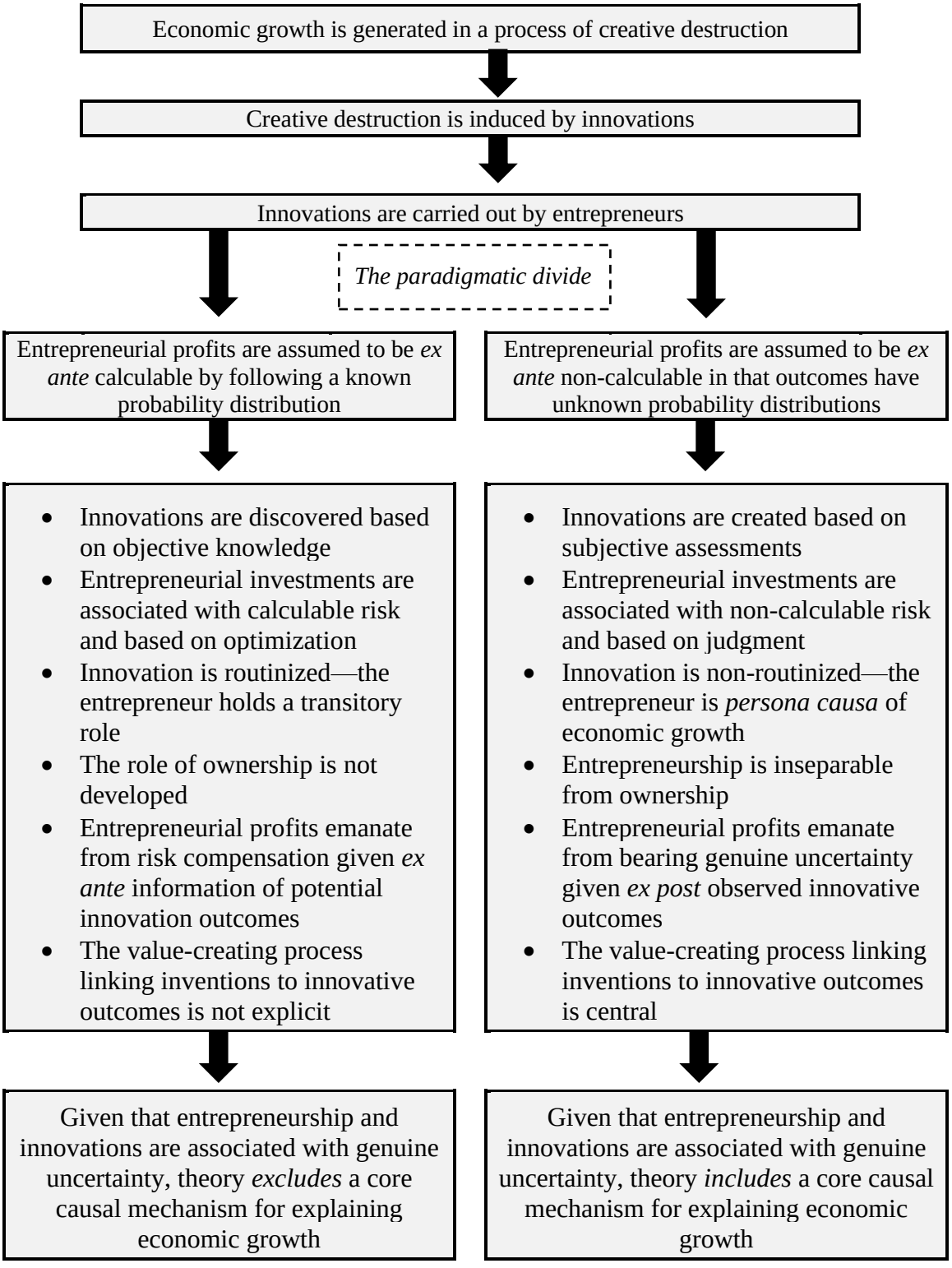
A broader understanding of the growth process may lead research onto previously unexplored paths that will increase the explanatory power of the theory. For instance, the

existence of substantial transaction costs caused by genuine uncertainty may help explain the global prevalence of family ownership and where family firms account for a substantial share of employment and growth (Andersson et al 2018). This is likely to have significant macroeconomic implications as family firms have been found to systematically deviate from the standard assumptions of firm behavior.[30] Hence, by better understanding the interplay between entrepreneurship, ownership, firm organization, and innovation, growth theory may be augmented in ways that enhances both its predictive power and usefulness for policy analysis.

