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EERI Research Paper Series No 13/2013

ISSN: 2031-4892

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Uncertainty, flexible labour relations and R&D expenditure

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Abstract

This paper examines the effects of uncertainty and flexible labour contracts on the Research and Development (R&D) expenditure. Using a panel of Italian manufacturing firms, we find a hump-shaped relationship between workforce flexibility and R&D outlays. Moreover, as predicted by the real options theory, our results suggest that product market uncertainty reduces R&D efforts and that flexible labour contracts countervail the adverse effect of uncertainty on R&D.

Keywords: real options theory, R&D, uncertainty, temporary workers.

JEL codes: D22, D81, J41, O31.

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[†]The authors would like to thank participants at the EEA/ESEM conference in Gothenburg. The authors acknowledge the Capitalia group for providing the survey data. The organisation does not bear any responsibility for the analysis or interpretations presented in this paper. The usual disclaimers apply.

1 Introduction

Firms' R&D investment is crucial to the development of new products and processes, and the improvement of existing ones. A recent strand of the literature has highlighted the role played by uncertainty on R&D investments. In particular, empirical evidence both at a macro (Goel and Ram, 2001) and a micro (Czarnitzki and Toole, 2007, 2011) level suggests that higher uncertainty reduces current R&D investments, and that firms react to the incentives able to reduce the effects of uncertainty, such as patent protection and R&D subsidies.

This paper argues that the adverse effects of uncertainty may also be countervailed by making the firms' cost structure more flexible through the use of fixed-term workers. In case of unfavourable market conditions, by increasing the control over future cost adjustments, firms reduce the adverse effects of uncertainty and, consequently, may increase R&D investments. By using a panel of Italian manufacturing firms, we provide empirical evidence of this mechanism. In addition, this article evaluates whether, and to what extent, the use of flexible labour influences the level of private R&D investment. Technological change often requires labour reallocation, while tight labour market regulations can slow labour flows among firms and industries. As a consequence, resources are allocated more efficiently in a flexible regime and, thus, investments raise. By contrast, as the share of flexible workers grows, other forces may lead to the opposite result. For instance, it becomes more difficult to retain knowledge within firms and keep high levels of workers' loyalty and commitment, leading to lower R&D investments (Zhou et al., 2011). Our estimates detect a non-monotonic relationship between R&D expenditure and the use of flexible labour. Thus, we infer that flexibility is needed to allow firms to reach their optimal level of R&D, but there is a threshold beyond which higher flexibility becomes harmful.

The results are robust to different specifications of the baseline model and three variants of the uncertainty measure. Moreover, our estimates are confirmed when the share of fixed term workers is treated as a potential endogenous regressor.

The evidence presented in this paper is also intended to better inform the policy debate on labour market reforms. The inverse U-shaped relationship between flexible labour and R&D implies that excessive regulation is detrimental to the optimal choices of innovating firms, but excessive deregulation could result in efficiency gains achieved through short-run employment practises dominating the gains from long-run innovation strategies, leading to lower innovative efforts and, consequently, to lower innovation, welfare and growth.

The rest of the paper is organised as follows. Section 2 reviews the relevant literature and states our research purposes. Section 3 deals with data, variables and methods. The empirical findings are discussed in section 4, while section 5 concludes.

2 Literature review and research questions

Recent developments in the theory of investment have shown that simple rules based on the Net Present Value (NPV) of expected cash flows are not as accurate as one may wish in explaining firms' investment decisions. In particular, real options investment theory predicts that the interaction between uncertainty and the degree of investment irreversibility[1] leads firms to put value on the option to wait and, thus, to alter the optimal level of current investments as compared to those predicted by a NPV rule of thumb[2]. Following the work of Pindyck (1991) and Dixit (1992), Abel et al. (1996) provide a general framework in which the effect of uncertainty on the current incentive to invest is determined by the exercise of *expandability* and *reversibility* options. While the former refers to the possibility of delaying an investment at some point in the future (thus it decreases current investments for increasing levels of uncertainty), the latter refers to the possibility of disinvesting at some point in the future (thus it increases current investments for increasing levels of uncertainty). The exercise of these options is based on a cost-benefit analysis and determines the sign and magnitude of the overall effect of uncertainty on firms' investment decision.

