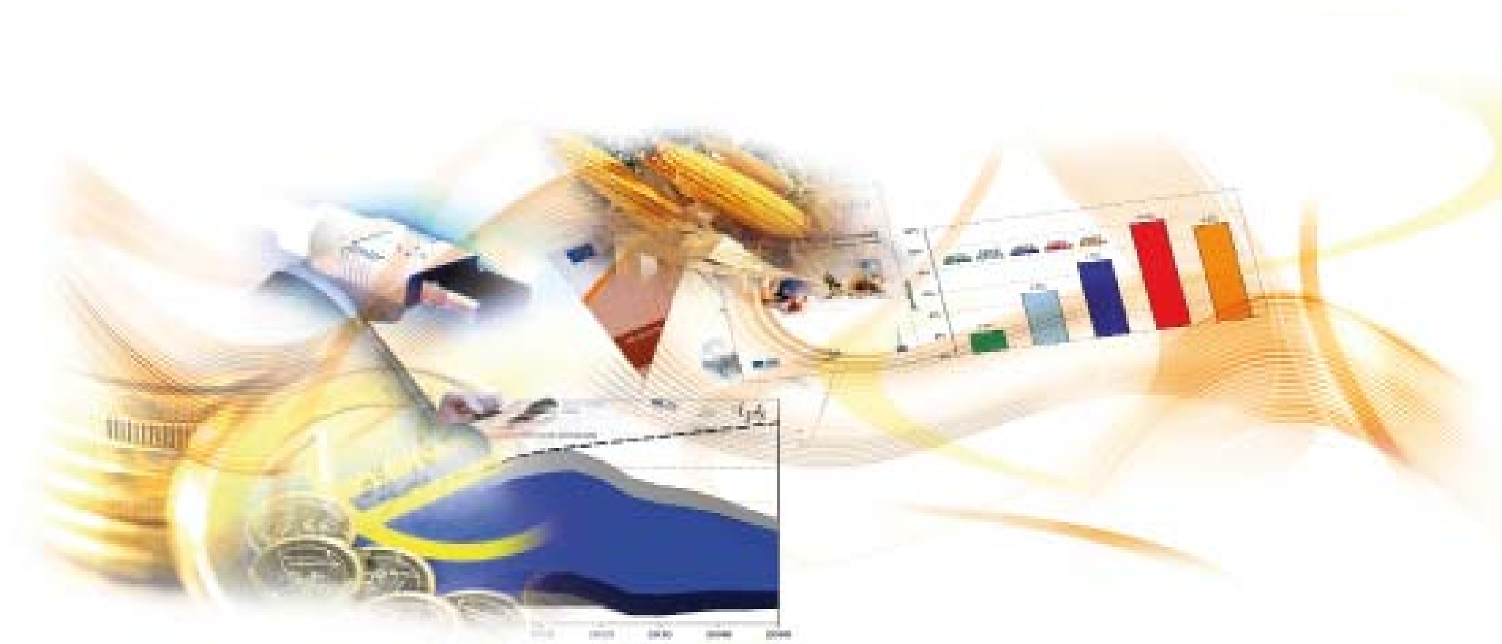
European Commission

JRC TECHNICAL REPORTS



IPTS Working Papers on Corporate R&D and Innovation – No 01/2015

R&D profitability: the role of risk and Knightian uncertainty

Sara Amoroso, Pietro Moncada-Paternò-Castello,
Antonio Vezzani

2015

Joint Research Centre

European Commission
Joint Research Centre
Institute for Prospective Technological Studies

Contact information
Fernando Hervás Soriano
Address: Edificio Expo. c/ Inca Garcilaso, 3. E-41092 Seville (Spain)
E-mail: jrc-ipts-kfg-secretariat@ec.europa.eu
Tel.: +34 954488463
Fax: +34 954488326

JRC Science Hub
https://ec.europa.eu/jrc

JRC94558

ISSN 1831-9408 (online)

Spain: European Commission, Joint Research Centre, 2015

Abstract

This paper provides the first empirical attempt of linking firms' profits and investment in R&D revisiting Knight's (1921) distinction between uncertainty and risk. Along with the risky profit-maximizing scenario, identifying a second, off-setting, unpredictable bias that leads to heterogeneous returns to R&D investments is crucial to fully understand the drivers of corporate profits.

R&D profitability: the role of risk and Knightian uncertainty

Sara Amoroso*[a], Pietro Moncada-Paternó-Castello[a], and Antonio Vezzani[a]

[a] *JRC-IPTS, European Commission*

Abstract

This paper provides the first empirical attempt of linking firms' profits and investment in R&D revisiting Knight's (1921) distinction between uncertainty and risk. Along with the risky profit-maximizing scenario, identifying a second, off-setting, unpredictable bias that leads to heterogeneous returns to R&D investments is crucial to fully understand the drivers of corporate profits.

JEL classification: O30, D22, D81.

Keywords: Corporate R&D investment, firms' operating profits, Knightian uncertainty, ambiguity.

1 Introduction

The expected returns to R&D investment are typically subject to strong uncertainty. Innovations can be thought as unique events, and the process aimed at producing them (i.e. R&D investment) is an intrinsically uncertain economic activity.