The presented discussion may lead researchers to raise the question, "*Why* don't current neo-Schumpeterian models incorporate genuine uncertainty?" The explanation is likely linked to the theoretical and methodological approach of the literature and, specifically, to the prevalence of equilibrium modeling in the field (Hébert and Link 2007). The rationale behind this assertion is the fact that equilibrium is fundamentally incompatible with genuine uncertainty; this suggests a need for a more pluralistic methodological approach (Hébert and Link 2007). In the presence of uncertainty, an equilibrium or "optimum" output of innovative activities cannot be objectively defined. Hence, to yield a richer and more inclusive theory of entrepreneurship and economic growth, a more inclusive approach to economic theory and methodology is needed. Figure 2 summarizes the main points of the analysis.

[30] In a supplementary analysis we find no occurrences of the terms "family business", "family control", or "family firm" (Johansson et al. 2020).

Figure 2. The paradigmatic divide in entrepreneurial frameworks.




## 5 Concluding remarks

This study explores the position of the neo-Schumpeterian entrepreneur relative to Schumpeter Mark I and II, i.e., Schumpeter (1934), where the entrepreneur is the *persona causa* of

innovation and economic growth, and Schumpeter (1942), where the entrepreneur is envisaged as becoming superfluous. This is accomplished by quantitatively reviewing the terminology applied in neo-Schumpeterian growth theory and by qualitatively reviewing neo-Schumpeterian conceptualization of entrepreneurship and innovation. The analysis is based on almost 750 peer-reviewed articles on neo-Schumpeterian growth published over the years 1990–2018.

By quantitatively analyzing the literature, we find that less than one-third of all articles include the term "entrepreneur" and less than two percent mention Schumpeter's key concept "new combinations", and then only to position their discussion relative to Schumpeterian terminology. Our analysis of reference lists shows that less than one-tenth of articles include references to either Schumpeter (1934) or Schumpeter (1942). Rather, the literature adheres closely to its roots in endogenous growth theory, which abstracts from the Schumpeterian entrepreneur. Similarly, Frank Knight and Israel Kirzner, who are, in addition to Schumpeter, the most influential scholars on contemporary entrepreneurship research, are absent from the examined literature.[31] Only three out of 754 articles mention either Knight or Kirzner, and only two of these discuss implications for entrepreneurial decision-making. As a corollary, the related concepts of judgment, genuine uncertainty, and alertness are not discussed.

Our qualitative analysis of the literature's conceptualizations of entrepreneurship and innovation reveals two common themes. First, the neo-Schumpeterian entrepreneur is defined based on his/her role as an undertaker of innovative investments, notably in terms of R&D. Second, the outcome of innovative activity is assumed to follow an *ex ante* and objectively known probability distribution; hence, the expected costs and benefits of innovative ventures are assumed to be *ex ante* calculable.

By assuming that the expected value of innovative activity is fully calculable, the economic role of the neo-Schumpeterian entrepreneur is reduced to that of a routine decision-maker. As a result, the disruptive role of the Schumpeter Mark I entrepreneur becomes redundant. This conclusion is strengthened by the fact that references to Schumpeter (1934) are rare and that the articles do not use the terminology associated with Schumpeter's early work, including the concept of "new combinations".

