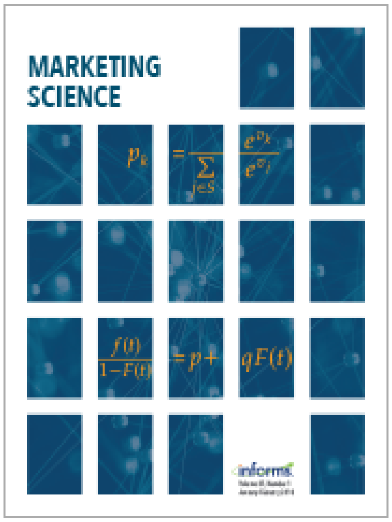

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Two Centuries of Innovations and Stock Market Bubbles

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Abstract. The interplay between innovation and the stock market has been extensively studied by scholars across all business disciplines. However, one phenomenon remains understudied: the association between innovation and stock market bubbles. Bubbles—defined as rapid increases and subsequent declines in stock prices—have been primarily examined by economists who generally do not focus on individual characteristics of innovations or on the consequences of bubbles for their parent firms. We set out to fill this gap in our paper. Using a sample of 51 major innovations introduced between 1825 and 2000, we test for bubbles in the stock prices of parent firms subsequent to the commercialization of these innovations. We identify bubbles in 73% of the cases. The magnitude of these bubbles increases with the radicalness of innovations, with their potential to generate indirect network effects, and with their public visibility at the time of commercialization. Moreover, we find that parent firms typically raise new equity capital during bubble periods and that the amount of equity raised is proportional to the magnitude of the bubble. Finally, we show that the buy-and-hold abnormal returns of parent firms are significantly positive between the beginning and the end of the bubble, suggesting that these innovations add value to their firm and to the economy, in spite of the bubble. Our findings have important implications for managers interested in commercializing innovations and for policy makers concerned with the stability of the financial system.

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Keywords: radical innovation • stock market bubbles • capital raised • diffusion • visibility • network effects

1. Introduction

A sizable stream of research has examined the interplay between innovation and the stock market. In marketing, the focus has been on short- and long-term abnormal returns associated with new product introductions. The marketing literature generally finds a positive impact of innovation on stock prices (e.g., Pauwels et al. 2004, Sood and Tellis 2009, Warren and Sorescu 2017) and concludes that many new products and technological innovations have spurred the growth of their parent firms and even of entire industries and countries (Tellis et al. 2009).

In turn, the literature in financial economics tends to take a more macro view of innovation. A significant part of this literature has studied the causes and consequences of technological revolutions—periods when technological advances bring abrupt and long-lasting changes to our society (Lamoreaux et al. 2007, Perez 2002). A few authors working in this domain suggest that the stock market plays a critical role in financing innovations launched during technological revolutions, particularly beginning with the 1920s (Hsu et al. 2014, Neal and Davis 2007, O'Sullivan 2007, Perez 2002). Others observe that such revolutions tend to be associated with stock market bubbles—a rapid increase and subsequent decline in stock prices—citing, as examples, radio stock prices during 1929–1930 and Internet stock prices during 1999–2000 (DeMarzo et al. 2007, Pástor and Veronesi 2009, Shiller 2015).

Are certain types of innovations more likely to be associated with stock market bubbles than others? If an innovation produces a bubble, are firms that commercialize it affected by the bubble, and if so, in what way? Can firms raise new capital during bubble periods and use it to accelerate the diffusion of the innovation? Extant literature does not provide clear answers to these questions. The lack of insight is due, in part, to the fact that the bubble literature in financial economics tends to view innovation as an undifferentiated output generated by an aggregate production function, rather than a collection of products with distinct characteristics. Moreover, studies in this area rarely incorporate a formal statistical measurement of bubbles, using instead ex post observations of sudden rises and declines in stock prices, and little attempt is made to link such price movements to specific innovations. A notable exception is by Frehen et al. (2013), who show that the South Sea Bubble of 1720—commonly thought of as a single occurrence by historians—actually consisted of two separate bubbles, each associated with contemporaneous innovations in two distinct industries: insurance and the Atlantic trade. Finally, most papers that study bubbles tend to focus on only one or two salient innovations, such as rail (Campbell 2012) or the Internet (Pástor and Veronesi 2009).

Overall, the academic literature in marketing and financial economics provides little systematic evidence of the link between external financing, innovation, and bubbles. However, understanding the extent to which the stock market plays a role in helping new industries develop and flourish is a topic of high relevance to managers seeking to finance innovation and to policy makers who seek to foster economic growth while maintaining the stability of the financial system. Managers might also be interested in learning whether certain types of innovations are more likely to be associated with disruptive patterns in their firm's stock price, and whether such patterns impact the eventual diffusion of the innovation.[1]

Our paper seeks to fill this gap through a study positioned at the interface of marketing, finance, and economics. Using the list of radical innovations identified by Chandy and Tellis (2000) as a starting point, we assemble a sample of 51 major innovations introduced between the years 1825 and 2000. For each of these innovations, we collect data on firms that commercialized it—which we call parent firms—and test whether these firms experienced bubbles in their stock prices following commercialization.

To detect bubbles, we look for significant differences between stock market prices and intrinsic values, using the econometric method proposed by West (1987). We then estimate a number of cross-sectional models to understand how these bubbles relate to various characteristics of each innovation. Next, we measure the amount of new equity capital raised by parent firms during bubble periods. Finally, we estimate the relation between this new capital raised and the subsequent visibility of the innovation in the public domain.

We present six important findings. First, we detect bubbles in approximately 73% of the innovations studied (37 out of 51). By contrast, the largest collection of innovations previously associated with bubbles can be found in the book by Shiller (2015), who describes nine possible bubbles, and argues that they tend to be associated with major shifts in technological paradigms.[2] Second, we show that the magnitude of these bubbles is positively related to the contemporaneous level of visibility of each innovation. To measure this visibility, we obtain from the Google Books Ngram Viewer the annual frequency with which the innovation is mentioned in public books, through time. Third, we find that bubbles are more likely to occur for innovations that have a higher degree of radicalness and for innovations that are more likely to generate indirect network effects. Fourth, we find that parent firms raise significantly more equity capital during bubble periods compared to the average firm in the market, and the amount of this new capital is proportional to the magnitude of the bubble. Fifth, we show that the new capital raised during bubble periods is positively associated with a faster and stronger increase in the visibility of the innovation after the bubble. Finally, we show that the buy-and-hold abnormal returns of parent firms are significantly positive between the beginning and the end of the bubble, suggesting that these innovations add value to their firms and to the economy, in spite of the bubble.

These findings have important implications for managers and policy makers. Managers of firms commercializing innovations that are radical (Chandy and Tellis 1998) or innovations that can generate indirect network effects (Stremersch et al. 2007) should be aware of a potentially disruptive pattern in their stock prices in the form of bubbles. At the same time, these bubbles may create a short window of opportunity during which equity capital could be raised on favorable terms. If this capital is judiciously invested, it can help accelerate the diffusion of the innovation. In terms of policy implications, our results suggest that bubbles might allow for faster building of the infrastructure needed for innovation to achieve its full economic potential. Therefore, at least from this narrow perspective, bubbles appear to act as an indirect, voluntary tax that some people pay to invest in what is essentially a public good. This implication is consistent with Olivier (2000), whose mathematical model predicts that stock market bubbles are beneficial to value creation, investment, and growth.

Our results also support the views expressed by former Federal Reserve Chairman Alan Greenspan, who opined that while bubbles are precipitated by exaggerated perceptions of economic growth, they also fuel the diffusion of the underlying innovation by providing the capital required for its commercialization (Lansing 2008). Without a bubble, he argued, a major innovation might not take off or achieve its full potential. Observing that "there were no bubbles in the Soviet Union," Greenspan concluded that policy makers should not attempt to quash bubbles since doing so could impede innovation and lead to suppressed economic activity over the long term (Guha 2008, p. 2).

We do not claim to establish causal relations in our paper. Instead, our goal is to provide a number of statistical tests to study stock market bubbles across the largest set of innovations used in this literature. As is the case with most papers that focus on first-order research questions, we are only able to answer a subset of questions that readers might deem important. The data collection for this project was laborious and extensive. Data for innovations from the 19th century and from the earlier part of the 20th century were challenging to obtain, and in many cases extensive manual searches had to be performed in newspapers and other contemporaneous sources. We nevertheless hope that our insights into the economic consequences of innovation will serve as impetus for additional research in this area.

The rest of the paper proceeds as follows. In Section 2, we present an overview of the theory that supports the existence of stock market bubbles, and we review the literature that links innovations with bubbles. We also present theoretical arguments that support the relation between individual innovation characteristics, stock market bubbles, and external financing. In Section 3, we discuss the economic consequences of bubbles. In Section 4, we describe the data collection process and empirical methodology. Section 5 presents the results, and Section 6 concludes with a discussion of the implications of our findings for researchers, managers, and policy makers.

2. Innovation and Stock Market Bubbles

We begin this section with a discussion of the economic theory of bubbles. We continue with a brief overview of the literature that links innovation and bubbles, and conclude with a set of empirical predictions that link bubbles with specific innovation characteristics.

2.1. Asset Price Bubbles

Bubbles occur when the price of an asset exceeds its intrinsic value by a significant amount and for a sufficiently long period of time. The literature in financial economics distinguishes between "behavioral" bubbles and "rational" bubbles (Scherbina and Schlusche 2014). Behavioral bubbles occur when investors deviate from the rational expectations model, perhaps because they overreact to news or fail to update their beliefs in a Bayesian manner. By contrast, rational bubbles occur despite all agents being perfectly rational and having access to the same information set.

We adopt the rational bubble approach because it is based on the rational expectations paradigm prevailing in financial economics. Fama (1998) argues that researchers should not reject rational expectations until (or unless) the alternative (behavioral) paradigm can do a better job at explaining existing empirical observations within a unified body of knowledge. While the literature in behavioral finance has evolved over the past 20 years, to our knowledge, there is no unified behavioral theory of bubbles. Indeed, Scherbina and Schlusche (2014) discuss no fewer than 18 papers grouped into four different categories of behavioral-based models of bubbles. In turn, each category is based on a unique set of underlying cognitive biases (such as self-attribution or conservatism). Collectively, these 18 papers provide little guidance for our research because there is no systematic way to determine, ex ante, which cognitive biases apply to various innovations or time periods. By contrast, the rational bubble approach allows us to develop a parsimonious set of testable predictions that apply uniformly to all innovations in our sample.

A common theoretical explanation for rational bubbles is the mathematical, discrete-time model of Blanchard and Fischer (1989). Versions of this model have been used in other papers, including those by Blanchard and Watson (1982), Froot and Obstfeld (1991), Rappoport and White (1993), White (1990), and Scherbina and Schlusche (2014). The model explains how bubbles may arise even if all economic agents act rationally. Blanchard and Fischer (1989, pp. 213–223) posit that the price of an asset in one period is equal to the discounted value of its expected price and cash flows during the next period. They then seek to find the theoretical value of the price during the current period, expressed only in terms of future cash flows and discount rates.

Blanchard and Fischer (1989) show that the solution to their model is not unique. There are, in fact, an infinite number of solutions. One of them (the fundamental solution) is the well-known present value of future cash flows, which defines the intrinsic value of an asset. All other solutions include a "bubble" component: a positive quantity that is artificially added to the intrinsic value. We know very little about this bubble component. Blanchard and Fischer's (1989) theory tells us only that it is expected to grow at a rate r, equal to the discount rate of the asset. This property is not very useful because it allows for an infinite number of outcomes. For example, *any* random number that grows through time at rate r is a potential bubble. Ideally, we would like to obtain more specific properties for this bubble so that we may learn something about its magnitude and determinants.

Fortunately, a special case of the rational bubble theory allows us to narrow down the set of bubble solutions and obtain useful testable implications. This special case was proposed by Froot and Obstfeld (1991), who introduced the concept of *intrinsic bubbles*, a subset of rational bubbles. With intrinsic bubbles, the magnitude of the bubble component is proportional to the contemporaneous value of the asset's cash flows (or to the value of another proxy that is correlated with cash flows).