This paper provides the first empirical attempt of linking firms' profits and investment in R&D revisiting Knight's (1921) distinction between uncertainty and risk. In particular, Knight used the word 'risk' to describe the "measurable uncertainty", where the possible outcomes are known and they can be classified in groups and assigned probabilities "either through calculation a priori or from statistics of past experience" (Knight, 1921, p.232). The 'true' uncertainty, on the other hand, applies to situations where no probability can be computed, as agents do not have the information necessary to assign a probability measure "because the situation dealt with is in a high degree unique" (Knight, 1921, p.233). For Knight, such uncertainty is the essence of entrepreneurial activity, without which there could be no profits in a (perfectly) competitive setting, since the probabilistically predictable extra margins profits would be eliminated (Noorderhaven, 2003; Freytag and Thurik, 2007). Bronk (2011) named "ontological uncertainty" the implausibility to imagine a firm having a model of well-founded expectation of the additional benefits it may derive from future-generation products whose nature is not yet known. This type of uncertainty is emblematically associated to radical innovations that shift the parameters of the market. The future opportunities and risks are simply not known and learnt only at the times of discoveries. Standard models in economics assume that agents use probabilities to quantify all uncertainties regardless of their source or nature. Specifically, the literature of economics of innovation on the returns to R&D investments either omits the uncertainty from the drivers of profitability (Hall et al., 2009; Coad and Rao, 2010; Bogliacino and Pianta, 2013) or it captures only the measurable uncertainty, i.e. risk (Dixit and Pindyck, 2012; Bloom and Reenen, 2002; Doraszelski and Jaumandreu, 2013).

With this paper, we fill the gap in the empirical literature on the returns to R&D, introducing and examining the effect of both risk and Knightian or 'true' uncertainty. In particular, additional to the 'predictable' part of the uncertainty faced by the company, we consider what the economic analysis refers to as *ambiguity*. The notion of ambiguity derives from the interpretation of uncertainty as the lack of predictability due to the complexity of information. In this setting, we measure the profit maximization response of firms in the presence of ambiguity and test the hypotheses found in the theoretical literature concerning the returns to R&D in an uncertain scenario. Moreover, we control for two measures of ambiguity. The first is a firm-level proxy that we propose, based on previous theoretical work. The second is the country-level Hofstede's (1980) Uncertainty Avoidance Indicator (UAI). We also control for physical capital expenditures and industry characteristics.

Our main contribution to the empirical literature on the returns to R&D consists in testing some of the hypotheses that have been advanced by the theoretical

* Corresponding author: sara.amoroso@ec.europa.eu

literature on industrial and innovation economics. The first set of conjectures concerns the impact of risk and uncertainty *on profits*. The Shumpeterian theory relating risk to profitability assumes that entrepreneurs require a higher return for taking on more risk, a so-called "risk premium" (Tobin, 1958). Using profit volatility as a measure of risk (Markowitz, 1952; Hurdle, 1974), we hypothesize that its correlation with the profits should be positive under this 'risk premium hypothesis'. As for the impact of uncertain and ambiguous investment environment on profits, firms tend to adopt a routinized behaviour when facing times of strong uncertainty, as to cope with the highly unpredictable discovery process, and tend to lower their R&D effort. The lowered R&D effort may result in a lower innovation rate and, ultimately, in lower profits (Cozzi and Giordani, 2011; Becker, 2004; Dosi and Egidi, 1991).

The second set of hypotheses regards the effect of risk and uncertainty *on R&D returns*. The hypothesis concerning the impact of risk on the returns to R&D follows the risk-bearing rationale (Chambers et al., 2002; Chan et al., 2001), i.e. the presence of risk yields to positive R&D returns. Additionally, using two proxies of ambiguity, we advocate the work of Chen and Epstein (2002) that shows how asset returns can be expressed as a sum of a risk premium and an ambiguity premium, i.e. the presence of both risk and ambiguity may lead to higher R&D returns than when ambiguity is not taken into account.

We test the following set of assumptions and present evidence on the relation between R&D investment and the uncertainty of future benefits from those investments using the EU Industrial R&D Investment Scoreboard data, which contains information on a sample of the largest R&D investing corporations worldwide.

2 Risk, uncertainty and ambiguity

In its famous dissertation "Risk, Uncertainty and Profit" (1921) Frank H. Knight made its central distinction between measurable risk and immeasurable uncertainty. Risk is a situation where it is possible to calculate the probabilities associated with a range of scenarios; while uncertainty is a situation where neither its probability distribution nor its mode of occurrence is known, because, for example, the situation is unique. Few years later, Keynes (1936) focused on forecast and valuation over the expected returns to investments and stated that they "cannot be uniquely correct, since our existing knowledge does not provide a sufficient basis for a calculated mathematical expectation". Although the differentiation between risk and uncertainty has been somewhat overlooked by the neo-classical literature (Hodgson, 2011), it is crucial to understand the variability in profits. Bronk (2011) and Lane and Maxfield (2005) examined and discussed the nature and sources of immeasurable uncertainty. In particular, Bronk (2011) made the relevant distinction between 'ontological' and 'epistemological' uncertainty.

Ontological uncertainty "implies the impossibility of knowing even the categories and possible nature of what has yet to be created or yet to evolve" (Bronk, 2011, p.9). Very few studies investigated the impact that this sources of uncertainty have on R&D investment and innovation. One of the first economist to tackle the impact of this type of uncertainty on R&D and profitability is Sutton (2006), who offered a theoretical framework to address the fundamental difference between a probabilistic setting and one in which the firm faces a set of unique, unrepeatable circumstances. Sutton (2006) explored the relationship between firm's investment in capabilities (e.g. know-how), profitability and survival using a model of Knightian uncertainty.[1] Sutton's (2006) theoretical model predicts that, in a Knightian uncertain environment, investing in capabilities matters for the firm's survival, but depending upon the costs of "mastering know-how", it may or may not lead to higher profitability.