R&D is often considered as an investment with low or null reversibility, indeed it requires the purchase of capital and labour services that do not directly increase production (e.g. research equipment, establishing and maintaining laboratories, salaries of research personnel). If one acknowledges that R&D investment has a high degree of irreversibility, the impact of uncertainty on R&D investments is negative because firms can exercise only the expandability option. Surprisingly, only few studies examine this relationship empirically[3]. By using the 5-year moving standard deviation of inflation and the 5-year moving average of inflation as measures of uncertainty, Goel and Ram (2001) confirm the adverse effect of uncertainty on the share of R&D over GDP for a panel of OECD countries. Minton and Schrand (1999) use *Compustat* data to relate, among other variables, R&D costs to cash flow volatility. They also find evidence of a negative relationship between uncertainty and R&D expenditure. Finally, Czarnitzki and Toole (2007, 2011) come to similar conclusions by focusing on measures of product market uncertainty. Our first objective is, thus, to contribute to this literature by offering empirical evidence for the Italian case.

A second goal of this paper is to incorporate a measure of flexible labour in the above mentioned empirical literature to investigate whether the legal framework governing the relationships between employers and employees affects the R&D expenditure of firms. As a matter of fact, there is a growing interest in the role played by labour market institutions on the ability of firms and countries to innovate. In particular, there is a widespread perception that some institutional features designed to protect workers — such as employment protection or social security — may actually be an obstacle to successful innovation strategies. For instance, Saint-Paul (2002) develops a model in which rigidities in the labour market, formalised through firing restrictions, have implications on aggregate R&D investments. The author shows that countries with more stringent labour market regulations will tend to produce relatively secure goods to avoid paying the costs of adjusting the labor force, thus they specialise in innovations aimed at improving existing products, rather than innovations aimed at introducing new products. While this prediction emerges empirically in most studies based on aggregate data[4], few authors have attempted so far to investigate this relationship on a micro basis. From this point of view, several theoretical motivations can help us understand the relevance of flexible employer-employee relations. First, let consider the knowledge stock of a firm as proxied by the accumulation of past R&D investments (Bloom, 2007). Shorter job tenure may weaken the knowledge accumulation process within the organisation and increase the risk of revealing trade secrets and technological knowledge to competitors, leading to lower investments in R&D. At the same time, if short-term contracts are used as a screening device, firms are able to select high ability workers among the pull of job applicants. Higher levels of skills within the firm may trigger higher R&D efforts. Third, lower protection against dismissals may reduce the unions' power to bargain over future wages and, consequently, the ability of appropriating the rent generated by innovations. It follows that the R&D incentive is greater in a flexible regime where firms are able to capture a greater share of the returns to innovative investments. However, when unions bargain also over employment levels, the relationship between union strength and R&D is inverse U-shaped (Ulph and Ulph, 1998). Fourth, labour flexibility can have an impact on the R&D expenditure through its effect on productivity. Several studies have explored this relation both theoretically and empirically, but no consensus has been reached on the sign of the effect[5]. Technological change often requires labour reallocation, while firing restrictions can slow labour flows among firms and industries. As a result, resources are allocated more efficiently in a flexible regime and, thus, investments raise[6]. At the same time, both firms and workers may reduce investments in specific human capital because of the shorter expected duration of a contract, thus productivity falls (Dolado et al., 2002). However, the fall in productivity might only be temporary (Boeri and Garibaldi, 2007) and sufficiently high rates of conversion of temporary contracts into permanent ones may induce both fixed-term workers to work harder (Dolado and Stucchi, 2008) and firms to provide more effective training.