We mentioned earlier that the solution to the Blanchard and Fischer (1989) model may or may not include a bubble. While both scenarios are theoretically possible, only one of them will be observed in reality—either the asset price includes a bubble or it does not. Mathematics alone cannot help us determine which of these scenarios will prevail. For this, we need to know more about the underlying economic conditions.

In Web Appendix A, we provide a simplified version of the Blanchard and Fischer (1989) model, along with an economic interpretation of their solution. We also discuss the intuition behind Froot and Obstfeld's (1991) theory of intrinsic bubbles and explain how its predictions relate to our paper. We argue that bubbles are more likely to occur when the following four conditions are met: (1) the asset is expected to live for an indefinite period of time (as is the case with stocks), (2) no bubble-free close substitute exists for the asset, (3) investors have exploding expectations about the future cash flows generated by the asset, and (4) short selling is costly or subject to constraints. When we overlay the theory of intrinsic bubbles on the basic model of Blanchard and Fischer (1989), we obtain the additional prediction that the magnitude of a bubble is proportional to a proxy for the cash flows generated by the asset at the time when the bubble occurs. These economic implications form the basis for our predictions about the determinants and consequences of bubbles associated with innovations. We present these predictions in Sections 2.3 and 3, respectively.[3]

2.2. Relation Between Innovation, External Financing, and Bubbles

A review of the bubble literature reveals several aspects that warrant further inquiry. First, a few authors note that stock market bubbles occur during industrial revolutions; however, this observation is made primarily in case studies, books, and in the popular press (Gross 2009, Kindleberger and Aliber 2005, Perez 2002, Shiller 2015, Wood 2006).[4] Perhaps because of the tendency to look for bubbles during these periods of intense technological progress, only a limited set of bubbles has been examined in academic studies. For instance, Campbell (2012) studies the British railway bubble of the 1840s, Ofek and Richardson (2003) study the Internet bubble of 1999–2000, and Pástor and Veronesi (2009) study the Internet bubble and the American railroads before the Civil War, while Frehen et al. (2013) establish a link between the stock market bubbles of 1720 and innovations that at the time were taking place in the insurance and Atlantic trade industries.

Second, with the exceptions mentioned above, this literature tends to focus on marketwide bubbles, rather than on industry-specific bubbles spurred by individual innovations. Moreover, academic papers in this stream tend to view innovation as an undifferentiated aggregate output, which precludes the study of product-specific characteristics. For example, Nicholas (2008) evaluates the extent to which the stock market during the 1920s responded to contemporaneous changes in the intellectual capital of U.S. firms, measured using citation-weighted patents assigned to each firm. He finds that excess stock returns during 1928–1929 are positively related to firms' intellectual capital, but does not evaluate the relation between stock returns and specific products.

Third, the literature does not provide a unified view on why bubbles might be associated with innovations, and why some bubbles might be larger than others. This could be a consequence of different philosophical perspectives regarding the underlying causes of bubbles. For example, several authors take the view that bubbles are caused by irrational investors (e.g., Ferguson 2008, Perez 2002, Shiller 2015). Others adopt a more rational view of bubbles but tend to focus on only one or two bubbles and, therefore, lack context to systematically examine common patterns across innovations. As a result, the rationale presented in support of the bubble varies from investor myopia (Campbell 2012) to changes in the systematic risk of parent firms (Pástor and Veronesi 2009).

A number of questions remain unanswered. Perhaps the most salient relates to the scale of the relation between innovation and bubbles: Does this relation extend to all innovations or is it confined to technological revolutions? Because innovations vary on a continuum in terms of technological advances and benefits they bring to consumers, it is important to understand where on this continuum the boundary that could trigger a bubble might lie.

What happens after the bubble is also of interest. A number of authors have argued that the collapse of bubbles is disruptive to economic activity (Perez 2002, Wood 2006), but are there other, more desirable outcomes? Rapp (2014, p. 21) proposed that "when stock prices increase, firms can raise cash from existing and new investors at lower costs." Thus, bubbles could create a favorable environment for firms to raise new equity capital during the commercialization phase of new products. However, there is no systematic evidence that supports this assertion. Finally, we know very little about the longer-term prospects of products whose parent firms are subject to bubbles. Do bubbles help or hurt the visibility and eventual diffusion of innovations?

We address some of these open questions using a novel data set that spans multiple industries across the 19th and 20th centuries. In Section 2.3, we leverage the theories proposed by Blanchard and Fischer (1989) and by Froot and Obstfeld (1991) to make predictions on the determinants and consequences of bubbles associated with innovation.

2.3. Which Innovations Are More Likely to Be Associated with Bubbles?

We mentioned earlier that the literature in financial economics has not examined how differences in innovation characteristics may impact stock prices. By contrast, research in marketing has examined the differential effect of radical versus incremental innovation on stock prices. When compared with incremental innovations, radical innovations—defined as "new products that (1) incorporate substantially different technology from existing products and (2) can fulfill key customer needs better than existing products" (Chandy and Tellis 1998, p. 475)—are associated with stronger long-term stock performance and also with higher firm risk (Pauwels et al. 2004, Sood and Tellis 2009, Sorescu and Spanjol 2008). The overarching conclusion from this stream of research is that the superior benefits provided by radical innovation eventually result in a broader adoption of these products, which translates into higher revenues and profits.

To understand the relation between bubbles and specific innovation characteristics, we return to the theoretical framework of intrinsic rational bubbles presented in Section 2.1. Recall that from Blanchard and Fischer (1989) and Froot and Obstfeld (1991) we had derived a set of conditions that are more conducive to the emergence of bubbles. We now turn to interpreting these conditions within the context of our current research.

Two of the four conditions that underlie the formation of bubbles are met by all innovations in our sample. Specifically, the first condition—indefinitely lived assets—is met by all stocks. Unless a firm is in bankruptcy, the expectation is that it will continue to operate for the foreseeable future. The fourth condition—costly short selling—is also likely to be met by all stocks in our sample. Danielsen and Sorescu (2001) provide several reasons why investors find it difficult to establish short positions in the stock market. For example, investors do not immediately get access to the proceeds from short selling, investors face high search costs for finding a willing security lender, and there is always a risk of a "short squeeze," that is, of a premature request to liquidate the short position before investors can earn a profit (also see Akbas et al. 2017).

The second and third conditions are met by some but not all firms. The second condition—the absence of a close substitute in the stock market—is more likely to be met in the case of innovations whose characteristics are very different from those of existing products. By definition, radical innovations meet these criteria (at the product category level), since they provide significantly higher consumer benefits and incorporate a new technology relative to existing products. Because of these characteristics, parent firms that commercialize radical innovations are exposed to risks previously unknown to investors, which cannot be easily hedged using existing assets. The more radical the innovation, the fewer close-substitute stocks are available in the stock market.[5] Because close-substitute stocks are necessary to arbitrage away mispricing and prevent the bubble from growing, a lower number of close-substitute stocks may lead to bigger bubbles. Thus, our first prediction is that *the higher the level of radicalness of innovations, the larger the magnitude of the innovation bubble*.

The third condition—exploding expectations of future cash flows—is more likely to be satisfied by innovations believed to offer quasi-unlimited revenue potential. We propose that network goods meet this condition. Network goods and services are those whose value to adopters increases as a function of the number of other people who use them (e.g., Gupta et al. 1999, Hall 2005). Direct and indirect network externalities have been distinguished in the literature (Katz and Shapiro 1986). The steam engine exemplifies direct externalities, because the utility derived from rail transportation increased along with its diffusion (the size and geographic reach of the rail network). A good example of indirect externalities is given by the recent growth in the app industry, spurred by smartphones and tablets. In turn, apps provide smart devices with increased functionality, arguably broadening those devices' appeal and potentially strengthening their diffusion (e.g., Stremersch et al. 2007).

Assessing the future cash flows of an innovation is particularly difficult if it requires an estimation of the magnitude of network effects. Network effects could exponentially increase the adoption of a technology within and across industries, indicating that the innovation has the potential to generate exploding future cash flows. Investors—particularly optimistic ones—will factor this possibility into their valuation. Therefore, we suggest that *the magnitude of a bubble increases with an innovation's potential for network externalities*.

Finally, we derive a third testable implication from the intrinsic bubble model of Froot and Obstfeld (1991). Their research suggests that the magnitude of an intrinsic bubble is proportional to the contemporaneous cash flows generated by the underlying innovation, or to any exogenous variable that is correlated to these cash flows. In support of this prediction, Froot and Obstfeld (1991) provide macro-level evidence of intrinsic bubbles obtained from aggregate stock returns and dividends in the United States during the period from 1900 to 1988.

Recall that the intrinsic bubble theory requires that we measure innovation-specific cash flows that are *contemporaneous* with the bubble. In the absence of specific information about cash flows—which are not directly observable—investors are likely to anchor their valuations on metrics that are visible and that, in their opinion, might be correlated to cash flows. We propose that the public visibility of the innovation around the time of the bubble is a good exogenous proxy for the extent to which it has been adopted by the public, and therefore for the cash flows that it generates. To develop this proxy, we use the Google Books Ngram Viewer, an Internet search engine that provides annual frequencies of any search terms that appear in print up to 2008. We obtain from Google Ngram the annual frequencies for each innovation at the time of the bubble.

While admittedly imperfect, the Google Ngram proxy has the distinct advantage of not suffering from retrospective bias because it contains information that was publicly known at the outset of the bubble. In addition, Google Ngram data are available for all innovations in our sample, which provides us with a consistent proxy for cash flows that is comparable across several innovations and time periods. In turn, this consistency facilitates cross-sectional analysis in a sample that is otherwise quite heterogeneous. Thus, our third prediction is that *the magnitude of a bubble increases with the public visibility of the innovation as captured by its contemporaneous Google Ngram frequency of mentions in printed books*.

In sum, we predict that the magnitude of innovation bubbles is increasing in the degree of radicalness, in the potential for network externalities, and in the contemporaneous visibility of the innovation. In Section 3, we examine the consequences of bubbles for the parent firms and for the public visibility and eventual diffusion of the innovation.

3. What Are the Consequences of Bubbles?

3.1. The Economic Value Added of Bubbles

The intrinsic bubble theory of Froot and Obstfeld (1991) is based on the premise that when bubbles occur, they do so because the underlying asset—in this case, the stocks of parent firms—adds significant value to the economy. This prediction is corroborated by Olivier (2000, p. 133), who argues that "the real impact of a [rational] bubble depends on the type of asset that is being speculated on. Speculative bubbles on equity raise the market value of firms, thus encouraging entrepreneurship, firm creation, investment, and growth." Therefore, *we expect innovations that are subject to bubbles to have, on average, positive net present value* (*NPV*) *despite the presence of bubbles*. We test this prediction in our paper, with NPV measured as the abnormal returns earned by the stocks of parent firms, from the beginning to the end of the bubble.

3.2. Capital Raised in the Stock Market

A critical question of interest to managers is how to raise the capital needed to finance innovations. This is particularly true for innovations that are fueled by new technologies, which require significant capital investment. While it might be natural today to assume that this new capital could be easily raised by issuing new equity, historical evidence suggests that this was not always the case. Indeed, prior to the mid-1920s, innovations were financed mostly with private capital raised from the owners' personal network (Lamoreaux et al. 2007, O'Sullivan 2007). The stock market began to play a more significant role in financing innovation beginning with the aircraft and radio industries in the 1920s (O'Sullivan 2007). Since that time, firms have increasingly relied on equity capital raised from public sources.

We expect that the presence of bubbles could make it easier for parent firms to raise equity capital because one consequence of overvalued stocks is a temporary reduction in the firm's cost of equity during the bubble period. In turn, this could make it attractive for managers to raise new equity capital in the form of initial public offerings (IPOs) or seasoned equity offerings (SEOs). This new capital would be raised by issuing overvalued shares, which is favorable to the firm's existing shareholders, but not to its new shareholders.