When innovations are modeled as discovered opportunities whose expected value is exogenously given, analysis of the value-creating process becomes unnecessary. This includes the different stages of economic development, i.e., the processes that connect the conception of

[31] One single paper out of 754 cites Knight and recognizes the limitations of using *ex ante* calculable risk rather than genuine uncertainty to conceptualize potential innovative outcomes: Heertje (1995). Two papers cite either Knight or Kirzner as seminal contributions: Cantner et al. (2009) and Sanders and Weitzel (2012), respectively.

a new idea to its subsequent introduction and market dissemination. This abstracts from the distinction between the inventive and entrepreneurial functions, which is a further digression from Schumpeter Mark I. Relatedly, the assumption that the value of a given innovation is objectively and *ex ante* calculable may partially explain the seeming lack of diversity in terms of how innovative ventures are currently modeled. As a result, other types of innovations discussed in Schumpeter (1934), such as the creation of new or improved organizational structures with the ability to generate and exploit innovations through time, become less relevant. This also explains why discussions of ownership and the nature of entrepreneurial skills are so scarce.

In contrast to the neo-Schumpeterian conceptualization of the innovation process, a key component of the innovation process of Schumpeter Mark I consists of the value generation process undertaken by entrepreneurs in the absence of calculable outcomes. In this process, the value of a new idea is endogenously imputed based on the subjective valuation of the entrepreneur and, over time, through its dissemination in the marketplace.

By assuming that returns on innovative activity are *ex ante* calculable, the neo-Schumpeterian conceptualization of economic growth precludes genuine uncertainty, disregarding that this is a pervasive characteristic of business life. By re-introducing the entrepreneur into mainstream growth models, neo-Schumpeterian growth theorists also need to address what is arguably the most fundamental characteristic of the entrepreneurial function, namely, bearing uncertainty. More generally, the reemergence of entrepreneurship evokes theoretical and methodological issues that leading mainstream economists have avoided for a long time, such as the nature of knowledge and information and the validity of equilibrium modeling for capturing the workings of the economy.

To conclude, although bearing genuine uncertainty is an important part of entrepreneurship, neo-Schumpeterian growth theory has thus far not properly addressed the entrepreneurial function and its remuneration. This suggests a pressing need for the field to extend its current theoretical and methodological boundaries to confront and challenge a number of its core results regarding the causal mechanisms that connect entrepreneurship to innovation and economic growth.

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## Appendix A: Core articles


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## Appendix B: Identification process and search terminology

To identify the neo-Schumpeterian literature, a set of 45 core articles was selected based on the reviews of Acemoglu (2009), Aghion and Howitt (2009), Aghion et al. (2015) and Akcigit and Nicholas (2019). Once identified, all articles were subjected to text mining analysis in which the frequencies of different word combinations were analyzed across articles, covering all combinations consisting of up to five words. In this study, an extensive dictionary of generic English phrases was utilized to omit irrelevant entries, such as "this study shows".

Once the core terminology across articles was identified, co-occurrences related to each of the identified terms were extracted to capture auxiliary terminology. By analyzing co-occurrences, we found that the identified terminology is strongly interrelated. Moreover, most articles use similar auxiliary terminology, such as "growth rate", "economic growth", "technological change", and "steady state". This high degree of overlap of terminology suggests that the selected articles emanate from the same literature.[32] Once core and auxiliary terminology were identified, the resulting words and phrases were combined to build search strings to be used in bibliometric databases.

After extracting the most frequently used terminology across influential articles as identified by seminal authors in the field, the resulting search strings were inserted into *CrossRef*, *Google Scholar*, *Scopus*, and the *Web of Science*. The initial search process yielded a total of 22,838 unique results.[33] All publications without a timestamp were excluded due to difficulties in determining their publication date (2,403 observations, 11 percent), and all non-English publications were omitted (2,828 observations, 12 percent).