Given the overall theoretical ambiguity, this study contributes to the debate by offering empirical evidence of the overall effect of labour flexibility on R&D outlays at the firm level. In particular, the interaction among these forces may produce a non linear dependence patter between temporary workforce and R&D investments, thus we test the hypothesis of a non-monotonic relationship through the inclusion of a linear and a squared term in the empirical model. Quantitative work relating the use of fixed-term contracts to innovative activities is still inconclusive. Serrano and Altuzarra (2010) test the presence of a non-linear relationship between the share of fixed-term workers and a dichotomous indicator of R&D activities. Even though the sign of the coefficients supports their hypothesis, the coefficients are not statistically significant. Arvanitis (2005) uses cross sectional data on Swiss enterprises and finds mixed results of the impact of flexibility on measures of product and process innovation. Differently, Michie and Sheehan (1999) find that short-term contracts have a negative effect on investment in R&D and new technologies.

A further contribution of the present study is to quantify the effect of the interplay of workforce flexibility and uncertainty on the R&D expenditure. We provide two explanations why, in the presence of uncertainty about future returns, flexible labour may have an impact on R&D. First, consider the case of temporary workers as part of the research personnel. As pointed out by Pindyck (1991), [..] *investments in new* (permanent) *workers may be partly irreversible because of high costs of hiring, training, and firing* [..]. In light of the real options investment theory, it means that firms are left with the expandability option alone. Thus, more uncertainty increases the value of deferring hiring permanent workers. Differently, the use of temporary contracts brings new opportunities to the firms because it partially restores the reversibility option of the investment. Indeed, temporary contracts usually can be terminated at will and at little cost by employers. It follows that flexible labour may increase R&D investments to the extent that it is able to countervail the adverse effects of uncertainty.

Second, consider the case of temporary workers as employed in the production process. Since one of the aims of the R&D investments is to ultimately introduce new products in the market, firms may face future workforce expansion decisions to produce the new products. Since firms exhibit a forward-looking behaviour, the worsening of market conditions will eventually brings losses that firms may try to offset by adjusting their labour force, but this is a viable strategy only if part of the workforce is hired under flexible contracts with low firing restrictions. Therefore, more flexibility increases current R&D investments because firms insure themselves by increasing their control over future labour cost adjustments.

Even if both implications are empirically testable, our data does not allow us to distinguish whether temporary workers are employed as research personnel or in the production process. Therefore, we can not identify the two effects separately but, since in both scenarios more flexibility leads to higher R&D investments, we can still estimate the overall effect.

To the best of our knowledge, there is a lack of empirical evidence on this topic. To check if temporary workers are able to mitigate the effect of uncertainty, we include in the empirical model an interaction term between the share of fixed-term workers and the level of uncertainty. We find evidence in support of our hypothesis.

3 Data, variables and methods

3.1 Data, variables and summary statistics

This paper uses micro data from the eighth and ninth waves of the *Survey of Italian Manufacturing Firms* (SIMF) collected, respectively, in 2001 and 2004 by *Capitalia* Bank Research Centre [7]. The dataset contains a unique combination of self-reported measures of R&D expenditures and information on fixed-term and permanent labour contracts which is well suited to analyse the effect of flexible labour contracts on firms' innovation activity.

The SIMF is carried out every three years and deliver information on the three years prior to the interview, thus the overall time dimension of the waves that we consider span from 1998 to 2003. Each survey is a representative sample of Italian manufacturing firms with more than 10 employees[8]. Nese and O'Higgins (2007) discuss the problem of panel attrition in the SIMF and they advice against the use of more than two consecutive waves when trying to build a panel. For this reason, and to avoid overlap with structural reforms of the Italian labour market, we decided to consider only the 2001 and 2004 waves of the available surveys[9]. By merging the two waves, we build a panel of 2136 firms. Among them, we select those firms with a positive R&D expenditure at least in one year (around 47% of all firms). Then, firms with missing years and/or missing or inconsistent data are excluded from the analysis. As it will be clarified in the following, the uncertainty measure at time t is build by using information, alternatively, of the two, three or all previous available years. Thus, the estimates on R&D outlays are carried out on a sample of 800 firms observed over the period 2000-2003 while, to build lagged regressors, we use the information referring to the period 1998-2003.