Although managers would normally want to issue new equity when their stock is overvalued, most of the time they are not able to do so without paying a penalty because of adverse selection. Indeed, investors usually view SEOs as a signal of overvaluation, and a mere announcement of an SEO typically results in an immediate decline in the market value of the firm (see, e.g., Myers and Majluf 1984). In a nonbubble environment, this decline would offset any benefits obtained from issuing overvalued stock. The bubble environment, however, might be different: it might provide a unique opportunity for managers to raise cheap equity capital without worrying about sending negative signals to the market. If this were true, we would expect parent firms to raise an abnormally high amount of equity capital during bubble periods. We provide empirical evidence on this issue in our paper.

3.3. Postbubble Trajectory of Innovation

We have so far focused on the consequences of bubbles for parent firms. We now turn to the potential consequences of bubbles for the innovations themselves. Can a bubble affect the public visibility, and ultimately the diffusion, of an innovation, and if so, in what way?

The diffusion literature has examined several milestones in the life cycle of a new product. The first milestone is the takeoff time, defined by Golder and Tellis (1997, p. 257) as "the point of transition from the introductory stage to the growth stage of the product life cycle," a point when a dramatic increase in sales occurs. Determinants of the takeoff time include a reduction in the price of the innovation and the level of market penetration (Golder and Tellis 1997). Another determinant of takeoff that is particularly relevant to our context is the performance of the parent firm's stock in the early commercialization stages: a strong positive abnormal stock performance has been found to predict takeoff in the subsequent year (Markovitch and Golder 2008), suggesting that takeoff could follow shortly after a bubble has emerged. Finally, the parent firm's ability to raise cheap equity capital during a bubble essentially reduces the cost of the innovation, which can potentially reduce its price and shorten its time to takeoff (Golder and Tellis 1997). Therefore, we expect that *the magnitude of the bubble and the capital raised during the bubble are positively related to how quickly takeoff occurs*.

We do not measure diffusion directly. Rather, we use as a proxy the time series of visibility obtained from Google Ngram, beginning with the commercialization date of each innovation. Just as visibility could serve as an ex ante proxy for the innovation's cash flows, it can also serve as an ex post proxy for its diffusion. Using this proxy, we estimate the takeoff of each innovation as the inflection point in the time series of Google Ngram visibility. In Web Appendix D we show, for a subsample of 25 innovations, that the takeoff estimated from visibility correlates highly with the takeoff estimated from product adoption data.

The literature on new product diffusion also makes predictions about the shape of the diffusion curve after takeoff. Initial models predicted a monotonic increase in sales up to the peak of growth, followed by a slowdown (e.g., Peres et al. 2010). Other authors have argued that the diffusion curve follows a chasm and saddle pattern, where sudden decreases in sales follow the initial rise (Golder and Tellis 2004, Mahajan and Muller 1998). In all cases, as newer technologies become available, the diffusion curve eventually plateaus and starts declining. The point at which it plateaus has been assumed to be the point of market saturation, but researchers have focused less on this saturation point compared to the takeoff point.

We argue that the same characteristics of a bubble that lead to an accelerated takeoff are also associated with a higher market saturation point. A lower innovation cost obtained from the parent firm's ability to raise cheap capital will not only lead to a faster takeoff but also to a broader adoption of the innovation. Thus, we expect that *the magnitude of the bubble and the capital raised during the bubble are positively related to the visibility that the innovation achieves after takeoff*. This visibility is proxied by the maximum Google Ngram value that the innovation attains in its lifetime.

4. Data and Methods

4.1. Selection of Innovations Included in Our Sample

Assembling a comprehensive data set of innovations introduced during the last two centuries is a challenging task. We start with the largest set of radical innovations documented in the literature, a list of 64 new products introduced between 1864 and 1998 provided in Chandy and Tellis (2000). The authors used the historical approach to data collection (Golder 2000) and consulted "more than 250 books and 500 articles in periodicals" to construct their sample (Chandy and Tellis 2000, p. 5). Therefore, we believe that this list constitutes a good initial sampling frame for our study. Of the 64 innovations mentioned in Chandy and Tellis (2000), we were able to identify and collect data for 43 innovations commercialized between 1886 and 1998.[6]

In our review of the literature on technological revolutions, we also encountered a few additional innovations that have been singled out by economists as being notable in their ability to spur economic growth. For instance, Shiller (2015, p. 125) mentions the steam engine train, motion pictures, and the Internet (or, more specifically, the World Wide Web) as major innovations that ushered what he calls "a new era." Through this archival process, we add eight additional innovations to the Chandy and Tellis (2000) list: the steam engine train, the telegraph, motion pictures, rayon, the airplane, the Internet, the GPS receiver, and the smartphone. Table WA-B3 in Web Appendix B details the sources used to identify these innovations. Our final sample consists of 51 innovations.

4.2. Identifications of Parent Firms and of Financial Data Used for the Bubble Tests

After assembling our sample of innovations, we identify the date when each innovation was commercialized, as well as the parent firms involved in the commercialization process. To do so we use extensive archival searches encompassing a large number of books and articles on the history of technology, major U.S. and UK journals that date back to the 19th century (such as the *Wall Street Journal* and the *London Times*), and academic articles that examine the diffusion of innovations (e.g., Agarwal and Bayus 2002, Golder and Tellis 1997).

From the set of parent firms, we select those with available stock and dividend data. For most innovations in the 20th century, company-specific data are available from the Center for Research in Security Prices (CRSP) beginning with the year 1925. For earlier innovations, we turn to the Cowles Foundation database (https://som.yale.edu/faculty-research/our-centers-initiatives/international-center-finance/data/historical-cowles), which covers the period from 1871 to 1938. Unlike the CRSP, Cowles provides data on industry indices, not on individual companies. If we are able to identify a clear industry index that corresponds to a particular innovation (for example, "automobile"), we use the Cowles price and dividend data for that index, and the set of parent firms for that particular innovation is deemed to be the set that the Cowles researchers had chosen to include in their index.

If the Cowles index is too broad (for example, "appliances" instead of "refrigerator"), we identify parent

Table 1. Sources of Stock and Dividend Data

Data source	Description
CRSP data set	Monthly, stock-level data are available from the Center for Research in Security Prices at the University of Chicago from December 1925 to the present. Stock-level data are used to construct a price index and monthly dividend series for each innovation. The monthly price index is constructed using the value-weighted average return (excluding dividends) of the stocks included in the index. The monthly dividend series for each index is constructed by first computing each stock's monthly dividend yield as the difference between its total monthly return and its monthly return excluding dividends. The monthly dividend yield of the index is then computed as the value-weighted average of the component stocks' dividend yields. Monthly dividends in terms of the price index are computed as the product of the index's dividend yield and the value of the price index at the end of the prior month.
London Stock Exchange (Old LSE data set)	The Old LSE data set was produced by compiling hard copy entries from the *Investors Monthly Manual*, a record of the London Stock Exchange for the period from 1871 to 1930. Common stock prices and dividends from this data set are used to construct the required price indexes and dividend series in a manner consistent with those that are based on CRSP data.
The Cowles Commission for Research in Economics	The Cowles data set, produced from the Cowles Commission's third monograph (1939), contains industry-level common stock data series for the period 1871 to 1938. We use two price indexes from these data: a price index that excludes dividends and a total return index that includes both dividends and price appreciation. As we do with the CRSP data, we use the difference in the returns of these two indexes to construct a monthly, industry-level dividend series denominated in terms of the price index.
Compustat Global	Monthly, stock-level data for foreign stocks are available from Compustat Global from January 1985 to the present. Variables constructed from this data set are computed in the same manner as described above for the CRSP data. This data set was used to collect stock price and dividend data for Japanese firms that did not trade in the United States during the time period of interest.
New York Stock Exchange (Old NYSE data set)	The Old NYSE data set was produced from data used in Goetzmann et al. (2001). Common stock prices and dividends from this data set are used to construct the required price indexes and dividend series in a manner consistent with those that are based on the CRSP data.

Note. This table presents the data sources used to collect stock and dividend data for the bubble tests.

companies from historical sources and collect data on individual stocks from the Historical London Stock Exchange and Historical New York Stock Exchange databases, both of which are available at Yale University in electronic format. Finally, data not available in electronic format are hand collected from contemporaneous newspapers in the United States and the United Kingdom. One exception is the data set on the UK railroad industry from the 19th century, which was provided to us by Gareth Campbell (Campbell 2012).

Table 1 describes our data sources, and Table 2 provides a list of the 51 innovations in our sample, along with the years of commercialization and the corresponding portfolios of parent firms. A full description of the history of these innovations is available on request from the authors. For innovations not covered by the CRSP or Cowles, we occasionally have to confine our analysis to a single firm, because of data availability. For example, for the telegraph industry, we study only the stock of Western Union, as we are unable to identify data for other companies. Our results are not likely to be biased by these single-firm portfolios.[7]

Our portfolios do not contain the complete set of early entrants in each industry. While this is a limitation caused by data availability, our goal here is to create clean portfolios for the measurement of bubbles, rather than to extensively study the entry process into new industries. As a result, we are primarily concerned with building portfolios that have significant exposure to the focal innovation (and little exposure to everything else), rather than to make the portfolios as comprehensive as possible. To accomplish this goal, we endeavor as much as possible to include in our test portfolios only firms that are pure plays, in the sense that their product portfolio includes primarily the innovation and not much else. To the extent to which our test portfolios may occasionally include firms that are not pure plays (such as multiproduct firms that commercialize other products in addition to the focal innovation), the inclusion of such firms would merely bias our results toward zero, because these firms would have a smaller exposure to the economic forces that ignite the bubble.[8]

4.3. Characteristics of Innovations That Are More Likely to Be Associated with Bubbles

Previously, we identified three innovation characteristics that increase the probability of a bubble: the innovation's degree of radicalness, its potential to generate network effects, and the extent of its public visibility. Ideally, we would like to collect contemporaneous data for each of these three characteristics to minimize the risk of a retrospective bias. However, we could only do so in the case of visibility. We measure contemporaneous visibility using the Google Ngram data, which