Epistemological uncertainty, or ambiguity, relates to the complexity of information that agents need to handle.[2] Ambiguity occurs when the likelihoods of events are too imprecise to be properly summarized by probabilities because the available information is incomplete and/or imperfect. The sensitivity toward uncertainty, i.e. ambiguity attitude, has been intensively investigated by the literature on decision under uncertainty. In their seminal paper, Gilboa and Schmeidler (1989), axiomatized a maxmin decision rule, where an agent can be characterized by a utility function and a set of prior (subjective) probabilities, such that the chosen economic prospect maximizes the minimal expected utility, where the minimum is taken over the priors in the set (minimizing the perception of uncertainty). More recently Gajdos et al. (2008) showed how the aggregation of preferences of the decision makers described by Gilboa and Schmeidler (1989) is possible only when all individuals differ in their preferences but not in their beliefs. This, however, is quite restrictive. Every company

[1] Sutton's (2006) modeling of Knightian uncertainty rests on the hypothesis of rational, profit-maximizing firms facing an environment that cannot be described probabilistically. Subjective probabilities can be assigned to outcomes, but these cannot be updated.

[2] The term complexity can refer to the massive amount of information to which economic agents are exposed (market characteristics, technological information, etc.) and the unmanageable costs both in terms of money and time that would be necessary to collect and analyse the relevant data in order to make an optimal decision. The term complexity can also refer to the difficulty of making ex-ante predictions in dynamic non-linear systems. In fact, the economy is permanently in disruptive motion as agents explore, interact, learn, and adapt. These disruptions snowball into larger phenomena. One driver of disruption is technological change, and "a novel technology is not just a one-time disruption to equilibrium, it is a permanent ongoing generator and demander of further technologies that themselves generate and demand still further technologies" (Arthur, 2009). This is a more technical definition of complexity that belongs to complexity economics literature. The interested reader is referred to Arthur (2009) for a review.

wants to make profits, but entrepreneurs have very different views about the way to achieve this common goal. Gajdos et al. (2008) widened the subjective expected utility framework and modelled risk and ambiguity aversion through two separate parameters. The embodiment of subjective expected utilities theories in the empirical framework have found two channels (de Palma et al., 2008): experiments in the field of cumulative prospect theory (Tversky and Kahneman, 1992) and random utility models (McFadden, 2001) applied to discrete choice models. In this latter econometric literature (see Train, 2003), the ambiguity enters in the form of a weighting function that scales the individual-specific utility functions by their perceptions and beliefs. These weighting functions take usually a parametric form, and the estimated parameters confirm that the perception of a risky event shape the weighting function (Loomes et al., 2002; Abdellaoui et al., 2011). Generally the results confirm the aversion of individuals toward ambiguity. In the fields of economics of uncertainty and financial economics, many studies have reported evidence of anomalies in the returns to equity. The so-called "equity risk-premium puzzle" (ERP puzzle), or variance premium puzzle, is an observed anomaly for which the equity returns are excessive with respect to risk (Mehra and Prescott, 1985). Studies on ambiguity aversion have tried to explain the ERP puzzle. The suggested hypothesis is that if ambiguity is present in decision-making process, the overall attitude towards risk may be accentuated, which will increase the ERP level (Chen and Epstein, 2002; Bollerslev et al., 2009; Miao and Wang, 2011).

The literature on R&D and real option valuation of R&D projects offers both theoretical and empirical predictions. Cozzi and Giordani (2011) incorporated the economic agents' ambiguous beliefs about the innovative process in a neo-Schumpeterian growth framework. Their theoretical model predicts that when agents (e.g. companies) face "a complex and changing environment, a relatively high α (ambiguity aversion) embodies a cautious evaluation of profitable opportunities of investment, and gives rise to a persistently low R&D-effort behavior, and viceversa" (Cozzi and Giordani, 2011, p. 306). The authors alleged that the lowered investment in R&D could lead to lower profits. Their theoretical prediction help to explain the evidence of the heterogeneous R&D efforts across countries due to different cultural/country-specific attitudes towards ambiguity, and the impact on the variability of profits. Dobbelaere et al. (2008) and Pennings and Sereno (2011) calculated the probability to start a R&D project and its option value, respectively, given the presence of 'technical' and economic uncertainty. In Dobbelaere et al. (2008), the authors showed, both theoretically and empirically, that when firms operate in favourable 'technical' (cost) uncertainty and market uncertainty conditions (i.e., a firm experiences a increase in demand or an decrease in the cost of R&D), an increase of the market volatility increases the likelihood of undertaking R&D. The good and bad states of technical and market uncertainty are modelled as independent lotteries and the firm does not have a priori knowledge on the outcome. Pennings and Sereno (2011) show that both types of uncertainty have a positive impact on the R&D option value. However, in their modelling framework, what they define as technological uncertainty, often interchanging the terminology, is the measurable risk of failure of pharmaceutical R&D projects at different stages of the project.[3]