As dependent variable, we use an input-based measure of firms' R&D activity[10], namely yearly R&D expenditure in millions of euros[11]. Consistently with well known stylised facts, firms in our sample show a high degree of persistency in R&D investment behaviour. Indeed, by looking at transitional probabilities, around 90% of firm-year observations that undertook such investment at time t, did it also at time $t+1$. Moreover, more than 67% of those who did not invest at time t, did not invest also at time $t+1$.

Among all the possible kinds of investment a firm might undertake, R&D is probably the most sensitive to uncertainty. In particular, given the framework of this study, product market uncertainty seems to be a natural candidate to describe the kind of uncertainty that firms take into account while deciding the R&D effort. Moreover, Czarnitzki and Toole (2007) clarify that this measure may also capture both consumer demand and competitive pressures in the marketplace. For these reasons, uncertainty at time t has been proxied by the standard deviation of past sales per-employee, where firm's sales per-employee are normalised by the average sales per-employee in firm's operating industry[12]. Note that dividing firm's sales by the number of employees is intended to purge from firm size effects, while the normalisation procedure should be able to eliminate, or at least mitigate, differences in trends and industry specific characteristics both at demand and product level[13].

To check the stability of our results, we compute three versions of the uncertainty measure. The first one uses information of the previous two years, the second uses information of the previous three years, while the third is based on all past information contained in the data, thus the number of past observations available for each firm varies from two to five.

To summarise, the uncertainty measure reflects revenues volatility, and we expect it to have a negative impact on firms' R&D investments. While, to test the U-shaped relationship between flexible labour relations and R&D expenditure, the empirical model includes the share of temporary workers over the firm workforce and its squared value. Also, we consider the interaction term between uncertainty and the share of temporary workers in order to identify to what extent temporary contracts may countervail the adverse effect of uncertainty.

In addition to the variables of interest, we add a rich set of control variables to better explain firms' innovative efforts[14]. First, we make use of a dummy for past R&D expenditure to account for the persistency of R&D behaviour detected in the sample. Also, firms in more technology-intensive industries may have a higher propensity to conduct R&D than those in more labor-intensive sectors. Thus, the model includes dummy variables for Pavitt sectors, namely technological, scale and traditional industries. Moreover, because size reflects access to finance, scale economies and differences in the organisation of work, we include dummies for firm size measured by the number of employees at the firm[15]. Hirings and separations of workers across firms embody information about knowledge circulation, and is a potential source of spillovers. Thus, firms may benefit from knowledge inflow and suffer from knowledge outflow simultaneously. To the extent that firm's R&D knowledge is primarily embodied in persons, high worker flows may result in lower appropriability of workers' knowledge and lower incentives to innovate. Therefore we include in the model the coefficients of variation of inflow and outflow worker turnover rates built on the ATECO classification. Finally, other firms' characteristics included in the model are: firm's location, legal form, sales and squared sales, investments in physical capital and workforce composition. Summary statistics

Table 1: Summary statistics (1859 firm-year observations, 800 firms)

Variable	Mean	Std.Dev.
R&D expenditure	0.308	0.784
Uncertainty$_{t-1}$	0.083	0.222
Share of temporary workers	0.034	0.101
Dummy R&D$_{t-1}$	0.746	0.435
Revenues$_{t-1}$	25.043	59.374
Investment in physical capital$_{t-1}$	0.873	2.557
Dummy large firm	0.114	0.317
Dummy medium firm	0.300	0.458
Dummy small firm	0.587	0.493
Pavitt sector: traditional	0.073	0.260
Pavitt sector: special	0.374	0.484
Pavitt sector: technological	0.554	0.497
Dummy corporations	0.985	0.122
Northern firms	0.729	0.445
Share of executives$_{t-1}$	0.017	0.029
Share of high level white collars$_{t-1}$	0.019	0.038
Share of low level white collars$_{t-1}$	0.262	0.164
Share of blue collars$_{t-1}$	0.648	0.184
Worker inflow rate$_{t-1}$	0.115	0.217
Worker outflow rate$_{t-1}$	0.095	0.193
Coefficient of variation of worker inflow rate$_{t-1}$	0.398	0.344
Coefficient of variation of worker outflow rate$_{t-1}$	0.409	0.358

Notes: Nominal variables are in millions of euros. Uncertainty has been measured by the standard deviation of past two-years sales per-employee, where firm's sales per-employee are normalised by the average sales per-employee in firm's operating industry. The size of firms is proxied by a dummy for small (lower than 51 employees), medium (from 51 to 250 employees) and large firms (more than 250 employees). Worker inflow (outflow) rate is the ratio of hirings (separations) over the workforce.

are reported in table 1.