Table 2. Firms Included in the Bubble Analysis of Each Innovation

Innovation	Comm. year	Firms (and initial year) included in index
Steam engine train	1825	Campbell (2000) Railway Index
Telegraph	1845	Western Union (1865)
Incandescent vacuum lamp	1880	Cowles Electrical Equipment Index components: Edison General Electric/General Electric (1890)
Automobile	1886	Cowles Automobiles and Trucks Index components: General Motors (1912), Chrysler (1914), Studebaker (1912), Willys-Overland (1915), Chandler Motor Car (1916), Saxon Motor Car (1916), Stutz Motor Car (1916), White Motor (1916), Pierce-Arrow Motor Car (1917), Fisher Body (1918), Hupp Motor (1918), Mack Trucks (1920), Packard Motor Car (1920)
Portable camera	1888	Eastman Kodak (1904)
Disk phonograph	1894	Gramophone company (1904)
Motion pictures	1898	Cowles Theater and Motion Picture Index components: Famous Players-Lasky (1919, later renamed to Paramount Publix), Loew's (1920), Radio-Keith-Orpheum (1920)
Photoelectric scanning fax	1907	Cowles Utilities—Telephone and Telegraph Index Components: American Telephone and Telegraph (1907), New York and New Jersey Telephone (1907), Central South America Telegraph (1907), Mackay Companies (1907), Pacific Telephone and Telegraph (1909), All America Cables (1918)
Electric clothes washer	1908	Cowles Electrical Equipment Index components: General Electric (1908), Electric Storage Battery Co. (1915), National Conduit and Cable (1917), Westinghouse Electric and Manufacturing (1918)
Electric percolator	1908	Cowles Electrical Equipment Index components: General Electric (1908), Electric Storage Battery Co. (1915), National Conduit and Cable (1917), Westinghouse Electric and Manufacturing (1918)
Electric toaster	1908	Cowles Electrical Equipment Index components: General Electric (1908), Electric Storage Battery Co. (1915), National Conduit and Cable (1917), Westinghouse Electric and Manufacturing (1918)
Rayon	1910	Cowles index: Industrial Rayon Corp. (1926), Tubize Artificial Silk Co. of America (1926), Snia Viscosa Co. (1926), Celanese Corp. of America (1927), Tubize Chatillon Corp. (1930)
Refrigerator	1916	General Electric (1925), Kelvinator (1926)
Airplane	1919	Bendix Aviation (1925), Curtiss Aeroplane (1927), Wright Aeronautical (1925), Curtiss Wright Corporation (1929), National Air Transport (1929), United Aircraft and Transport (1929)
Radio	1919	RCA (1925), AT&T (1925), Westinghouse Electric and Manufacturing (1925)
Electric typewriter	1920	IBM (1928)
Electric blanket[a]	1930	General Electric (1928)
Electric dishwasher[a]	1930	General Electric (1928)
Electric shaver	1930	Remington Rand (1928)
Electric garbage disposer	1935	General Electric (1928)
TV	1936	Admiral (1945), Crosley (1940), Emerson (1945), Farnsworth Television and Radio (1943), General Electric (1940), Galvin Manufacturing/Motorola (1946), Philco (1940), RCA (1940), Westinghouse Electric (1940), Zenith (1940)
Fluorescent light bulb	1938	General Electric (1936), Westinghouse Electric and Mfg (1936)
FM radio	1940	RCA (1935), Westinghouse Electric and Mfg (1935), Zenith Radio (1935), Philco (1940), Galvin Manufacturing/Motorola (1946)
Ballpoint pen	1945	Eversharp (1946)
Magnetic tape player	1947	Minnesota, Mining and Mfg (1946)
Microwave oven	1947	Raytheon (1958), Litton (1958)
NTSC color TV	1954	General Electric (1952), Philco (1952), RCA (1952), Raytheon (1952), Hoffman Electronics (1955)
Electric can opener	1956	Westinghouse Electric (1950)
Videocassette recorder	1956	North American Phillips (1950), RCA (1950), Magnavox (1950), Ampex (1959)
Electronic watch	1957	Bulova Watch (1955), Hamilton Watch (1955), Elgin National Watch (1955)
Cassette	1964	North American Phillips (1962), Memorex (1968), Sony (1970), Fuji (1972), Hitachi (1972), TDK Electronics (1975)
Electronic desktop calculator	1964	Texas Instruments (1959), Hewlett-Packard (1959), Friden (1959), Wang Laboratories (1968)
Electronic pocket calculator	1968	Texas Instruments (1965), Hewlett-Packard (1965), Canon (1965), Bowmar Instrument (1965), Craig (1969), Toshiba (1972)
Dot-matrix printer	1970	Centronix Data Computer (1972)
Single-player video game	1972	Magnavox (1969), General Instrument (1969), Centuri (1972), Bally Manufacturing (1972), Williams Electronics (1981)
Digital LED watch	1975	Texas Instruments (1973)
Disposable shaver	1975	Gillette (1975), Schick (1975), Bic Pen (1975)

Table 2. (Continued)

Innovation	Comm. year	Firms (and initial year) included in index
Personal computer	1975	Apple (1980), Commodore (1978), IBM (1978), Intel (1978), RadioShack (1978), Lotus Development (1983), Ashton Tate (1983), Compaq (1983)
Laser printer	1976	Hewlett-Packard (1974), IBM (1974), Xerox (1974), Canon (1974)
Laser disc player	1978	MCA (1976), Pioneer (1976), Sony (1976), Phillips (1976)
Mobile phone	1979	AT&T (1980), Motorola (1980), Ericsson (1981), Interdigital (1981), SBC (1984), Nokia (1988), Qualcomm (1991)
Camcorder	1983	Hitatchi (1983), JVC (1983), Panasonic (1983), Sony (1983)
Compact disc player	1983	Panasonic (1981), Philips (1981), Sony (1981), Toshiba (1981)
Portable computer	1983	IBM (1975), Radioshack (1975), Hewlett-Packard (1975)
Digital camera	1989	Fuji (1986), Nikon (1986), Casio (1986), Olympus (1986)
Internet[b]	1991	List of Internet IPOs included in Loughran and Ritter (2004)
Minidisc player	1992	Sony (1990)
Digital video disc player	1997	Sony (1990)
Digital high-definition TV	1998	Zenith (1990), Sony (1990), Panasonic (1990), Hitatchi (1990), Technicolor (1999)
GPS receiver	2000	Garmin (2000), Lowrance (2000), Trimble (2000)
Smartphone	2000	Apple (2002), Ericsson (2002), Handspring (2002), Nokia (2002), Research in Motion (2002), Google (2004)

Notes. This table presents the names of the firm(s) included in the test portfolio of each innovation. The year of each firm's entry into the portfolio is included in parentheses. For the Internet industry, we provide the source of the index employed. The first column shows the name of each innovation and the second column shows the year of commercialization.

[a]Because the electric blanket and the electric dishwasher were introduced in the same year (1930), and because the test portfolio for both products is limited to General Electric, we can only perform a joint bubble test for these two products. If a bubble is detected, it could be attributed to either one of the two innovations or to both.

[b]We use the term Internet to refer to the World Wide Web (WWW) enhancement to the Internet technology. Tim Berners-Lee invented the WWW in 1990, and the concept was first commercialized in 1991. Berners-Lee's invention consisted of three new technologies that remain in place today: HTML, URL, and HTTP. These technologies allowed for a user-friendly communication among computers, which made the Internet accessible to the general public.

shows the frequency with which a search term appears in published books through time. To measure radicalness and the potential for network effects, we use ratings obtained from participants in a Mechanical Turk (MTurk) study. While these ratings are provided post hoc (and could be affected by memory bias), they provide a consistent measure across our diverse sample of innovations. We describe below the MTurk and Google Ngram measures and the two data sources used to obtain them.

4.3.1. MTurk Study. We asked 100 participants in an MTurk study to rate the 51 innovations included in our sample on several dimensions relevant to our research. We requested that the participants be U.S. based, have a Human Intelligence Task (HIT) approval rate of 95% or higher, and have "masters" qualifications in MTurk. Participants were each paid $5 and took an average of 52 minutes to complete the survey.

At the beginning of the survey, we provided specific definitions for our characteristics of interest, along with examples of innovations that were not part of the list to be evaluated. We provided the most commonly referenced definitions of radical innovation, direct and indirect network effects, and disruptive innovation. We present these definitions in Web Appendix C. Disruptive innovations are initially inferior to existing products. However, through time, they improve and become the dominant players in the market (Sood and Tellis 2011). The "disruptive" dimension has not been studied previously in relation to stock prices, and is not part of our theoretical framework that links innovation with bubbles. We include this dimension in the MTurk survey to control for the possibility that *any* new product that is fundamentally different from the status quo might be associated with a bubble, not just radical innovations. Disruptive innovations, when introduced, do not provide higher consumer benefits than existing alternatives (unlike radical innovations). Therefore, comparing the effects of disruptive and radical innovation in relation to bubbles can yield interesting insights on how investors value products that provide significant increases in consumer benefits.

After providing the definitions and examples of radical, disruptive, direct network effect, and indirect network effect, we instructed participants to evaluate each innovation in relation to the existing technology at the time of its commercialization. For instance, we told participants that when they evaluate the color TV on the radical dimension, they should do so in relation to the black and white TV that was the standard when the color TV was commercialized. To facilitate this task, we listed innovations in the order of commercialization. For each characteristic, we presented respondents with our list of innovations and asked them to rate their agreement on a one-to-five scale (where 1 is "strongly disagree" and 5 is "strongly agree") that each innovation has that particular characteristic. We also allowed respondents to choose the following option: "I am not able to make an assessment." The survey included four reading checks. Only respondents who correctly completed all reading checks were able to finish the survey and obtain payment.

We use the average ratings across the 100 participants to measure the characteristics of the 51 innovations in our sample. The sample average of these average ratings is as follows: 4.10 for the radical dimension, 3.51 for disruptive, 3.44 for indirect network effects, and 3.25 for direct network effects.[9] We acknowledge that these post hoc ratings might not fully capture the consumer perceptions of these products at the time when they were introduced. However, we hope that this preliminary effort, which allows us to present some cross-sectional evidence on the association between innovation characteristics and stock market bubbles, will stimulate additional research on the valuation of distinct types of innovations.

4.3.2. Google Ngram Data. Given the span and scope of our sample, data on a single measure of diffusion—such as product-level sales—would be very difficult to obtain. Instead, to gain preliminary insight into the adoption of each innovation, we measure its contemporaneous visibility in the public domain using the annual frequency with which the innovation is mentioned in printed books. The numerator of this frequency measure is the number of times that a given word appears in print in all books digitized by Google in a given year. The denominator includes the total number of words in all books during the same year. For example, the Ngram value for the word "radio" in 1929 is 1.92×10^{-5}. Thus, the word "radio" represents one in every 52,035 words across all books published that year.

We use Google Ngram data to compute three measures of visibility of relevance to our study.[10] First, to test the intrinsic bubble model of Froot and Obstfeld (1991), we use Ngram frequencies measured during the year when the bubble is detected as a proxy for contemporaneous cash flows. Second, to measure the magnitude of postbubble visibility, we use the maximum value of Ngram frequencies achieved during the lifetime of the innovation, regardless of date, which is a proxy for the market saturation point. Third, the rate of increase in visibility is measured as the distance in time between the commercialization date and the inflection point in the time plot of Ngram frequencies. The inflection point, a proxy for takeoff, is the year with the largest positive change in the Ngram frequencies.[11]

To evaluate the extent to which visibility is an appropriate proxy for diffusion, we collect product adoption data for a subsample of 25 innovations. Adoption data for 24 of these innovations are obtained from the *Statistical Abstract of the United States*, published annually by the Bureau of the Census. In addition, we obtain adoption data for the Internet from the World Bank, which publishes annual measures of Internet usage per 100 inhabitants. We then compare the adoption data with the visibility data previously obtained from Google Ngram. The results are presented in Web Appendix D and in Table WA-D1. Panel A of Table WA-D1 shows our data sources and the particular measure of product adoption obtained for each of these 25 innovations. Panel B of Table WA-D1 compares the takeoff dates computed from visibility data with the takeoff dates computed from product adoption data. The two measures correlate very highly. Overall, the results presented in Web Appendix D suggest that the visibility measure computed from Google Ngram data is a good proxy for product adoption.

4.4. Detecting Stock Market Bubbles

We use the statistical method developed by West (1987) to detect the presence of bubbles in the time series of stock prices. For each innovation, we form a single test portfolio containing all firms shown in the rightmost column of Table 2. For each test portfolio, we compute a monthly value-weighted price index and, separately, a monthly value-weighted dividend index, using as weights the market capitalization of each stock at the end of the previous month. The Cowles data set already comes in the form of value-weighted test portfolios. In the end, this process produces 102 different time series, two series (dividends and prices) for each of the 51 innovations.

We perform a bubble test for each innovation using the price and dividend time series of its respective test portfolio. We require a minimum of 24 months to estimate the parameters of the model. After a bubble is detected, we continue the process until the model indicates that a bubble is no longer present. Our empirical specification is motivated by the model of West (1987), which begins with the no-arbitrage condition that the current-period stock price is equal to the discounted value of the next-period stock price and dividends

$$P_t = \rho_t E_t[P_{t+1} + d_{t+1}] + \epsilon_t, \tag{1}$$

where E_t is the expectation operator, $\rho_t = 1/(1 + k_t)$, and k_t is the discount rate for the stock at time t. West's (1987) model further assumes that the aggregate dividend of each test portfolio follows a zero-mean, AR(1) process

$$d_t = \varphi_t d_{t-1} + \nu_t. \tag{2}$$

From Equations (1) and (2), we obtain F_t^*, the fundamental value of the stock

$$F_t^* = \delta_t d_t, \tag{3}$$

where

$$\delta_t = \frac{\rho_t \varphi_t}{1 - \rho_t \varphi_t}. \tag{4}$$

If no bubble is present, the price of the stock, P_t, equals its fundamental value, F_t^*. Thus,

$$P_t = \delta_t d_t. \tag{5}$$

According to Equation (5), in the absence of bubbles, the observed stock price, P_t, should equal to a multiple δ_t of the current dividend d_t, where δ_t depends, as shown in Equation (4), only on the fundamental parameters that govern the stock's law of motion: ρ_t and φ_t.[12] However, if bubbles are present, the observed stock price P_t could be significantly higher. The bubble test consists of comparing δ_t estimated in Equation (5) with its intrinsic value estimated in Equation (4). If δ_t exceeds this intrinsic value, the stock price P_t is higher than the present value of its future dividends, implying that a bubble is present.