Aside from the aforementioned few papers that discussed and empirically tackled the issue of 'true' uncertainty relative to R&D and profitability of R&D projects, most of the literature focused on the relation between measurable uncertainty (e.g. volatility, risk), and the returns to physical and intangible investments, such as R&D. The results across literatures are heterogenous. For example, Czarnitzki and Toole (2011) using the variance of the firms' revenues to proxy for the market volatility, found that uncertainty about market returns significantly reduces firm-level R&D investment. Differently, the empirical finance literature (Chan et al., 2001; Chambers et al., 2002; Pastor and Pietro, 2003; Vo, 2013) reported evidence of higher returns to R&D investments when the investment scenario involves more risk and volatility. In particular, Chan et al. (2001) pointed at the mispricing rationale for this positive correlation between risk, R&D intensity and firms' profitability. The hypothesis of mispricing suggests that, when R&D expenditure is high, investors tend to understate profits because it is recorded as an expense on the accounting balance sheets, and overstate the earnings when R&D is low. Thus, the value created by the R&D spending tends to be understated in the period in which it takes place, but results in higher future excess returns. Chambers et al. (2002), Pastor and Pietro (2003), and Vo (2013) tested both the hypotheses of mispricing and the risk-bearing hypothesis that R&D intensive firms will earn high returns as a consequence of a risk-premium. In general, their empirical results suggest that the positive association between R&D levels and returns is mainly due to the compensation for bearing risk. They find that high R&D intensity companies (which generally have poor past returns) tend to earn larger excess returns (in excess of the risk-free returns). They also find R&D intensity to be positively associated with return volatility.

Taking stock of both the theoretical and the empirical work, we test some of the hypotheses advanced in these literatures concerning the role played by risk and ambiguity in business activities.

[3] In Pennings and Sereno (2011), the risk of failure and abandoning the project is modelled as a function on the "arrival intensity of important information" (Pennings and Sereno, 2011, p.376) which is depending on the firm's estimations of the probabilities of success of the previous stages.

3 Empirical setting

In this section we propose an empirical framework to explain the impact of risk, firm-level and country-level ambiguity attitude on companies' profits and on investment returns. After a brief description of the dataset, we discuss the measures used to proxy the different dimensions of ambiguity and the regression model.

3.1 Data

We estimate the corporate returns to R&D and to physical capital using a sample of firms contained in the EU Industrial R&D Investment Scoreboard.[4] This is a scoreboard analysis of top corporate R&D investors worldwide, which the Institute of Prospective Technological Studies (IPTS, Joint Research Centre, European Commission) has conducted annually since 2004. The dataset contains economic and financial data of the top 2000 world R&D investors and cover the 2004-2012 period. In particular, starting from top ranked companies for 2012, historical financial data are collected to analyse their trajectories along the time period considered. Data are collected from the companies' published accounts and refer to the ultimate parent company in the case of consolidated groups. Subsidiaries are included when consolidated group accounts of the ultimate parent company are not available. The key variable of the EU R&D Scoreboard is the cash investment in R&D (as from international accounting standards) that the companies funded themselves, excluding those undertaken under contract for customers such as government or other companies. In addition, data on net sales, operating profit, capital expenditure, number of employees and market capitalization are reported. The EU R&D Scoreboard economic data are nominal and expressed in Euros with all foreign currencies converted at the exchange rate of the year-end closing date (31 December). The country attributed to a given company refers to the country where headquarter is located. All the economic figures have been deflated using the GDP deflators published by the World Bank, and using 2004 as the reference year. For companies located in the Cayman Islands we applied the World average deflator. In the case of companies based in Taiwan (Chinese Taipei), we used the "Implicit GDP Price Indices" taken from the OECD-MSTI database. The EU R&D Scoreboard covers nearly all the more important players in term of R&D investments in the World (especially in mid-high and high-tech sectors) and accounts for nearly 90% of the total world R&D expenditure (European Commission, 2013).

3.2 Risk and uncertainty proxies

Among the approaches to deal with risk, we advocate that of Markowitz (1952) who used variance of losses as a risk measure. Similarly, in this paper, we take the variance of operating profits. To proxy for uncertainty we take two indicators: a firm-level and a country-level measure of ambiguity attitude.

The first indicator of ambiguity is constructed as deriving from the information gap between an 'estimate' and a 'possibility' (Ben-Haim, 2006). The estimate, α_{it}, is the 'entrepreneur's forecast error' which included both the expected ranges of favourable and unfavourable business scenarios, and the individual attitude towards ambiguity, i.e. how the companies react to the self-assessed α. The 'possibility', θ, is the volatility of the public opinion of a company's net worth (market capitalisation), which is assumed to capture both the risk in the stock market and the shareholders' incomplete information over the profitability of the company. In fact, according to the ERP puzzle rationale (observed returns on stocks higher than expected), θ may include also the subjective return expectations of the shareholders.

Precisely, we take the absolute deviation between the residual term of a regression that estimate the expected returns to R&D and to physical capital and the market capitalization volatility. We first obtain the estimate

$$\alpha_{it} = OP_{it} - E(OP_{it}|R\&D_{it-1}, PhyCap_{it-1})$$

as the difference between the observed operating profits of firm i at time t and the expected returns to the investment in R&D and physical capital at time t. Then we construct the firm-level ambiguity measure as

$$Amb_{it} \equiv |\alpha_{it} - \theta_i|,$$

where θ is the standard deviation of the market capitalization of company i.

The second indicator is the Uncertainty Avoidance Indicator (UAI) introduced by Hofstede (1980).[5] is defined as the extent to which the members of a culture feel threatened by uncertain or unknown situations.