3.2 Research methods

This section describes the methods used to test our research questions. Given the structure of the data, we adopt a random-effect Tobit model for panel data. In particular, we interpret our dependent variable y as a corner solution response variable, which takes the value 0 with positive probability while it is a continuous variable over strictly positive values. This means that some firms in our sample do not find optimal to engage in R&D activities[16].

The Tobit equation can be written as $y_{it} = max\left(0, \alpha_i + x_{it}\beta + \epsilon_{it}\right)$, where y_{it} is the observed R&D expenditure of firm i at time t, α_i is the unobserved firm-specific effect, x_{it} is the set of regressors, β is the set of parameters of interest and $\epsilon_{it}|x_{it}, \alpha_i \sim N\left(0, \sigma_\epsilon^2\right)$ is the error component.

We implement three different specifications of the empirical model. The first one includes the uncertainty measure and is aimed at checking the prediction of the real options investments theory. The second specification adds the share of temporary workers and its squared value to identify the direct effect of flexible labour relations on the R&D investment. The last specification also considers the interaction term between uncertainty and the share of temporary workers to identify the joint effect of temporary workers and uncertainty on the R&D expenditure. Each model specification has been replicated for each version of the uncertainty measure. We would also like to be confident that our strategy is able to identify real options investment behaviour. As in Czarnitzki and Toole (2007), we assume that each firm's risk preferences are related to its recent innovation strategy. While the authors use the average share of new product sales relative to each firm's industry to describe past innovation strategy, we use the two-years average of past R&D intensity[17]. This variable should capture firms' risk preferences, increasing the credibility of the results.

A major concern in our empirical strategy is that there might be a problem of endogeneity of the fraction of flexible workers over the firm's workforce due to the potential correlation between the flexibility measure and the error term. In order to validate the results, we adopt a simultaneous equation Tobit model similar to the one described in Smith and Blundell (1986), with the only difference being that our potential endogenous regressor is left-censored at zero and right-censored at one. The method is a two-stage procedure. In the first stage, we estimate a reduced form equation by Tobit in which the share of flexible contracts is explained by its lagged value, lagged uncertainty, lagged outflow and inflow turnover rates, lagged revenues and its squared value, firm size and industry, location and workforce composition. The residuals from the first stage are plugged into the Tobit estimation of the R&D equation. Exogeneity is then evaluated by means of a simple t-statistics on the coefficient of the first stage residuals. In particular, if we can not reject the null hypothesis, the fraction of temporary workers is an endogenous regressor and the standard errors for the R&D equation are not valid. Instead, if the t-test confirms exogeneity, then the second stage coefficients should not differ in magnitude and significance levels from those obtained in the Tobit regression that does not include the first stage residuals among its regressors.

4 Estimation results

The main results from the Tobit regressions are reported in tables 2 and 3. We show the estimated coefficients for three model specifications and repeat the econometric analysis for each version of the uncertainty measure. Specifically, in table 2 we use the uncertainty measure computed as the two-years standard deviation of past sales per-employee; in panel (a) of table 3 the uncertainty measure is the three-years standard deviation of past sales per-employee; in panel (b) of table 3 the uncertainty is proxied by the standard deviation of past sales per-employee for all available years. Firm's sales per-employee are normalised by the average sales per-employee in firm's operating industry.