Empirically, the bubble test examines whether $\hat{\delta}_t = [\hat{\rho}_t\hat{\varphi}_t/(1-\hat{\rho}_t\hat{\varphi}_t)]$. This test requires that we compute $\hat{\delta}_t$, $\hat{\rho}_t$, and $\hat{\varphi}_t$, the empirical estimates of parameters δ_t, ρ_t, and φ_t, and that we do so for all values of t. We estimate $\hat{\rho}_t$ from Equation (1), $\hat{\varphi}_t$ from Equation (2), and $\hat{\delta}_t$ from Equation (4). The empirical specification for each of these equations includes an intercept and an error term.

We define H_t, a test statistic for detecting bubbles, as follows:

$$H_t = \left\{\hat{\delta}_t - \left[\hat{\rho}_t\hat{\varphi}_t/(1-\hat{\rho}_t\hat{\varphi}_t)\right]\right\}/\hat{\sigma}_t, \tag{6}$$

where $\hat{\sigma}_t$, the standard error of the H_t statistic, is computed using the heteroskedasticity-adjusted method of Newey and West (1987). This test statistic follows a chi-square distribution with two degrees of freedom (West 1987). We estimate H_t each month, t, for each innovation, beginning with the 25th month in the time series of returns and dividends.

Detecting the Beginning and End of the Bubble. A bubble is deemed to form in month t if the H_t statistic is significantly positive at the 10% level (two-tail test) during months t, $t+1$, and $t+2$. The bubble is deemed to continue beyond month $t+2$ so long as the H_t statistic remains significantly positive. Once a bubble is detected, we allow up to two consecutive months of insignificant H statistics before concluding that the bubble has ended. The bubble is deemed to end when the H statistic is no longer significantly positive and remains so for at least two months.

Measuring the Magnitude of a Bubble. We define mispricing as the difference between the observed price of the test portfolio and the fundamental value predicted by Equation (3). For each innovation, we compute mispricing for each month, t, during the bubble's existence. The peak of the bubble is deemed to occur when mispricing is highest. We measure the magnitude of the bubble as the ratio of mispricing to the fundamental value of the test portfolio, computed at the peak of the bubble. Its statistical significance is the p-value of the contemporaneous H_t statistic.

5. Results

We begin by performing a bubble test for each of the 51 innovations in our sample. The results are presented in Table 3. Our method identifies bubbles in approximately 73% of the innovations studied (37 out of 51 innovations). The results corroborate the presence of bubbles in a number of cases that had been conjectured in books and in the popular press. For example, we identify bubbles in the rail, telegraph, automobile, radio, airplane, and Internet industries. We also identify bubbles in innovations that had not been mentioned previously in the literature, such as the personal computer or the microwave oven. Finally, we find no evidence of bubbles in the remaining 14 innovations, which include the color TV and the electronic watch.

5.1. Economic Value Added

To measure the economic value added of each innovation, we compute the buy-and-hold abnormal returns (BHARs) of each innovation's test portfolio from the beginning to the end of the bubble. BHARs are obtained by subtracting the buy-and-hold returns of the stock market from the buy-and-hold returns of the test portfolio.[13] We compute this measure for each innovation. The statistical significance is obtained from the monthly time series variation using a t-test of paired differences. The results are presented in Table 4. The first column in Table 4 lists all 37 innovations for which we have previously identified bubbles, and the second column provides the year of commercialization. The third column in Table 4 shows the buy-and-hold returns of parent firms from the beginning to the end of the bubble. The fourth column shows the buy-and-hold returns of the market during that same period. The fifth column shows the BHARs, computed as the difference between the previous two columns. The last column shows the p-value for all positive values of BHAR.

Despite the presence of bubbles, we find evidence of positive economic value added for innovations in our sample. On average, firms in our test portfolios did well during the bubbles, both in absolute terms and by comparison to the market. A hypothetical investor who purchased a typical test portfolio immediately prior to the start of the bubble and remained invested throughout the bubble would have earned, at the end of the bubble, an average return of 65.01%, compared to an average market return of only 20.42%. The average difference of 44.58% is statistically larger than zero ($p = 0.0054$). In approximately 76% of the cases studied (28 out of 37), the test portfolio was worth more (in market-adjusted terms) at the end of the bubble than it was at the beginning. This fraction is statistically different from $\frac{1}{2}$ ($p = 0.0233$).

5.2. Do Bubbles Lead or Lag Visibility

We compare the start date of each innovation bubble with the takeoff in visibility (computed as the inflection

Table 3. Bubbles Associated with the Stock Prices of Innovating Companies

Innovation	Comm. year	Bubble detected?	Bubble start date	Bubble peak date	Bubble magnitude Value (%)	Bubble magnitude p-value	Bubble end date
Steam engine train	1825	Yes	8/1843	3/1844	31.1	0.0001	2/1845
Telegraph	1845	Yes	12/1870	2/1873	75.6	0.0123	9/1873
Incandescent vacuum lamp	1880	Yes	6/1892	10/1892	16.3	0.0410	4/1893
Automobile	1886	Yes	3/1919	11/1919	119.5	0.0166	9/1920
Portable camera	1888	Yes	7/1918	4/1921	101.1	0.0753	4/1921
Disk phonograph	1894	Yes	7/1906	4/1907	102.6	0.0014	1/1908
Motion pictures	1898	Yes	9/1921	9/1922	49.8	0.0002	5/1923
Photoelectric scanning fax	1907	No					
Electric clothes washer	1908	No					
Electric percolator	1908	No					
Electric toaster	1908	No					
Rayon	1910	Yes	2/1928	4/1928	24.4	0.0001	7/1928
Refrigerator	1916	Yes	4/1928	8/1929	369.3	0.0009	9/1930
Airplane	1919	Yes	1/1928	2/1929	183.9	0.0024	9/1929
Radio	1919	Yes	1/1928	8/1929	86.5	0.0252	11/1930
Electric typewriter	1920	Yes	4/1933	7/1935	51.8	0.0063	12/1935
Electric blanket	1930	Yes[a]	11/1938	11/1938	41.2	0.0972	10/1939
Electric dishwasher	1930	Yes[a]	11/1938	11/1938	41.2	0.0972	10/1939
Electric shaver	1930	No					
Electric garbage disposer	1935	Yes	11/1944	5/1945	12.0	0.0931	7/1945
TV	1936	Yes	2/1943	1/1946	50.3	0.0012	9/1946
Fluorescent light bulb	1938	No					
FM radio	1940	Yes	11/1947	5/1948	26.4	0.0871	3/1949
Ballpoint pen	1945	Yes	1/1955	3/1956	47.7	0.0001	9/1957
Magnetic tape player	1947	Yes	2/1960	6/1960	62.9	0.0001	8/1960
Microwave oven	1947	Yes	8/1965	2/1966	59.2	0.0002	4/1966
NTSC color TV	1954	No					
Electric can opener	1956	No					
Videocassette recorder	1956	Yes	12/1965	4/1966	79.1	0.0065	6/1966
Electronic watch	1957	No					
Cassette	1964	Yes	8/1969	11/1969	72.9	0.0001	3/1970
Electronic desktop calculator	1964	Yes	12/1971	10/1973	50.3	0.0001	6/1974
Electronic pocket calculator	1968	Yes	12/1971	1/1973	46.9	0.0001	11/1973
Dot-matrix printer	1970	No					
Single-player video game	1972	Yes	3/1979	11/1981	171.2	0.0029	1/1984
Digital LED watch	1975	No					
Disposable shaver	1975	Yes	6/1979	8/1979	20.1	0.0001	8/1979
Personal computer	1975	Yes	7/1982	5/1983	86.2	0.0031	8/1983
Laser printer	1976	No					
Laser disc player	1978	Yes	9/1983	12/1989	186.1	0.0454	6/1990
Mobile phone	1979	Yes	7/1986	12/1989	101.9	0.0001	8/1991
Camcorder	1983	Yes	1/1988	7/1988	50.7	0.0001	6/1990
Compact disc player	1983	Yes	10/1985	6/1987	93.5	0.0711	6/1987
Portable computer	1983	No					
Digital camera	1989	No					
Internet	1991	Yes	2/1998	2/2000	54.1	0.0001	3/2000
Minidisc player	1992	Yes	4/1992	1/1994	43.6	0.0010	8/1994
Digital video disc player	1997	Yes	12/1997	12/1997	58.5	0.0665	7/1998
Digital high-definition TV	1998	Yes	3/1999	6/1999	35.7	0.0936	6/1999
GPS receiver	2000	Yes	4/2007	9/2007	96.7	0.0001	12/2007
Smartphone	2000	Yes	8/2004	9/2005	134.9	0.0275	9/2005

Notes. The table shows the extent to which firms associated with each innovation experience stock price bubbles. Each bubble is identified using West's (1987) model, described in this paper. When the model detects a bubble, we show the start, peak, and end dates (year/month) of each bubble. The bubble peak date is the month with the largest difference between the observed price index of the test portfolio and its predicted price index from the model. At each peak date, we show the bubble magnitude as the percentage difference between observed prices and predicted values, and the corresponding p-value of the H-statistic from the bubble test.

[a]Because the electric blanket and the electric dishwasher were introduced in the same year (1930), and because the test portfolios for both products consist of the same firm (General Electric), we are only able to perform a joint bubble test for these two innovations. The bubble detected here could be attributed to either one of the two innovations or to both. We chose to attribute the bubble in the analysis to both innovations, but the results remain substantively the same if we attribute it to either one of the two innovations.

Table 4. Buy-and-Hold Returns for the Beginning to End of the Bubble Period

		Buy-and-hold returns from beginning to end of bubble (%)			
Innovation	Comm. year	Innov. stocks	Market	Difference (BHAR)	*p*-value
Steam engine train	1825	45.20	13.20	32.00	0.0135
Telegraph	1845	54.70	−22.90	77.60	0.0037
Incandescent vacuum lamp	1880	−4.33	−4.69	0.36	0.4599
Automobile	1886	38.80	0.00	38.80	0.1275
Portable camera	1888	88.10	−3.70	91.80	0.0144
Disk phonograph	1894	80.20	2.20	78.00	0.0264
Motion pictures	1898	35.40	34.50	0.90	0.2734
Rayon	1910	−14.60	7.90	−22.50	
Refrigerator	1916	54.30	−13.30	67.60	0.0321
Airplane	1919	128.90	54.30	74.60	0.1757
Radio	1919	18.50	−18.80	37.30	0.0232
Electric typewriter	1920	145.00	140.50	4.50	0.4992
Electric blanket	1930	−14.21	0.78	−14.99	
Electric dishwasher	1930	−14.21	0.78	−14.99	
Electric garbage disposer	1935	12.62	14.66	−2.04	
TV	1936	18.90	54.00	−35.10	
FM radio	1940	−0.16	−4.65	4.49	0.3254
Ballpoint pen	1945	1.80	15.30	−13.50	
Magnetic tape player	1947	34.47	2.94	31.52	0.1003
Microwave oven	1947	75.60	9.50	66.10	0.0216
Videocassette recorder	1956	3.02	−5.90	8.92	0.2777
Cassette	1964	10.10	−1.90	12.00	0.3073
Electronic desktop calculator	1964	53.04	−15.40	68.44	0.0065
Electronic pocket calculator	1968	97.21	−2.79	100.00	0.0021
Single-player video game	1972	36.84	80.74	−43.90	
Disposable shaver	1975	16.04	11.77	4.27	0.1837
Personal computer	1975	105.20	54.00	51.20	0.0797
Laser disc player	1978	264.44	92.06	172.38	0.0649
Mobile phone	1979	55.10	43.80	11.20	0.3858
Camcorder	1983	24.38	40.27	−15.89	
Compact disc player	1983	97.50	58.70	38.80	0.2398
Internet	1991	570.60	54.60	516.00	0.0018
Minidisc player	1992	50.86	18.22	32.65	0.2105
Digital video disc player	1997	12.75	13.43	−0.68	
Digital high-definition TV	1998	42.63	11.52	31.11	0.1258
GPS receiver	2000	64.80	3.90	60.90	0.0707
Smartphone	2000	115.70	15.90	99.70	0.0157
Average		65.01	20.42	44.58	0.0054

Notes. For each innovation where a bubble has been detected, the table shows the buy-and-hold returns realized by firms associated with the innovation, the buy-and-hold returns of the stock market during the same period, and the buy-and-hold abnormal returns (BHARs), consisting of the difference between the previous two variables. These abnormal returns provide a measure of the economic value added by the innovation during the bubble period. The last column provides the *p*-value of a test that each BHAR is significantly higher than zero (for positive BHARs). The last row in the table shows the sample mean of all variables, as well as the *p*-value of a test that the sample mean BHAR is equal to zero.

point in the Google Ngram data). On average, bubbles lead the takeoff in visibility, which is what we would expect if market investors are forward looking.