The index measures the attitude of a society toward uncertainty and it is used as a measure of national uncertainty aversion. It was derived from a cross-country psychology survey of 88,000 IBM employees across more than 70 countries.[6] The questions asked in the survey were closely linked to the IBM employees job environment and their tasks. The comparability of responds across countries is ensured by the design of the survey. In fact, all the respondents occupied marketing and customer service positions, which are likely to share similar working environment across IBM foreign subsidiaries. The indicator is constructed by averaging the answers to psychological survey questions on three dimensions related to people's attitude toward uncertainty: rule orientation, employment stability, and stress. The index ranges from a minimum of

[4] http://iri.jrc.ec.europa.eu/

[5] For more information on the construction of the index, see http://geert-hofstede.com/countries.html.

[6] See Rapp et al. (2010) for a review of the studies that incorporated Hofstede's uncertainty avoidance construct.

-150 to a maximum of +230, with higher UAI indicating higher national uncertainty aversion and relative scarcity of uncertainty-tolerant entrepreneurs, workers, and investors.

Summary statistics of the variables used for the empirical analysis are presented in Table 1, where averages, medians, standard deviations and numbers of observation are shown. The dependent variable, the operating profits, OP, the investment in R&D, $R\&D$, and the investment in physical capital, $PhyCap$, are expressed in Euro billion. The $log(R\&D)$ and $log(PhyCap)$ are the natural logarithms of these variables. All the variables expressed in levels are left-skewed, including the country-level indicator of ambiguity, UAI. The number of UAIs was matched with 31 countries.

Below the summary statistics, we also report the Pearson's correlation matrix to facilitate the understanding of the relationship between variables, without a priori causation implication. The coefficients are statistically significant at the 0.01 percent level. Risk, tangible investment (physical capital) and operating profits are strongly correlated (correlation coefficient larger than 0.7), operating profits, tangible and intangible (R&D) investment are moderately correlated (between 0.5 and 0.7). Firm- and country-level ambiguity indicators are negatively and positively associated with the operating profits, respectively. However, when calculating the correlation between UAI and the average of OP by country, the coefficient is negative (-0.16).

3.3 Empirical specification

In line with the literature on R&D returns, we examine the returns to physical capital and R&D investment when companies face a risky, uncertain, complex and dynamic environment. For a company i at time t, we use the following specification

$$\begin{aligned} OP_{it} &= \beta_0 + \beta_1 OP_{it-1} + \beta_2 log(R\&D)_{it-1} \\ &\quad + \beta_3 log(PhyCap)_{it-1} + \gamma' x_{it} + \delta_t + S_i + \epsilon_{it} \\ x'_{it} &= (Risk_i, Amb_{it}, UAI^c) \end{aligned} \quad (1)$$

where OP are the operating profits arising from the sale/disposal of businesses or fixed assets, $log(R\&D)$ is the logarithm of R&D investment and is the cash investment funded by the companies themselves, excluding R&D contracted with governments or other companies. It also excludes the share of any other associated company or joint venture R&D. The logarithm of physical capital, $log(PhyCap)$, is the (capitalised) expenditure used by a company to acquire or upgrade physical assets. The vector x contains a measure of risk and both measures of ambiguity: a proxy of firm-level ambiguity, *uncertainty*, and the country-level ambiguity indicator, UAI. The remainder term, $\delta_t + S_i + \epsilon_{it}$, accounts for yearly and sectoral effects, and a measurement error, respectively.

4 Results and discussion

Most of the literature in innovation economics focused on the relationship between firm performance and R&D adopting either a knowledge capital production function la Griliches (1979) (Doraszelski and Jaumandreu, 2013), or an accounting approach, where the focus is on the relationship between accounting based performance measures and R&D investments (Lev, 2000). Our paper adopts this latter approach, as we estimate eq. (1) to quantify the impact of investment in intangible and tangible assets, risk and ambiguity on firm future profits, using financial data on the top world R&D investors contained in the EU R&D Scoreboard.

To alleviate potential endogeneity problems due to simultaneity of the decision to invest and profits, we take lagged control variables. Firm-level ambiguity is taken at time t, i.e. the same time in which the company observes its current level of profits, because the current level of ambiguity is derived from the ex-ante beliefs of companies and shareholders, which are expressed at time $t-1$. The estimation results of the linear regression model are reported in Table 2, where results from six alternative specifications are displayed. To control for fixed industry effects and for macroeconomic shocks that might affect the firms in the sample, we include but do not report yearly and industry dummies.

We find that the partial elasticities of tangible and intangible assets (physical capital and R&D, respectively) are all positive and we report the actual elasticities[7] at the bottom of Table 2. The R&D elasticities vary from 0.024 (column 2) to 0.067 (column 1). These results are in line with most of the literature measuring the returns to R&D. For example, Doraszelski and Jaumandreu (2006) adopting a production function approach found that the coefficients vary between 0.017 and 0.075. In general, our results are comparable to many other studies which used different approaches (Hall et al., 2009, see). In two out of six cases, the expected return on intangible assets is lower than that on tangible ones. More precisely, we found that controlling for risk and not for firm-level uncertainty leads to larger capital elasticities and, therefore, to larger tangible assets return. It is widely accepted that the rates of return to R&D are larger than the rate of return on physical investment (see Nadiri, 1993; Kumbhakar et al., 2012).[8] We believe that in the first specification the estimated coefficients are overestimated. In this scenario, the econometrician assumes that a company is not aware of risk nor ambiguity, or simply ignores them, leading to an optimistic scenario of inflated tangible and intangible asset coefficients. On the other hand, column 2 and column 3 underestimate the coefficients. If

[7] The elasticities of R&D and physical capital are derived as $\frac{\partial log(OP)}{\partial log(R\&D)}$ and $\frac{\partial log(OP)}{\partial log(PhyCap)}$ respectively.