By applying the above constraints, an initial dataset was obtained consisting of 17,607 papers, including 6,517 peer-reviewed articles (37 percent), 2,506 working papers (14 percent), 1,169 discussion papers (7 percent), 30 policy papers (0.1 percent), 718 doctoral theses (4 percent) and 6,667 works published outside official academic series, such as preliminary drafts and reports (38 percent). We included unpublished works to account for publication bias (Cooper et al. 1997; Lipsey and Wilson 2001).[34]

[32] The resulting search strings can be found in Table B1 below.
[33] These results were also cross-referenced against articles that cite core literature.
[34] To ensure text legibility, all articles were processed using text recognition algorithms, so-called Optical Character Recognition (OCR).

Despite efforts to refine search strings, the obtained data were still likely to contain inconsistencies. Specifically, terminology used in neo-Schumpeterian growth is also used in related endogenous growth models as well as in Austrian and evolutionary economics. Therefore, to accurately identify the target literature, all articles were subjected to text analyses using supervised machine learning. All article texts were decomposed using a bag-of-words approach and categorized using a random forest algorithm (e.g., Breiman 2001).[35] To provide an initial training set, a random subsample constituting ten percent of the full dataset was drawn, and observations were stratified by their year of publication. Articles were then categorized as follows:

$$Population_i = \begin{cases} 1 \; if \; article \; i \; \in target \; population \\ 0 \; if \; article \; i \; \notin target \; population \end{cases}. \quad (1) \quad (1)$$

The random forest algorithm was trained by growing trees based on the terminology use of each article in the training set. Random forest classifiers are likely to be biased towards the majority class in the training set. Therefore, to facilitate accurate identification of the intended literature, the training dataset was balanced using random undersampling.[36] This was then estimated with the following model:

$$h(Population_i, \Theta_k), \quad s.t. \; \text{argmin} \, [1 - \textstyle\sum_{M=1}^{2}(p_M^2)], \quad (2)$$

where $[1 - \sum_{M=1}^{2}(p_M^2)]$ is the Gini impurity of each tree and $[\Theta_k]$ is a set of $k = 5{,}000$ independently and identically distributed random vectors drawn on the absolute frequencies of j distinct words across a random sample of $\sqrt{N}$ observations. Next, the algorithm was trained to identify the intended literature, and the resulting framework was used to classify observations across the full population based on the majority ruling across decision trees.

To provide an initial training set, a random subsample constituting ten percent of the full dataset was drawn, and observations were stratified by their year of publication. Articles were then categorized as follows:

[35] Bag-of-words refers to the process of decomposing texts and counting the number of instances of each distinct word represented within them.

[36] Competing techniques include cost-sensitive learning, random oversampling and synthetic minority oversampling (SMOTE). Cost sensitivity has been found to yield similar or even lower accuracy to that of undersampling, whereas it significantly increases computational requirements; random oversampling and SMOTE have been found to yield lower performance in sparse data (Weiss et al. 2007; Blagus and Lusa 2013).

$$Population_i = \begin{cases} 1 \; if \; article \; i \; \in target \; population \\ 0 \; if \; article \; i \; \notin target \; population \end{cases}. \quad (3)$$

The random forest algorithm was trained by growing trees based on the terminology use of each article in the training set. Random forest classifiers are likely to be biased towards the majority class in the training set. Therefore, to facilitate accurate identification of the intended literature, the training dataset was balanced using random undersampling. This was then estimated with the following model:

$$h(Population_i, \Theta_k), \quad s.t. \; \text{argmin} \left[ 1 - \sum_{M=1}^{2} (p_M^2) \right] \quad (4)$$