Of the 37 innovation bubbles in our sample, 28 start no later than the takeoff in visibility. For a formal statistical test, we calculate the difference (in years) between the year when the bubble starts and the year when the visibility takes off. We then average this difference across the 37 innovation bubbles in our sample. On average, bubbles lead visibility by approximately 4.5 years, and this difference is statistically different from zero ($t = 2.90$).

5.3. Determinants of Bubbles

We now turn to examining the determinants of bubbles. Table 5 presents the results. The dependent variable in Table 5 is the magnitude of the bubble for innovations where bubbles were detected. For the remaining innovations, the dependent variable is set to zero. We use a Tobit model to account for the fact that the magnitude of the bubble is left-censored to zero. The first four independent variables in Table 5 are the characteristics of innovations previously mentioned: radical, disruptive, indirect network effects, and direct network effects. These variables represent the

Table 5. Factors Related to the Magnitude of Innovation Bubbles

Dependent variable: *Bubble_Mag* (*Magnitude of the Innovation Bubble*)						
Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Radical	82.92	83.60	86.82	87.43		
	*2.562***	*2.322***	*2.826****	*2.862****		
Disruptive	−86.92	−119.8	−77.04	−76.42		
	*−2.097***	*−2.476***	*−1.954**	*−1.951**		
Indirect Network Effects	55.33	87.93	58.96	58.20		
	*1.800**	*2.243***	*2.014***	*2.002***		
Direct Network Effects	−21.06	−44.14	−37.91	−38.53		
	−0.859	*−1.388*	*−1.533*	*−1.57*		
Ngram_Start			3.70		4.14	
			*2.057***		*2.161***	
Ngram_Peak				3.93		4.37
				*2.182***		*2.275***
Intercept	−112.7	−42.79	−140.2	−142.4	20.98	18.74
	−0.945	*−0.316*	*−1.234*	*−1.261*	*1.314*	*1.152*
AIC	457.02	366.59	454.98	454.49	459.71	459.25
No. obs.	51	43	51	51	51	51

Notes. The table shows the results of six models that relate the magnitude of the innovation bubble (*Bubble_Mag*) to two different categories of independent variables. The first category evaluates the extent to which the innovation (i) is *Radical*, (ii) is *Disruptive*, (iii) has *Direct Network Effects*, and (iv) has *Indirect Network Effects*. This evaluation is performed through an MTurk survey of 100 qualified respondents. The second category is the extent to which the innovation has been featured in books—as captured by Google Ngram frequencies—(i) up to the time when a bubble is detected (*Ngram_Start*) and (ii) up to the year of the peak of the bubble (*Ngram_Peak*). When no bubbles are detected, we compute estimated start and peak dates for the bubble based on the year of product commercialization. In such cases, *Ngram_Start* and *Ngram_Peak* are computed using Ngram frequencies based on the estimated (rather than actual) start and peak years of the bubble. Models 1 and 3–6 are estimated using the entire sample of 51 innovations. Model 2 is confined to the sample of radical innovations included in Chandy and Tellis (2000). The dependent variable is the *Bubble_Mag* when a bubble is detected. When a bubble is not detected, *Bubble_Mag* is set to zero. All models are estimated using a Tobit specification, which accounts for the magnitude of the bubble being censored at zero. The t-statistics are shown in italics under each coefficient.

*, **, and *** denote coefficients that are statistically significant at the 10%, 5%, and 1% levels, respectively.

average ratings provided by MTurk respondents on each characteristic. The remaining independent variables are two alternative proxies for the contemporaneous visibility of the innovation. They are obtained using the Ngram frequencies at the start of the bubble, and, alternatively, using the Ngram frequencies at the peak of the bubble.

In Model 1 we show that the magnitude of the bubble is positively related to the radical innovation measure ($\beta = 82.92$, $p < 0.05$) and negatively related to the disruptive innovation measure ($\beta = -86.92$, $p < 0.05$). The negative effect of the disruptive characteristic suggests that it is difficult for investors to forecast whether a new technology that is initially inferior to existing alternatives might one day improve and surpass these alternatives in performance. In regard to network effects, we find a significant positive association between the magnitude of the bubble and the presence of indirect network effects ($\beta = 55.33$, $p < 0.10$). However, the relation with direct network effects is insignificant. This could be due in part to the high correlation between indirect and direct network effects, but it is also possible that indirect network effects might be more closely aligned with the concept of exploding expectations mentioned in Section 2. Investor enthusiasm will be heightened if an innovation not only has the potential to generate significant growth in its own industry, but could also gain additional functionality through complementary products that would enhance its consumer benefits. Accurately determining all categories in which complementary products may be introduced, as well as the demand for these complementary products, could be even more difficult than assessing the primary demand for the focal innovation; optimism toward the innovation's potential could be compounded by optimism about complementary products. In Model 2 we show that these results also hold for the subset of radical innovations listed in Chandy and Tellis (2000), which constitute a more conservative subsample for our study.

The Ngram visibility variables are introduced in Models 3 through 6. As conjectured previously, we find a significantly positive relation between the bubble magnitude and the visibility of the innovation measured at the beginning of the bubble ($\beta = 3.70$, $p < 0.05$ in Model 3 and $\beta = 4.14$, $p < 0.05$ in Model 5) and at the peak of the bubble ($\beta = 3.93$, $p < 0.05$ in Model 4 and $\beta = 4.37$, $p < 0.05$ in Model 6). These results are consistent with the intrinsic bubble theory of Froot and Obstfeld (1991).[14]

5.4. Capital Raised and Postbubble Visibility of Innovations

In our next set of tests, we measure the amount of new equity capital raised during the bubble period and

Table 6. Analysis of Net Capital Raised and Postbubble Visibility

Panel A: Univariate statistics

Variable: Name	Variable: Description	Number of obs.	Mean value	t-stat.	p-value
DCapRaised	Market-adjusted capital raised during bubble	38	0.1857	1.65	0.1064$^{\Delta}$
*DCapRaised*2	Market-adjusted capital raised before and during bubble	37	0.2795	1.94	0.0602*
Ngram_Max	Highest value of Ngram for innovations with bubbles minus that of innovations without bubbles	38	2.1622	2.33	0.0256**
Ngram_Inflex	Time to inflection point for innovations with bubbles minus that of innovations without bubbles; time to inflection point is the difference, in years, between the commercialization date and the date when variable Ngram reaches its inflection point through time	38	4.5929	1.11	0.2727

Panel B: Cross-sectional analysis

Dependent variable	*CapRaised*	*DCapRaised*	*Ngram_Max*					*Ngram_Inflex*				
Indep. variables	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14	Model 15	Model 16	Model 17	Model 18
Bubble_Mag	0.00523	0.00575			0.0224	0.0168	0.0169			−0.0399	−0.0212	−0.0210
	2.48**	*2.82****			*2.46***	*1.91**	*1.80**			*−1.28*	*−0.79*	*−0.73*
CapRaised			1.5275			1.0576		−4.1631			−3.5719	
			5.50***			*3.14****		*−2.26***			*−2.22***	
DCapRaised				1.4806			0.9467		−3.9418			−3.2794
				5.68***			*2.89****		*−2.19***			*−2.04***
Intercept	−0.1240	−0.1237	5.5365	5.5018	4.5729	4.7040	4.6900	12.9706	13.0479	14.4609	14.0179	14.0552
	−0.80	*−0.82*	*13.53****	*13.09****	*8.82****	*9.62****	*9.47****	*7.02****	*6.97****	*5.52****	*5.24****	*5.19****
R-square	0.1458	0.1813	0.1614	0.1475	0.1847	0.2508	0.2341	0.0676	0.0590	0.0331	0.0756	0.0665
Number of obs.	38	38	38	38	38	38	38	38	38	38	38	38

Notes. The table shows an analysis of net capital raised and postbubble visibility for the 38 innovations in our sample that were commercialized in 1919 and later, beginning with the radio and the airplane. *CapRaised* is the percentage of capital raised during the bubble period divided by the market value of equity before the bubble. *DCapRaised* is the difference between *CapRaised* and the percentage capital raised by the entire stock market during that same period. *DCapRaised2* is the same as *DCapRaised* except that it is measured beginning with the commercialization date through the end of the bubble. All three values are winsorized at the 99th percentile to mitigate the effect of outliers. The postbubble visibility is measured with *Ngram_Inflex* (the difference, in years, between the commercialization date and the date when the Ngram time series reaches its inflection point) and with *Ngram_Max* (the maximum value of the Google Ngram frequency during the lifetime of an innovation). *Bubble_Mag* is the magnitude of the innovation bubble; when a bubble is not detected, *Bubble_Mag* is set to zero. Panel A shows univariate descriptive statistics, and panel B presents cross-sectional regressions. Standard errors in Models 9 through 18 are corrected for heteroskedasticity using White's method (1980). The t-statistics are shown in italics in panel B.

*, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively (two-tailed test); $^{\Delta}$ denotes a coefficient that is marginally insignificant ($p = 0.1064$).

examine how this new capital relates to the postbubble visibility of innovations. The results are presented in Table 6.

Panel A of Table 6 provides univariate statistics for the dependent variables. The first two variables in panel A are measures of market-adjusted equity raised by parent firms around the bubble period. The first of these variables, *DCapRaised*, measures equity raised during the bubble period only. The second variable, *DCapRaised*2, measures the equity raised between the commercialization date and the end of the bubble. Both variables are computed as the amount of new equity raised by parent firms divided by the market value of equity of these parent firms at the beginning of the bubble, minus the equivalent ratio of equity capital raised by the broader stock market during the same period.[15] On average, firms in our sample are able to raise new equity capital during the bubble corresponding to 18.57% of these firms' market value of equity at the beginning of the bubble. The result is borderline insignificant (p = 0.1064), perhaps because of the low power of the small sample size ($N = 38$). Better statistical significance is achieved when the new equity raised is measured over a longer period—from the commercialization date until the end of the bubble. In this case, the average equity capital raised is 27.95% ($p = 0.0602$).[16]

Turning now to the postbubble visibility of the innovation, the third variable in panel A, *Ngram_Max*, shows the difference between the average of the highest value of Ngram frequencies achieved by innovations with bubbles and the same average achieved by innovations without bubbles. As conjectured, this difference is positive and statistically significant ($p = 0.0256$), suggesting that innovations with bubbles become significantly more visible during the postbubble period.

The fourth variable in panel A, *Ngram_Inflex*, measures the length of time between commercialization and the Ngram inflection point computed for innovations with bubbles, minus that for innovations without bubbles. As conjectured, innovations with bubbles have a higher rate of increase in postbubble visibility: the Ngram inflection point is achieved 4.59 years earlier, on average, when compared to innovations without bubbles. This result, however, is not statistically different from zero, perhaps because of the low power of the test. Another possibility is that the capital raised during the bubble may be the factor that leads to a faster takeoff rather than the magnitude of the bubble itself. We examine this possibility in our cross-sectional analysis.

The results of the cross-sectional analysis are shown in panel B of Table 6. The first two models in panel B examine the relation between new equity capital raised during the bubble (the dependent variable) and the magnitude of the bubble. In Model 7, the dependent variable is the actual amount of equity capital raised (as a fraction of prebubble capital) *without any market adjustment*. In Model 8, the capital raised is market adjusted. The independent variable in both models is the magnitude of the bubble. As discussed previously, the magnitude of the bubble could be inversely proportional to the cost of equity during the bubble. The results in Models 7 and 8 show that, on average, firms raise more equity capital when the magnitude of the bubble is higher ($\beta = 0.00523$, $p < 0.05$ in Model 7 and $\beta = 0.00575$, $p < 0.01$ in Model 8), perhaps taking advantage of temporarily lower funding costs.