[8] Some studies suggested that there may be large adjustment costs to R&D investment which are not taken into account.

Table 1: Summary statistics

variable	mean	median	sd	N
OP	498.45	61.54	2021.46	23946
$R\&D$	166.03	29.85	570.70	22909
$log(R\&D)$	10.49	10.30	1.54	22909
$PhyCap$	358.14	38.07	1349.50	20346
$log(PhyCap)$	10.49	10.55	2.31	20346
$risk$	249.18	44.16	806.64	25478
Amb	1725.27	549.85	4821.12	18828
UAI	59.54	46.00	21.46	24452(31)
α	451.96	187.98	1410.28	19457
θ	1694.25	367.97	5089.30	21534

Correlation Matrix

	1.	2.	3.	4.	5.
1. OP	1.00				
2. $R\&D$	0.52	1.00			
3. $PhyCap$	0.75	0.62	1.00		
4. $risk$	0.71	0.67	0.77	1.00	
5. Amb	-0.04	0.39	0.33	0.32	1.00
6. UAI	$0.12^{\dagger}$	0.16	0.23	0.05	0.05

Note: Averages and medians across companies and years. † the correlation between mean country OP and UAI is -0.16, significant at the 0.01 percent

we assume that firms are uncertainty-adverse, and control only for their aversion to profit volatility, we may pick a scenario where enterprises discount the assets returns more heavily than they might have marked down by a proper (subjective) calculation of the riskiness of investment. Notably, the coefficients reported in columns 2 and 3 are the smallest. For the other specifications, our empirical prediction of higher expected R&D returns compared to physical capital returns for R&D intensive firms is confirmed (Chan et al., 2001; Miao and Wang, 2011).

In line with the risk premium hypothesis, and as Chambers et al. (2002), Pennings and Sereno (2011), and Vo (2013) we find a positive effect of the risk on the earnings of companies. The coefficients are found to be around 0.43 when controlling for firm-level ambiguity aversion (columns 4 and 5) and around 0.33 when omitting it (columns 2 and 3).

The sets of regressors included in columns 3 and 4 both include risk and ambiguity. While column 3 account for country-level ambiguity, column 4 controls for the firm-level one. Both indicators point to a negative ambiguity-profits relationship (-0.866 and -0.024 for the country- and the firm-level indicators, respectively). This result is in part explained by Cozzi and Giordani (2011); Mazzucato and Tancioni (2013), whose theoretical studies suggested that the higher the ambiguity (and ambiguity aversion), the more cautious the evaluation of the expected R&D and innovation returns. This gives rise to two distinct effects. On the one hand, it decreases the profits as a consequence of a more "routinized" R&D investment behaviour which slows down the innovation process and, in turn, the profits of the firm. On the other hand, enlarging the mispricing hypothesis advanced by Chan et al. (2001) to ambiguity, it might lead to higher returns to R&D. This is due to the fact that the value generated by R&D investment is understated by the ambiguity-averse firm, but results in higher future excess returns. In fact, the R&D elasticities are 0.028 and 0.039 in columns 3 and 4, respectively higher than the R&D elasticity estimated omitting ambiguity (0.024, column 2).

An alternative hypothesis is the one offered by the literature on the ERP puzzle (Mehra and Prescott, 1985; Chen and Epstein, 2002; Bollerslev et al., 2009; Miao and Wang, 2011). This theoretical strand of study suggests that, in presence of ambiguity, the overall attitude towards risk is accentuated, and the observed disproportionate assets risk-premia is indeed the sum of a premium for risk and a separate premium for ambiguity (Chen and Epstein, 2002).

When controlling for risk and both measures of ambiguity the R&D and physical capital elasticities are larger (0.044 and 0.035, respectively in column 5) than those found in the other specifications, but not statistically different.

5 Conclusions

We propose an empirical framework to examine the returns to physical capital and to R&D investment when companies face a risky, uncertain, complex and dynamic environment.

We contribute to the literature on the returns to R&D by testing some of the hypotheses that have been ad-

Table 2: Estimation results

dep. var.: OP_{it}	(1)	(2)	(3)	(4)	(5)
OP_{it-1}	0.875***	0.802***	0.804***	0.804***	0.805***
	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)
$log(R\&D)_{it-1}$	37.333***	13.119*	15.591**	21.897***	24.861***
	(6.847)	(6.794)	(7.227)	(6.995)	(7.429)
$log(PhyCap)_{it-1}$	27.083***	16.141***	17.804***	18.074***	19.663***
	(5.324)	(5.247)	(5.556)	(5.400)	(5.711)
$risk_i$		0.338***	0.330***	0.436***	0.428***
		(0.014)	(0.014)	(0.016)	(0.017)
Amb_{it}				-0.024***	-0.024***
				(0.002)	(0.002)
UAI			-0.866**		-0.861**
			(0.356)		(0.362)
Time dummies	✓	✓	✓	✓	✓
Industry dummies	✓	✓	✓	✓	✓
Constant	-583.106***	-231.001***	-212.627**	-336.184***	-323.339***
	(79.313)	(79.166)	(82.636)	(81.039)	(84.574)
Observations	17,004	17,004	16,226	16,500	15,753
R-squared	0.815	0.822	0.819	0.824	0.821
$R\&D\ elasticity$	0.067***	0.024**	0.028***	0.039***	0.044***
	(0.012)	(0.012)	(0.012)	(0.012)	(0.013)
$PhyCap\ elasticity$	0.049***	0.029***	0.032***	0.032***	0.035***
	(0.010)	(0.009)	(0.010)	(0.010)	(0.010)