where $[1 - \sum_{M=1}^{2}(p_M^2)]$ is the Gini impurity of each tree and $[\Theta_k]$ is a set of $k = 5{,}000$ independently and identically distributed random vectors drawn on the absolute frequencies of j distinct words across a random sample of $\sqrt{N}$ observations.[37] Next, the algorithm was trained to identify the intended literature, and the resulting framework was used to classify observations across the full population based on the majority ruling across decision trees. Finally, once the initial algorithm was trained and a prediction was produced, all observations that fell above the prediction threshold were manually reviewed in an iterative process, after which the previous steps were once again executed. This process was repeated until no additional documents were identified by the algorithm. The performance of the final algorithm was gauged using 50-fold cross validation with *k*-fold cross-validation, which is a conventional metric for evaluating the performance of machine learning algorithms (e.g., Hastie 2001).[38] In this process, all quantiles of the data were systematically cycled through and excluded from the training set. It was then used to test the predictive accuracy of the algorithm based on predictions yielded from the remaining $k - 1$ quantiles at all $q$ distinct voting scores. In equivalence to the main process, these models were tested using $k = 5{,}000$ trees.[39] The outcome of this process is presented in the form of a receiver operating characteristic curve (ROC) in Figure B1 below.

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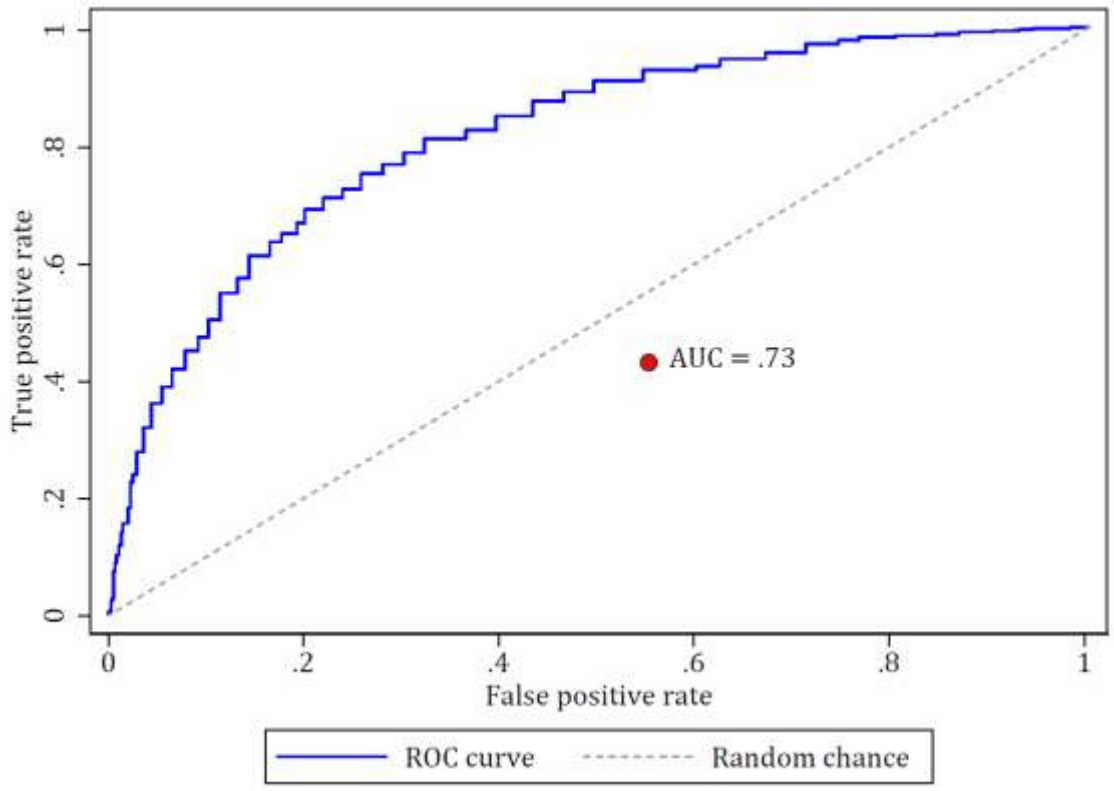
[37] The number of distinct words drawn in each round was equal to the square root of the total wordcount. The number of distinct words was approximately 27,000. Due to computational limitations, however, bagged words were limited to approximately 11,000 words, where the least frequent words across articles were removed.