In Models 9 through 13 of panel B, the dependent variable is the maximum level of visibility achieved by each innovation subsequent to the bubble (measured using Ngram frequencies). In Models 14 through 18, the dependent variable is the time distance between commercialization and the inflection point of the Ngram time series. This time distance is the inverse of the rate of increase in postbubble visibility. The independent variables in Models 9 through 18 are the magnitude of the bubble and the two measures of equity capital that had been previously used as dependent variables (in Models 7 and 8).

The results from Models 9 through 13 show that the maximum postbubble visibility is positively related to the new capital raised during the bubble ($\beta = 1.5275$, $p < 0.01$ in Model 9 and $\beta = 1.4806$, $p < 0.01$ in Model 10) and to the magnitude of the bubble ($\beta = 0.0224$, $p < 0.05$ in Model 11). When both independent variables are included (Models 12 and 13), the coefficients remain statistically significant.

The results from Models 14 through 18 show that the time lag between commercialization and the Ngram inflection point is negatively related to the amount of new capital raised during the bubble, but not to the magnitude of the bubble. The coefficient of the new capital raised is $\beta = -4.1631$, $p < 0.05$, in Model 14; $\beta = -3.9418$, $p < 0.05$, in Model 15; $\beta = -3.5719$, $p < 0.05$, in Model 17; and $\beta = -3.2794$, $p < 0.05$, in Model 18. This suggests that the effect of the bubble magnitude on the rate of increase in visibility is channeled through the new capital raised during the bubble, rather than through the bubble itself.

Overall, the results in panel B of Table 6 suggest that parent firms faced with larger stock market bubbles raise more capital, on average. In turn, this capital is positively related to the maximum visibility achieved by each innovation (postbubble) and to the rate of increase in this visibility.

5.5. Macroeconomic Factors Impacting Bubbles

A common hypothesis in the popular press is that bubbles are fueled by the availability of cheap credit (Kindleberger and Aliber 2005, Wood 2006) and by the collective frenzy afflicting investors during good economic times (Perez 2002). We find no support for this hypothesis. We use two different approaches to determine whether macroeconomic conditions explain the occurrence of innovation bubbles. First, we estimate a negative binomial model in which the dependent variable is the number of innovation bubbles encountered each year during the period from 1800 to 2010.[17] Independent variables include the level of interest rates that year, the growth rate in gross domestic product (GDP) over the previous year, the ratio of national debt to GDP, and the ratio of the monetary base to GDP. None of these independent variables are statistically significant (the results are available from the authors on request).

Second, we evaluate the possibility that innovation bubbles in our sample might be caused by contemporaneous marketwide bubbles. To do so, we use West's (1987) model to determine whether marketwide bubbles occur during the same time periods as the innovation bubbles detected in Table 3. The results are presented in Table 7. We detect simultaneous stock market bubbles in 50% of the innovations studied (18 out of 36).[18] This fraction is significantly different from unity ($p < 0.0001$). Moreover, in 83% of the cases (15 out of 18), the magnitude of the marketwide bubble is smaller than the magnitude of the innovation bubble. This fraction is significantly different from $\frac{1}{2}$ ($p = 0.0365$).

Table 7. Contemporaneous Market Bubbles

			Bubble magnitude (%)		
Innovation	Comm. year	Market bubble detected?	Innov. stocks	Market	Difference
Steam engine train	1825	Yes	31.10	15.04	16.06
Telegraph	1845	Unknown	75.60	n/a	n/a
Incandescent vacuum lamp	1880	No	16.25		16.25
Automobile	1886	No	119.50		119.50
Portable camera	1888	No	101.10		101.10
Disk phonograph	1894	No	102.60		102.60
Motion pictures	1898	Yes	49.80	24.93	24.87
Rayon	1910	No	24.40		24.40
Refrigerator	1916	No	369.30		369.30
Airplane	1919	Yes	183.90	19.38	164.52
Radio	1919	Yes	86.50	19.38	67.12
Electric typewriter	1920	Yes	51.80	291.30	−239.50
Electric dishwasher	1930	Yes	41.24	7.10	34.14
Electric blanket	1930	Yes	41.24	7.10	34.14
Electric garbage disposer	1935	Yes	11.97	29.80	−17.83
TV	1936	Yes	50.30	29.76	20.54
FM radio	1940	No	26.41		26.41
Ballpoint pen	1945	Yes	47.70	27.86	19.84
Microwave oven	1947	No	59.20		59.20
Magnetic tape player	1947	No	62.90		62.90
Videocassette recorder	1956	No	79.14		79.14
Cassette	1964	No	72.90		72.90
Electronic desktop calculator	1964	Yes	50.31	20.85	29.46
Electronic pocket calculator	1968	Yes	46.90	20.85	26.05
Single-player video game	1972	No	171.16		171.16
Personal computer	1975	Yes	86.20	24.46	61.74
Disposable shaver	1975	No	20.10		20.10
Laser disc player	1978	No	186.11		186.11
Mobile phone	1979	Yes	101.90	20.86	81.04
Compact disc player	1983	Yes	93.50	15.35	78.15
Camcorder	1983	Yes	50.69	91.35	−40.65
Internet	1991	Yes	54.10	8.27	45.83
Minidisc player	1992	No	43.60		43.60
Digital video disc player	1997	No	58.50		58.50
Digital high-definition TV	1998	No	35.68		35.68
GPS receiver	2000	Yes	96.70	9.96	86.74
Smartphone	2000	No	134.90		134.90
Average			79.33	18.99	60.44

Notes. For each innovation where a bubble has been detected, the table shows the result of West's (1987) bubble test applied to the entire stock market at the time of the innovation bubble. When a marketwide bubble is detected, the table provides the magnitude of the market bubble (in percentage points). We are unable to conduct a market bubble test for the telegraph because of the absence of market dividend data during that period. The last column of the table shows the difference between the magnitude of the innovation bubble and the magnitude of the marketwide bubble. When no marketwide bubble is detected, the magnitude of the marketwide bubble is assumed to be zero for the purpose of computing this difference. The last row in the table shows the sample mean of the following bubble magnitudes: (i) all innovation bubbles, (ii) all market bubbles (including the values of zero previously mentioned), and (iii) the difference between the innovation bubble and the market bubble.

In addition, the difference in magnitude between marketwide bubbles and innovation bubbles is significantly negative ($p = 0.0699$). Finally, innovation bubbles tend to lead market bubbles, on average. Of the 18 market bubble cases, the innovation bubble leads the market bubble in 10 cases and lags the market bubble in 4 cases. In the remaining four cases, the innovation bubble begins at the same time as the market bubble. These results suggest that innovations are the ones spurring bubbles in the overall market, not the other way around.[19]

In short, we find no evidence that innovation bubbles are driven by low interest rates, by expansion in the monetary base, by high GDP growth, or by bubbles in the broader stock market. While it is entirely possible that other types of bubbles could be ignited by such macroeconomic conditions, innovation bubbles appear to be ignited by the innovation per se. This conclusion is consistent with the findings of Frehen et al. (2013), who show that the Dutch wind trade and South Sea Bubbles of 1720 were driven by innovation. The conclusion is also corroborated by the fact that we are detecting two innovation bubbles during the Great Depression of the 1930s, a period known for tight monetary policy and low economic growth.

6. Discussion and Conclusion

We explore a new facet of the interaction between the stock market and the consumer product market—the association between innovation and stock market bubbles. We examine 51 major innovations that were commercialized during the 19th and 20th centuries. In 37 of these 51 cases, we detect the presence of bubbles in the stock price of parent firms. We show that these bubbles are more likely to occur for innovations that are radical and that have the potential to generate indirect network effects. Moreover, the magnitude of these bubbles is proportional to the visibility of the underlying innovation at the time of the bubble, as measured by the contemporaneous frequency with which the innovation appears in books, obtained from Google Ngram. Parent firms that experience bubbles are shown to raise additional equity capital during the bubble period. In turn, this new equity capital is positively related to the magnitude and to the rate of increase in the visibility of the innovation after the bubble. Below we summarize our paper's contribution to theory, practice, and policy making; discuss the limitations of our research; and provide a set of implications and directions for future research.

6.1. Contributions to Theory, Practice, and Policy Making

To our knowledge, our study presents the most comprehensive evidence of a systematic association between innovations and bubbles. The popular press has long conjectured that technological revolutions and bubbles seem to go hand in hand, often attributing the cause of these bubbles to investor irrationality. However, there is insufficient academic evidence to support this conjecture. While a few studies in financial economics evaluate the presence of bubbles around innovations, these studies tend to focus on one or two industries and generally treat innovation as an undifferentiated output of the aggregate production function. Moreover, most studies do not provide formal statistical tests for bubbles, and there is still a significant degree of disagreement among authors about the causes and economic consequences of bubbles.

On the other hand, marketing studies do a better job at recognizing heterogeneity among various types of innovation and their impact on shareholder value (e.g., Pauwels et al. 2004, Sood and Tellis 2009, Sorescu and Spanjol 2008). However, the marketing literature does not explore the association between innovation, bubbles, and capital raised, or, more generally, the manner in which the new product market interacts with the stock market. Our paper seeks to bridge the gap between the innovation literatures in marketing and in financial economics by illustrating one way in which the marketing and finance functions come together to create and support economically significant innovation.

The financial consequences we document in this paper are noteworthy additions to the marketing literature and provide managers with actionable guidelines when major innovations appear on their radar screens. While these innovations are expected to be associated with stock price bubbles, they are also expected to add significant value to the parent firm after bubbles deflate. Thus, investing in the commercialization of innovations appears to be worthwhile, especially since bubbles seem to create a favorable environment for firms to raise cheap equity capital without sending negative signals to the market.

Our results challenge some of the views expressed in the popular press about the association of innovations with bubbles. We show that innovation bubbles are not confined to "technological revolutions." Table 3 shows a number of bubbles surrounding radical innovations (such as the microwave oven) in time periods that are not normally associated with technological revolutions. Moreover, we find no evidence that bubbles are fueled by strong GDP growth or by loose monetary policy. For example, we document two bubbles during the 1930s, a period of declining GDP and tight monetary policy. In short, innovation bubbles appear to be intrinsic to the innovation per se, and seem to be unrelated to aggregate macroeconomic conditions.

While more research is needed to fully understand the relation between bubbles, issuance of new equity capital, and the diffusion of innovations, the evidence presented in this paper suggests that bubbles could actually foster economic growth by facilitating the development of new infrastructure. This finding is consistent with the predictions of Olivier (2000). In spite of bubbles, innovating firms have higher stock market gains at the end of a bubble compared to the gains realized by the stock market as a whole during the same period. The negative consequences of bubbles are most likely confined to new investors who buy overvalued stocks close to the height of the bubble. These findings suggest that economic policies designed to suppress bubbles might be misguided. These implications are limited to bubbles that are spurred by important technological breakthroughs and cannot be extended to other types of bubbles, such as bubbles on intrinsically useless assets (e.g., tulip bulbs), bubbles caused by fraud (e.g., Enron), or bubbles possibly fueled by loose monetary policy.

6.2. Limitations

6.2.1. A Caveat on the Econometric Measurement of Bubbles. All econometric models that attempt to detect the presence of bubbles (including West 1987) are testing a joint null hypothesis that (i) no bubble is present and (ii) the correct dividend expectation model is used.

Rejecting the null hypothesis implies *either* that a bubble is present *or* that we are using the wrong dividend expectations model. While this problem does not have an econometric resolution, we offer a conceptual argument in favor of the bubble interpretation: the alternative interpretation—the wrong dividend model—carries the embedded assumption that the 37 innovations for which we detect bubbles *could have* generated even higher cash flows, but did not do so because of bad luck; that is, from an ex ante perspective, these innovations must have offered a nonzero probability of a subsequent increase in earnings at a rate significantly higher than what was actually observed in reality. Yet, by bad luck, this possibility never materialized. By contrast, the bubble explanation does not require this type of assumption and appears, at least to us, to be more credible. We acknowledge, however, that despite the weight of the evidence presented, one can never be certain that the price patterns shown in this paper are true bubbles as opposed to bubble-free valuations in anticipation of extraordinary events that never materialized.

