



# Value and risk dynamics over the innovation cycle



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## ABSTRACT

This paper studies investment in intellectual capital and corresponding value and risk dynamics over the innovation cycle. We assume that the innovation cycle consists of three phases, R&D, trial, and market introduction phases. We use a real option investment model to characterize firm value and risk dynamics over the innovation cycle and find that firm value is the sum of the value of assets in place and non-linear option values related to breakthrough, exit, and market introduction options. Firm risk over the innovation cycle is highly non-linear and quite distinct in different phases. During the R&D phase risk is high as the firm faces high operating leverage originating from R&D fixed costs together with technological uncertainty. During the trial phase risk is significantly lower and dominated by option risk to launch the product in the market while after the introduction of the product in the market risk is equivalent to the asset risk of the company. Our model is consistent with the view that positive excess returns of R&D intensive firms are a compensation for risk. Based on this insight we derive several testable predictions.

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## 1. Introduction

Are high excess stocks returns of R&D intensive firms the outcome of mispricing or compensation for R&D specific risk factors? This is a long and still ongoing debate in the empirical accounting and asset pricing literature that has not been fully settled yet. Advocates in favor of the mispricing view such as [Lev and Sougiannis \(1996\)](#), [Chan et al. \(2001\)](#), and [Ciftci et al. \(2011\)](#) argue that investors underreact to R&D investment because they are misled by conservative accounting rules which do not properly account for the future impact of R&D spending. Investors understand the true impact of R&D spending only with delay so that it takes time for excess returns to adjust to their true levels. Researchers in favor of the risk based view such as [Chambers et al. \(2002\)](#) argue that excess stock returns reflect compensation for systematic risk related to R&D investment.

The aim of our paper is to theoretically contribute to this debate by formulating a simple R&D investment model and studying risk dynamics over the innovation cycle. The innovation cycle in our analysis consists of only three phases, the phase when R&D investments prevail until the breakthrough has been achieved, the trial phase when the firm turns the innovation into a marketable product and the introduction phase when the new product is launched in the market. We present a theory of equity risk for a firm that invests in intellectual capital to increase the probability of a breakthrough,

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spends resources to turn the innovation into a marketable product, and decides when to market the new product. By focussing on the innovation cycle as a whole we are able to identify the main risk drivers for an R&D intensive firm and hence are able to shed light on the mispricing versus risk based view of excess stock returns.

Our analysis rests on three key assumptions: First, we assume that the firm faces two sources of uncertainty throughout its R&D cycle, market and technological uncertainty. Market uncertainty refers to the phenomenon that the value of an innovation changes as market conditions vary. This type of uncertainty is driven by changing cost conditions, varying degrees of competition, and stochastic demand for the new product. We model market uncertainty by letting the present value of the patent of the innovation vary stochastically over time. Technological uncertainty arises from the stochastic nature of the innovation process itself. During the R&D phase, the firm faces a random completion date for the innovation that is assumed to follow an exponential distribution. While the type of distribution is outside the control of management, control of the R&D process is possible by managing the hazard rate of the completion date.

The interplay of these two sources of uncertainty has extensively been studied in the literature by [Bena and Garlappi \(2013\)](#), [Miltersen and Schwartz \(2007\)](#) and [Weeds \(2002\)](#), for example. Technological uncertainty associated with R&D and innovations has been summarized by [Kamien and Schwartz \(1982\)](#) for the case of no competition and [Reinganum \(1982\)](#) for the case of R&D rivalry (see also the papers by [Dawid et al., 2013](#); [Weeds, 2002](#)).

The second assumption that we employ relates to the management of the hazard rate associated with technological uncertainty. We assume that management can increase the hazard rate of completing the innovation by investment in intellectual capital. The hazard rate for the completion date is the probability that a breakthrough will occur during the next small interval of time given that the innovation has not been completed yet. It is obvious that this conditional probability of completion must depend on the stock of intellectual capital available inside the company. We refer to intellectual capital as the knowledge-based equity of a firm ([Tan et al., 2007](#)) and identify it as the sum of human and structural capital. While structural capital refers to factors such as organizational infrastructure, networking system and corporate culture, human capital is employee-specific and entails employees' competence, skills, commitment and education ([Chen et al., 2005](#)). Intellectual capital has become a key competitive advantage in industries characterized by rapid product and process innovations ([Hsu and Fang, 2009](#); [Chen et al., 2005](#)) and is considered the *hidden factor* that drives a company's value ([Edvinsson and Malone, 1997](#); [Lev and Sougiannis, 1996](#); [Lev and Zarowin, 1999](#); [Ruta, 2009](#); [Yang and Lin, 2009](#)). We assume that management invests in intellectual capital with the investment being characterized by the following trade-off. First, the investment increases the rate of product innovation. Second, it increases fixed R&D expenditures. This trade-off allows us to study the relation between R&D levels measured by R&D expenditures and equity returns.

The third assumption that we employ in the paper is that throughout the entire innovation cycle the firm can abandon the R&D project altogether and leave the market. This exit strategy corresponds to an American put option that has strong consequences for the value and the risk dynamics of the company.

We derive the following main results in the paper. First, we show that firm risk during the R&D phase is significantly higher than during the trial and product marketing phases. This result supports the risk based view of excess returns for R&D intensive firms and is driven by fixed R&D expenditures (operating leverage) and technological uncertainty. As we show in [Section 3.2](#), technological uncertainty is directly related to firm risk with management being able to control the risk exposure through investment in intellectual capital. Investment in intellectual capital leads to our second result: we find that investment in intellectual capital and firm risk are negatively related. The economic intuition for this result is the following. Investment in intellectual capital increases the hazard rate at which the firm develops the new product and hence reduces technological uncertainty. Lower technological uncertainty reduces firm risk. With a lower risk profile and a higher firm value, our model is able to reproduce the positive association between R&D levels measured by R&D expenditures and stock returns. Third, we find a non-monotonic relation between firm risk of inactive firms (firms that do not optimally manage R&D spending) and active firms (those which optimally manage R&D). When expected cash flows from the new product are low an inactive firm is more risky than an active firm while at higher levels of expected cash flows an active firm is more risky than an inactive firm. Finally, we find that firm risk increases with expected time to innovation.

Our paper is related to the growing production-based asset pricing literature that ties stock returns to firms' investment and R&D policies ([Cochrane, 1991](#); [Berk et al., 2004](#); [Hansson, 2004](#); [Carlson et al., 2004](#)). [Hansson \(2004\)](#) argues that returns to human capital are important in explaining value premium puzzle. [Lin \(2012\)](#) explores the interaction between investments in tangible capital and in intangible capital and derives asset pricing implications. In contrast to most studies in the literature, we link optimal investment in intellectual capital and its components (structural capital and human capital) to stock returns over the life cycle of the R&D process.

Our framework is related to the paper by [Eisfeldt and Papanikolaou \(2013\)](#). They investigate the role of organization capital in the production of a common output and derive risk implications for the cross section of firms. They show that firms with more organization capital earn higher returns than firms with more physical capital. [Eisfeldt and Papanikolaou \(2013\)](#) assume that physical and organization capital are substitutes in the production process by making use of a linear production function. In our paper, the employment of human and structural capital does not produce an output like a consumption good but determines (produces a change of) the level of the hazard rate.

Most research on intellectual capital focuses on the components and the measures of intellectual capital ([Tan et al., 2008](#); [Sveiby, 1997](#)). A number of papers have found a positive relation between intellectual capital and firm value and performance ([Chen et al., 2005](#); [Orens et al., 2009](#); [Veltri and Silvestri, 2011](#)). Yet, little research explicitly addresses the

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