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

vanced by the theoretical works on industrial economics. The first set of conjectures concerns the impact of risk and uncertainty *on profits*. The Shumpeterian theory relating risk to profitability assumes that entrepreneurs require a higher return for taking on more risk, a so-called "risk premium" (Tobin, 1958). As for the impact of uncertain and ambiguous investment environment on profits, firms tend to adopt a routinized behaviour, as to cope with the highly unpredictable discovery process and tend to lower their R&D effort (Cozzi and Giordani, 2011; Becker, 2004; Dosi and Egidi, 1991). The lowered R&D effort may result in a lower innovation rate and, ultimately, in lower profits (Griliches, 1998). Our empirical findings confirm and quantify the theoretical predictions concerning the impact of risk and uncertainty on earnings. Both firm- and country-level measures of ambiguity have a significant negative impact on profits.

The second set of hypotheses regards the effect of risk and uncertainty *on R&D returns*. The hypothesis concerning the impact of risk on the returns to R&D follows the risk-bearing or a mispricing rationale (Chambers et al., 2002; Chan et al., 2001), i.e. higher risk yields to higher R&D returns. Additionally, using two proxies of ambiguity, we advocate the theoretical predictions of ERP puzzle literature (Mehra and Prescott, 1985; Chen and Epstein, 2002; Bollerslev et al., 2009; Miao and Wang, 2011) that show how asset returns can be expressed as a sum of a risk premium and an ambiguity premium, i.e. the presence of both risk and ambiguity may lead to higher R&D returns. In line with the risk premium and the mispricing hypotheses, we find that, for the average company, the R&D returns are positive when controlling for risk. These returns are higher when controlling for both risk and ambiguity, reflecting the conjectures of on a premium for risk and a separate premium for ambiguity.

References

Abdellaoui, M., Baillon, A., Placido, L., and Wakker, P. P. (2011). The rich domain of uncertainty: Source functions and their experimental implementation. *American Economic Review*, 101(2):695–723.

Arthur, W. (2009). *The Nature of Technology: What It Is and How It Evolves*. Free Press.

Becker, M. C. (2004). Organizational routines: a review of the literature. *Industrial and corporate change*, 13(4):643–678.

Ben-Haim, Y. (2006). *Info-gap decision theory: decisions under severe uncertainty*. Academic Press.

Bloom, N. and Reenen, J. V. (2002). Patents, real options and firm performance. *The Economic Journal*, 112(478):pp. C97–C116.

Bogliacino, F. and Pianta, M. (2013). Profits, R&D, and innovation–a model and a test. *Industrial and Corporate Change*, 22(3):649–678.

Bollerslev, T., Tauchen, G., and Zhou, H. (2009). Expected stock returns and variance risk premia. *Review of Financial Studies*, 22(11):4463–4492.

Bronk, R. (2011). Uncertainty, modelling monocultures and the financial crisis. *Business Economist*, 42(2):5.

Chambers, D., Jennings, R., and Thompson, RobertB., I. (2002). Excess Returns to R&D-Intensive Firms. *Review of Accounting Studies*, 7(2-3):133–158.

Chan, L. K., Lakonishok, J., and Sougiannis, T. (2001). The stock market valuation of research and development expenditures. *The Journal of Finance*, 56(6):2431–2456.

Chen, Z. and Epstein, L. (2002). Ambiguity, risk, and asset returns in continuous time. *Econometrica*, 70(4):pp. 1403–1443.

Coad, A. and Rao, R. (2010). Firm growth and R&D expenditure. *Economics of Innovation and New Technology*, 19(2):127–145.

Cozzi, G. and Giordani, P. E. (2011). Ambiguity attitude, R&D investments and economic growth. *Journal of Evolutionary Economics*, 21(2):303–319.

Czarnitzki, D. and Toole, A. A. (2011). Patent Protection, Market Uncertainty, and R&D Investment. *The Review of Economics and Statistics*, 93(1):147–159.

de Palma, A., Ben-Akiva, M., Brownstone, D., Holt, C., Magnac, T., McFadden, D., Moffatt, P., Picard, N., Train, K., Wakker, P., and Walker, J. (2008). Risk, uncertainty and discrete choice models. *Marketing Letters*, 19(3-4):269–285.

Dixit, A. K. and Pindyck, R. S. (2012). *Investment under Uncertainty*. Princeton University Press.

Dobbelaere, S., Luttens, R. I., and Peters, B. (2008). Starting an R&D Project under Uncertainty. Technical report.

Doraszelski, U. and Jaumandreu, J. (2006). R&D and productivity: The knowledge capital model revisited. *Cambridge, MA: Harvard University*.

Doraszelski, U. and Jaumandreu, J. (2013). R&D and Productivity: Estimating Endogenous Productivity. *Review of Economic Studies*, 80(4):1338–1383.