6.2.2. Discussion of Causality. We do not claim that we can unequivocally establish a causal relation between innovation and bubbles. We mainly aim to provide formal statistical tests that document stock market bubbles across the largest set of innovations identified to date. It is difficult to establish a causal relation between innovation and bubbles because the nature of our data—rare historical events—is not conducive to a formal statistical test of causality. Thus, we cannot exclude the alternative interpretation that bubbles and innovations might be jointly caused by a third, unknown factor, such as periodic changes in social norms that could foster both creativity in the product market and optimism in the stock market.

We note, however, that our paper's managerial implications do not change under this alternative hypothesis. To the extent that firms can take advantage of bubbles to raise equity capital on favorable terms, and to the extent that this new capital can facilitate the diffusion of the innovation, it does not matter whether bubbles are caused by innovation or whether both are jointly caused by a third factor, so long as both phenomena occur simultaneously. In both cases, our recommendations to policy makers and managers remain the same.

6.2.3. Data Limitations. Despite the significant effort invested into assembling our data, the sample is not without limitations. First, our sampling scheme consists of a set of commercially successful innovations. Over the time span of our sample, there could have been other new products introduced that had the potential to be radical and generate network effects but eventually failed in the marketplace. However, we note that this type of selection bias is a limitation that is common in the radical innovation and diffusion literatures, whereby most authors take a post hoc view in assembling the sample. Second, we were not able to control for the sales of each innovation as a percentage of the parent firm sales. We used archival data to qualitatively determine the extent to which each innovation was an important part of the firm's product portfolio at the time of commercialization. We endeavored to limit our test portfolios, as much as possible, to pure-play firms. However, we recognize that, despite our best efforts, there will be some variation in our sample in terms of the importance that the focal innovation plays in the product portfolio of its parent firm. This variation leads to an error in measurement problem that attenuates the coefficients in Table 6 toward zero. Thus, the results presented in Table 6 should be viewed as conservative.

6.3. Directions for Future Research

Our paper suggests five promising avenues for future research. First, our results imply that publicly traded firms might have a resource advantage when it comes to commercializing innovation because of the ease of access to new equity capital, particularly during bubble periods. If so, are privately held corporations at a disadvantage? Does the pattern of venture capital investment in private firms follow the patterns observed in the public equity markets?

Second, while we provide first-order evidence of the association between bubbles, external financing, and innovation, additional studies are needed to understand specifically how this new capital is actually deployed and how it affects the diffusion of the new product.

Third, the theory on intrinsic bubbles suggests that marketing metrics may play a critical role in determining the market value of firms in new industries. An important implication of this theory is that in the absence of accurate forecasts about long-term cash flows, investors are likely to anchor their valuation on observable short-term metrics of performance, and valuations are likely to exceed intrinsic values for a period of time. These short-term metrics most likely come from the product market, as opposed to the financial market, because information from the product market is typically the first to become available to investors. This is evidenced by examples in the dot.com era, where valuations were multiples of website traffic, or from more recent examples in the social media domain, where valuations are multiples of the number of users. Therefore, marketing metrics could play a critical role in determining the market value of companies in new industries. While our findings are certainly consistent with this interpretation, additional research is needed to provide a more direct link between marketing metrics and the valuation of companies that pursue a significant innovation strategy.

Fourth, the extent to which firms can appropriate gains from innovations associated with bubbles requires additional study. While we show in our paper that these innovations have a positive economic value added, we have not controlled for variations that may arise from firms' differential ability to protect their innovations through patents. Should a firm be able, through a strong patenting effort, to prevent competitors from commercializing the same technology, the firm might obtain monopolistic profits, but might also miss out on the network effects that arise when competitors leverage the same technology. These trade-offs are a fruitful area of future research.

Fifth, the social benefits of cheap equity financing provided by innovation bubbles must be evaluated against their social costs. The magnitude of these social costs depends, in part, on how these bubbles affect the aggregate disparity of wealth in the society. Shiller (2015) and Perez (2002) both hypothesize that bubbles have contributed to a significant increase in the disparity of wealth observed during the past 100 years, and Piketty (2013) presents evidence consistent with this prediction. If true, there is perhaps a significant hidden social cost of innovation bubbles, as no stable society appears to have survived over the long term when the levels of wealth became extremely concentrated.[20] Future research is needed to understand the relation between innovation bubbles and wealth inequality.

We hope that our research provides an impetus for others to further study the effects of innovation at the macro level, including their relation to the stock market, to economic growth, and to economic policy. At the micro level, we hope that our research can help managers better navigate through the perils of major shifts in technological paradigms and even learn how to profit from periods of temporary overvaluation that might provide windows of opportunity to obtain external financing on favorable terms.

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Endnotes

[1] As we describe in detail in Section 4, we do not measure diffusion directly; rather, we use a contemporaneous measure of the public visibility of innovations that is based on Google Books Ngram data. For a subsample of innovations, we show in Section 4 that the Ngram visibility data correlate highly with the actual diffusion data based on product adoption.

[2] The nine innovations mentioned by Shiller (2015) are the phonograph, electricity, trains, the automobile, radio, electrification, motion pictures, TV, and the Internet. However, Shiller (2015) does not conduct formal statistical tests to document the existence of the bubbles associated with these nine innovations.

[3] We do not focus here on the exact mechanism that might trigger a rational bubble; we only study boundary conditions that are conducive to the emergence of rational bubbles. The literature in financial economics discusses several trigger mechanisms for rational bubbles (e.g., Allen et al. 1993, Zeira 1999). Common among these papers is the idea that when the cost of entry into the stock market is low and there is asymmetric information among investors, an excessive number of investors will enter the stock market, driving the price of the stock temporarily above its intrinsic value. We note a very interesting parallel between this mechanism and the one that in the marketing literature has been shown to trigger excessive entry of firms into a new industry. Specifically, Shen and Villas-Boas (2010) and Shen (2014) show that under similar conditions of low entry costs into the product market and information asymmetry among firms, an excessive number of firms will enter a new industry, driving economic rents to become negative. Interestingly, both actions are perfectly rational.

[4] For example, *The Economist* (2000) observed that "technological revolutions and financial bubbles seem to go hand in hand," while Gross (2009) is featured on CNN Money under the title "The bubbles that built America" (see http://money.cnn.com/galleries/2007/news/0705/gallery.bubbles/index.html.).

[5] Even when several firms start commercializing a major innovation around the same time, their stocks are likely to be perceived as having a similar level of risk. Therefore, risk cannot be diversified away by investing in a portfolio of firms that manufacture the same radical innovation.

[6] We excluded 21 innovations from Chandy and Tellis (2000) for the following reasons: 12 innovations were excluded because none of the parent firms were publicly traded at the time of commercialization. Four additional innovations were excluded because dividend or price data were not available. Three innovations were considered duplicates of innovations already in our sample. One innovation was excluded because none of the parent firms were pure plays. The final innovation (telephone) was excluded because of the lack of data for Bell at the time of commercialization and because Bell's successor (AT&T) became a regulated utility in 1910. Firms in regulated industries typically face a cap on revenues that rules out the bubble solution in the Blanchard and Fischer (1989) model. A full explanation for each of these exclusions is presented in Web Appendix B.

[7] All of our bubble tests are performed on single time series, even those that are based on a large portfolio of firms. Specifically, if an innovation portfolio contains two or more firms, we begin by aggregating their prices and dividends into single industry-specific time series and perform the tests on these two aggregate time series as if the entire portfolio were a single firm. Moreover, the theory that underlies the formation of bubbles posits that firms commercializing the same innovation have the same probability of experiencing a bubble, as the bubble arises exogenously to firm characteristics, being driven instead by the characteristics of the innovation that meets the four conditions described in Section 2.1. Consequently, our results should not be affected by the number of firms included in each portfolio.

[8] A multiproduct firm can be viewed as a conglomerate of smaller, pure-play firms. Assuming that only one of the firm's products is innovative—and therefore subject to a potential bubble—the stock price of the multiproduct firm is likely to experience a smaller bubble than the stock of a pure play firm in the same industry. Therefore, the inclusion of multiproduct firms in our test portfolios creates an error in the measurement of the magnitude of innovation bubbles. In some of the tests we perform in Section 4, this measurement error is inconsequential because the bubble magnitude is used as a dependent variable. In other tests, where the bubble magnitude is an independent variable, the consequence of the measurement error is to reduce the coefficients toward zero, resulting in a more conservative test.

[9] Moreover, the ratings vary significantly across innovations to allow for a meaningful cross-sectional analysis. For the radical dimension, average ratings vary from 3.00 to 4.80; for the direct network dimension, they vary from 2.04 to 4.94; for the indirect network dimension, they vary from 2.09 to 4.65; and for the disruptive dimension, they vary from 2.63 to 4.35. The list of average ratings for all innovations for each of the four characteristics is presented in Web Appendix C. The correlations between these ratings range from 0.55 (correlation between disruptive and direct network effects) to 0.81 (correlation between direct and indirect network effects). The full correlation matrix is also presented in Web Appendix C.

[10] Ngram frequencies vary significantly in terms of order of magnitude from 10^{-5} to 10^{-9}, and, in some cases the Ngram count is identically zero. Therefore, all Ngram frequencies are adjusted using the natural log of $(1 + (RawNgram \times 10^{+9}))$, where *RawNgram* is the actual, raw Ngram frequency downloaded from Google. We do this to improve interpretability and mitigate the effects of heteroskedasticity.

[11] This is the discrete-time equivalent of setting the second derivative equal to zero.

[12] Parameter ρ_t is related to the *discount rate* for the stock, k_t, as follows: $\rho_t = 1/(1 + k_t)$. Parameter φ_t is related to the annual *growth rate of dividends*, g_t, as follows: $\varphi_t = (1 + g_t)$. This estimation is performed each month, t, over periods of time that start 24 months after the beginning of the time series. Progressively, each period of time is nested within the time period used during the subsequent month. For example, when we attempt to detect a bubble in month $t = 30$, we estimate parameters using data from months $t = 1$ to $t = 30$. The following month, when attempting to detect a bubble in month $t = 31$, we reestimate parameters with data from months $t = 1$ to $t = 31$, so the first time interval is nested within the second. Thus, the test allows for estimates of growth and discount rates to change over time; each month, the test produces an intertemporal average estimate of discount rates and growth rates, which takes into account all information available prior to that month.

[13] For example, for a bubble that starts in March 1887 and ends in June 1888, we would compute the buy-and-hold return of the test portfolio from March 1887 through June 1888 and subtract from it the buy-and-hold return of the market portfolio during that same period. If the buy-and-hold return of the test portfolio is 20% and the buy-and-hold return of the market is 5%, we would conclude that the focal innovation adds 15% in terms of economic value, even after accounting for the collapse of the bubble.

[14] The results remain substantively the same if Rayon is excluded from the sample. These results are presented in Web Appendix E.

[15] The amount of new equity raised is computed as the product of the number of shares issued times the price per share, adjusted for stock splits and stock dividends.

[16] However, not all industries appear to take advantage of overvalued prices to issue stock. Most of the new equity capital was issued by the airplane industry, Internet firms, and smartphone firms. To a lesser extent, firms in the radio, microwave oven, video game, laser disc player, camcorder, and GPS sectors also did issue more stock compared to the market.

[17] We also restrict this sample to the period from 1925 to 2010 and the results are unchanged.

[18] We are not able to perform a market bubble test associated with the telegraph bubble because of the lack of marketwide dividend data during the telegraph bubble period (1870–1873). Therefore, market bubble tests are conducted for only 36 of the 37 innovations for which we detect bubbles in Table 3.

[19] We also repeat the analysis presented in Table 5 after subtracting the magnitude of the market bubble from the magnitude of the innovation bubble. The results remain substantively similar.

[20] For example, Piketty (2013) offers wealth inequality as one of the leading causes of the French Revolution.

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