[38] *k*-fold cross validation can be applied to any set of *k* groups where $k \leq N$. In this regard, the choice of subsections to be tested follows an assessment of the tradeoff between computational bias, which asymptotically decreases in *k*, versus the computational resources needed to carry out the analysis. In this regard, $k = 50$ was chosen as a feasible intermediate point between the two.

[39] Random forest classifiers have strongly diminishing returns on computing additional trees. In a supplementary analysis, the number of trees was drastically increased. This analysis revealed that the

Figure B1. Receiver operating characteristic curve for the derived machine learning algorithm relative to identification through random chance.




By studying the results of the applied strategy, an area under the curve (a so-called AUC score) of 0.73 is obtained. The above-described strategy yielded a final population of 754 peer-reviewed articles featuring neo-Schumpeterian growth models. The process of manually reviewing the literature suggested a small number of false positives in each iteration. These articles were primarily in the fields of evolutionary or Austrian economics. A few articles analyzed related microeconomic models and variety-based endogenous growth models.[40] To test for the presence of false negatives in the extrapolated data, a random sample of negative outcomes was drawn. No false negatives were identified, which suggests that the algorithm yielded a reliable identification of the observed outcomes.[41] A complete list of the identified articles is presented in the online appendix.

corresponding AUC score increased only by half a percent. Hence, the presented results are likely to be an accurate representation of the main model in this regard.

[40] A recurrent issue for the derived algorithm is also difficulty in distinguishing between peer-reviewed articles and working papers.

[41] To obtain representativeness, a random sample of 1,700 observations (approximately 10 percent of negative responses) was drawn from the population.

The above-described strategy yielded a final population of 754 peer-reviewed articles featuring neo-Schumpeterian growth models. The process of manually reviewing the literature suggested a small number of false positives in each iteration, i.e., articles similar to the neo-Schumpeterian literature but that belonged to other fields. These articles were primarily in the fields of evolutionary or Austrian economics. A few articles analyzed related microeconomic models and variety-based endogenous growth models. Finally, to test for the presence of false negatives in the extrapolated data, a random sample of negative outcomes was drawn. No false negatives were identified, which suggests that the algorithm yielded a reliable identification of the observed outcomes. Table B1 presents the derived search terminology and gross number of results for each term and database.

Table B1. Applied search terminology divided across bibliometric sources, number of gross publications.

| Search string(s): | | Sources: | Years | No. of publications, gross[Ψ] |
|---|---|---|---|---|
| Mandatory (all terms) | Optional (any term) | | | |
| "Creative destruction", "Endogenous growth" | "Growth rate", "Economic growth", "Technological change", "Growth model", "Productivity growth", "Aghion and Howitt", "Growth rates", "Steady state", "Production function", "Marginal cost", "Schumpeter", "Grossman and Helpman", "Endogenous technological change", "Knowledge spillovers" | *Google Scholar* | 1990–2018 | 6,590 |
| "Endogenous growth model", "General equilibrium" | "Creative destruction", "Aghion and Howitt", "Schumpeterian model", "Grossman and Helpman" | *Google Scholar* | 1990–2018 | 2,230 |
| "Schumpeterian growth" | "Aghion and Howitt", "General equilibrium", "Grossman and Helpman" | *Google Scholar* | 1990–2018 | 2,600 |
| "Quality ladder*" | "Endogenous growth", "Schumpeterian model", "General equilibrium" | *Google Scholar* | 1990–2018 | 2,420 |

| | | | | |
|---|---|---|---|---|
| “Technological change”, “Creative destruction”, “Endogenous growth” | “Aghion and Howitt”, “Schumpeterian model”, “General equilibrium”, “Grossman and Helpman”, “Knowledge spillover” | *Google Scholar* | 1990–2018 | 6,520 |
| “Knowledge spillovers”, “Creative destruction” | “Endogenous growth”, “Aghion and Howitt”, “Schumpeterian model”, “General equilibrium”, “Grossman and Helpman”, “Endogenous technological change”, “Free entry”, “Global economy” | *Google Scholar* | 1990–2018 | 5,000 |
| “Productivity growth”, “Creative destruction” “Endogenous growth” | “Aghion and Howitt”, “Schumpeterian model”, “General equilibrium”, “Grossman and Helpman”, “Free entry” | *Google Scholar* | 1990–2018 | 4,710 |
| “Rate of innovation”, “Creative destruction” | “Endogenous growth”, “Aghion and Howitt”, “Steady state”, “Schumpeterian model”, “General equilibrium”, “Grossman and Helpman”, “Free entry” | *Google Scholar* | 1990–2018 | 1,680 |