Dosi, G. and Egidi, M. (1991). Substantive and procedural uncertainty. *Journal of Evolutionary Economics*, 1(2):145–168.

European Commission (2013). The 2013 EU Industrial R&D Investment Scoreboard.

Freytag, A. and Thurik, R. (2007). Entrepreneurship and its determinants in a cross-country setting. *Journal of Evolutionary Economics*, 17(2):117–131.

Gajdos, T., Tallon, J.-M., and Vergnaud, J.-C. (2008). Representation and aggregation of preferences under uncertainty. *Journal of Economic Theory*, 141(1):68 – 99.

Gilboa, I. and Schmeidler, D. (1989). Maxmin expected utility with non-unique prior. *Journal of Mathematical Economics*, 18(2):141 – 153.

Griliches, Z. (1979). Issues in assessing the contribution of research and development to productivity growth. *The Bell Journal of Economics*, pages 92–116.

Griliches, Z. (1998). *R&D and Productivity: The Econometric Evidence*. NBER Books. National Bureau of Economic Research, Inc.

Hall, B. H., Mairesse, J., and Mohnen, P. (2009). Measuring the Returns to R&D. Working Paper 15622, National Bureau of Economic Research.

Hodgson, G. (2011). The eclipse of the uncertainty concept in mainstream economics. *Journal of Economic Issues*, 45(1):159–175. Original article can be found at : http://mesharpe.metapress.com/ Copyright Newfound Press.

Hofstede, G. (1980). Culture and organizations. *International Studies of Management & Organization*, pages 15–41.

Hurdle, G. J. (1974). Leverage, risk, market structure and profitability. *The Review of Economics and Statistics*, 56(4):478–85.

Keynes, J. M. (1936). *The general theory of interest, employment and money*, volume 156. London: Macmillan.

Knight, F. (1921). *Risk, Uncertainty and Profit*. Boston, MA: Hart, Schaffner & Marx; Houghton Mifflin Co.

Kumbhakar, S. C., Ortega-Argilés, R., Potters, L., Vivarelli, M., and Voigt, P. (2012). Corporate R&D and firm efficiency: evidence from Europes top R&D investors. *Journal of Productivity Analysis*, 37(2):125–140.

Lane, D. A. and Maxfield, R. R. (2005). Ontological uncertainty and innovation. *Journal of Evolutionary Economics*, 15(1):3–50.

Lev, B. (2000). *Intangibles: Management, measurement, and reporting*. Brookings Institution Press.

Loomes, G., Moffatt, P. G., and Sugden, R. (2002). A Microeconometric Test of Alternative Stochastic Theories of Risky Choice. *Journal of Risk and Uncertainty*, 24(2):103–30.

Markowitz, H. (1952). Portfolio selection*. *The Journal of Finance*, 7(1):77–91.

Mazzucato, M. and Tancioni, M. (2013). R&D, Patents and Stock Return Volatility. In Pyka, A. and Andersen, E. S., editors, *Long Term Economic Development*, Economic Complexity and Evolution, pages 341–362. Springer Berlin Heidelberg.

McFadden, D. (2001). Economic Choices. *American Economic Review*, 91(3):351–378.

Mehra, R. and Prescott, E. C. (1985). The equity premium: A puzzle. *Journal of Monetary Economics*, 15(2):145–161.

Miao, J. and Wang, N. (2011). Risk, uncertainty, and option exercise. *Journal of Economic Dynamics and Control*, 35(4):442–461.

Nadiri, M. I. (1993). Innovations and Technological Spillovers. NBER Working Papers 4423, National Bureau of Economic Research, Inc.

Noorderhaven, N. (2003). Uncertainty avoidance and the rate of business ownership across 21 oecd countries, 1976-2004. *Journal of Evolutionary Economics*, 17(2):133–160.

Pastor, L. and Pietro, V. (2003). Stock valuation and learning about profitability. *The Journal of Finance*, 58(5):1749–1790.

Pennings, E. and Sereno, L. (2011). Evaluating pharmaceutical R&D under technical and economic uncertainty. *European Journal of Operational Research*, 212(2):374 – 385.

Rapp, J. K., Bernardi, R. A., and Bosco, S. M. (2010). Examining the use of Hofstede's uncertainty avoidance construct in international research: A 25-year review. *International Business Research*, 4(1):p3.

Sutton, J. (2006). Flexibility, profitability and survival in an (objective) model of knightian uncertainty. Technical report, Working paper, London School of Economics.

Tobin, J. (1958). Liquidity preference as behavior towards risk. *The Review of Economic Studies*, 25(2):65–86.

Train, K. (2003). *Discrete Choice Methods with Simulation*. Online economics textbooks. SUNY-Oswego, Department of Economics.

Tversky, A. and Kahneman, D. (1992). Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and uncertainty*, 5(4):297–323.

Vo, L. V. (2013). R&D Investments, Profitability Uncertainty and Firm's Valuation. *Available at SSRN 2287593*.

European Commission
Joint Research Centre – Institute for Prospective Technological Studies

Title: **R&D profitability: the role of risk and Knightian uncertainty**

Authors: Sara Amoroso, Pietro Moncada-Paternó-Castello, Antonio Vezzani

Spain: European Commission, Joint Research Centre

2015 – 11 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9408 (online)

JRC Mission

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners.

Serving society
Stimulating innovation
Supporting legislation