| | | | | |
|---|---|---|---|---|
| “Quality improvement”, “Creative destruction” | “Endogenous growth”, “Aghion and Howitt”, “Steady state”, “Schumpeterian model”, “General equilibrium”, “Knowledge spillovers”, “Grossman and Helpman”, “Endogenous technological change” | *Google Scholar* | 1990–2018 | 985 |
| “Schumpeter*”, “Endogenous” “Innovat*” “Equilibrium” “Aghion” “Howitt” | “Leapfrogging” “Step-by-step”, “Competition” | *Google Scholar* | 1990–2018 | 5,080 |
| “Schumpeter” | “Aghion”, “Howitt”, “Segerstrom”, “Grossman”, “Helpman”, “Dinopoulus”, “Akcigit”, ”Madsen”, ”Trajtenberg” | *Google Scholar* | 1990–2018 | 3,460 |
| “Endogenous growth”, “Schumpeter*” | “Leapfrogging”, “Step-by-step”, “Quality ladder”, “Creative destruction”, “Innovation” | *Google Scholar* | 1990–2018 | 15,800 |
| “Schumpeterian wave*”, “Endogenous growth” | | *Google Scholar* | 1990–2018 | 4,660 |
| “Creative destruction”, “Endogenous growth” | | *Google Scholar* | 1990–2018 | 2,000 |
| “Quality ladder*”, “Endogenous growth” | | *Google Scholar* | 1990–2018 | 1,890 |
| “Step-by-step”, “Endogenous growth”, “Innovation” | | *Google Scholar* | 1990–2018 | 11,600 |
| “Endogenous growth” “Innovation” | “Leap frogging” “Leap-frogging” | *Google Scholar* | 1990–2018 | 249 |

| | | | | |
|---|---|---|---|---|
| “Endogenous growth” “Innovation” | “Neck-to-neck” “Neck to neck”, “Neck by neck”, “Neck-by-neck” | *Google Scholar* | 1990–2018 | 93 |
| “Knowledge production function”, “Endogenous growth” | | *Google Scholar* | 1990–2018 | 1,640 |
| “Schumpeterian", “Differentiation” | “Vertical product*”, “vertical and horizontal product” | *Google Scholar* | 1990–2018 | 1,450 |
| “Endogenous growth”, “Differentiation” | “Vertical product*”, “vertical and horizontal product” | *Google Scholar* | 1990–2018 | 42 |
| “Endogenous growth”, “Patent race*” | | *Google Scholar* | 1990–2018 | 542 |
| “Endogenous growth”, “Vertical innovation” | | *Google Scholar* | 1990–2018 | 592 |
| “Endogenous growth” | “Patent ladder”, “Technology ladder” | *Google Scholar* | 1990–2018 | 254 |
| “Creative destruction”, “Endogenous growth” | “Growth rate”, “Economic growth”, “Technological change”, “Growth model”, “Productivity growth”, “Aghion and Howitt”, “Growth rates”, “Steady state”, “Production function”, “Marginal cost”, “Schumpeter”, “Grossman and Helpman”, “Endogenous technological change”, “Knowledge spillovers” | *Web of Science* | 1990–2018 | |
| “Endogenous growth model” | “Creative destruction”, “Aghion and Howitt”, “Schumpeterian model”, “Grossman and Helpman” | *Web of Science* | 1990–2018 | |

| | | | |
|---|---|---|---|
| “Schumpeterian growth” | “Aghion and Howitt”, “General equilibrium”, “Grossman and Helpman” | *Web of Science* | 1990–2018 |
| “Quality ladder*” | “Endogenous growth”, “Schumpeterian model”, “General equilibrium” | *Web of Science* | 1990–2018 |
| “Technological change”, “Creative destruction” | “Endogenous growth”, “Aghion and Howitt”, “Steady state”, “Schumpeterian model”, “General equilibrium”, “Grossman and Helpman”, “Knowledge spillovers”, “Global economy” | *Web of Science* | 1990–2018 |
| “Knowledge spillovers”, “Creative destruction” | “Endogenous growth”, “Aghion and Howitt”, “Schumpeterian model”, “General equilibrium”, “Grossman and Helpman”, “Endogenous technological change”, “Free entry”, “Global economy” | *Web of Science* | 1990–2018 |
| “Productivity growth”, “Creative destruction” | “Endogenous growth”, “Aghion and Howitt”, “Schumpeterian model”, “General equilibrium”, “Grossman and Helpman”, “Knowledge spillovers”, “Free entry” | *Web of Science* | 1990–2018 |
| “Rate of innovation”, “Creative destruction” | “Endogenous growth”, “Aghion and Howitt”, “Steady state”, “Schumpeterian model”, “General equilibrium”, “Grossman and Helpman”, “Free entry” | *Web of Science* | 1990–2018 |

| | | | | |
|---|---|---|---|---|
| “Quality improvement”, “Creative destruction” | “Endogenous growth”, “Aghion and Howitt”, “Steady state”, “Schumpeterian model”, “General equilibrium”, “Knowledge spillovers”, “Grossman and Helpman”, “Endogenous technological change” | *Web of Science* | 1990–2018 | |
| “Schumpeter*”, “Endogenous” “Innovat*” “Equilibrium” “Aghion” “Howitt” | “Leapfrogging” “Step-by-step”, “Competition” | *Web of Science* | 1990–2018 | 1 |
| “Schumpeter” | “Aghion”, “Howitt”, “Segerstrom”, “Grossman”, “Helpman”, “Dinopoulus”, “Akcigit”, ”Madsen”, Trajtenberg | *Web of Science* | 1990–2018 | 9 |
| “Endogenous growth”, “Schumpeter*” | “Leapfrogging”, “Step-by-step”, “Quality ladder”, “Creative destruction”, “Innovation” | *Web of Science* | 1990–2018 | 14 |
| “Schumpeterian wave*”, “Endogenous growth” | | *Web of Science* | 1990–2018 | 0 |
| “Creative destruction”, “Endogenous growth” | | *Web of Science* | 1990–2018 | 38 |
| “Quality ladder*”, “Endogenous growth” | | *Web of Science* | 1990–2018 | 46 |
| “Step-by-step”, “Endogenous growth” | “Innovation” | *Web of Science* | 1990–2018 | 3 |
| “Endogenous growth” “Innovation” | “Leap frogging” “Leap-frogging” | *Web of Science* | 1990–2018 | 0 |
| “Endogenous growth” “Innovation” | “Neck-to-neck” “Neck to neck” | | | 0 |

| | | | | |
|---|---|---|---|---|
| "Knowledge production function" | "Endogenous growth" | *Web of Science* | 1990–2018 | 10 |

*Note*: Search strings and results, per database across the period of 1990–2018. Search strings were used across *Google Scholar*, *CrossRef*, *Scopus* and *Web of Science*.
[Ψ] The gross number of publications in *Google Scholar* constitutes an approximation as returned when imputing each search string in the search engine. Consequently, search terms yielding returns of more than 1,000 are rounded off to the closest $10^{th}$ multiplier. In the identification process itself, the complete set of results is accounted for by compiling all individual search hits returned from *Google Scholar*. In a second stage, all publications containing non-English titles are removed, along with all publications that lack a time stamp.
"*" Indicates the use of wildcards.