In line with real option theory and with previous empirical evidence, the coefficient of the uncertainty variable has a negative sign in all the specifications, meaning that greater uncertainty increases the value of the expandability option and reduces current R&D investments because no reversibility option can be exercised by firms for each unit of capital that would be otherwise bought. In particular, the magnitude of the effect is clustered around -0.1131 and -0.1793, and it is always statistically significant at conventional levels. Note that when the estimates include the interaction term, the coefficient of the uncertainty variable is even stronger, probably because we purge for the positive impact that the variable exert when combined with the level of flexible labour.

From model specifications 2 and 3 in table 2, we find some evidence of a hump-shaped relationship between the use of flexible labour and the R&D expenditure, even though in model 3 we lose significance of the linear term of the share of temporary workers[18]. Of course, we are not able to identify which of the effects outlined in section 2 tend to prevail, but still the estimates suggest that a certain degree of flexibility is needed for innovation activities. For lower levels of flexibility, an increase in the use of fixed-term contracts tends to raise *ceteris paribus* the R&D expenditure, but only up to a threshold. Indeed, for higher levels of flexibility, the coefficient of the quadratic term tends to offset the positive impact of the linear term, and the R&D expenditure is decreasing in the share of fixed-term workers. Intuitively, a less regulated labour market makes room for efficiency gains achieved through short-run employment practises, which may dominate the gains from long-run innovation strategies. At the same time, a stringent regulation prevents firms to mitigate the negative effects of uncertainty with the consequence of lower R&D investments. In particular, the joint effect of the use of temporary workers and the uncertainty levels on the R&D expenditure is captured by the interaction term. The estimated coefficient is positive and statistically significant. This is a novel result in the literature and supports the idea that firms may expand R&D efforts as long as they can exercise a reversibility option by investing in temporary workers.

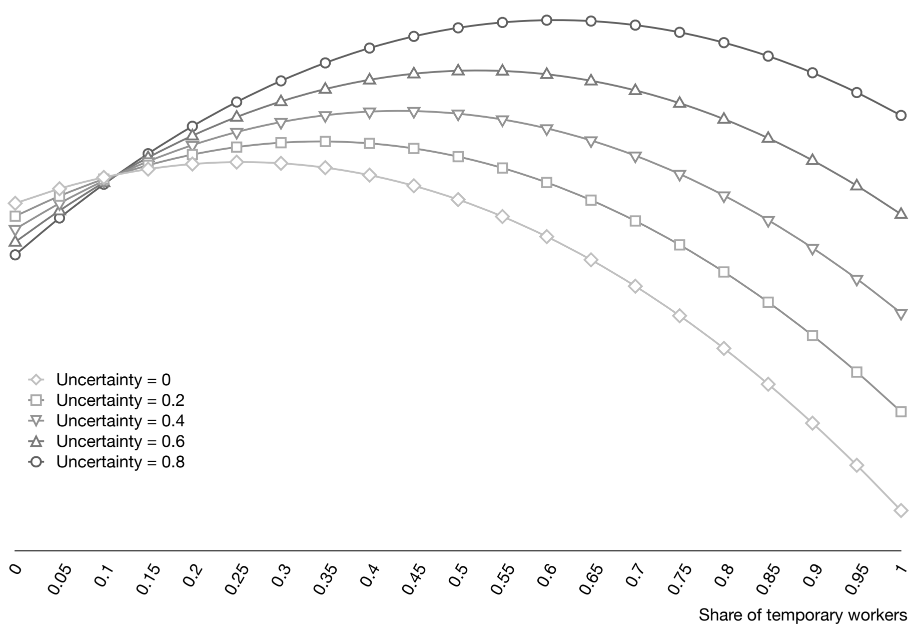
Based on the estimated coefficients of table 2 (model 3), figure 1 provides a graphical representation of the overall effect of uncertainty and flexible labour

Table 2: Tobit regressions: two-years measure of uncertainty

	Model 1	Model 2	Model 3
Uncertainty$_{t-1}$	-0.1141***	-0.1131***	-0.1297***
	(-0.040)	(-0.040)	(-0.040)
Share of temporary workers		0.7623*	0.648
		(-0.404)	(-0.408)
Squared Share of temporary workers		-1.2105**	-1.2663**
		(-0.572)	(-0.571)
Interaction term			1.1235*
			(-0.574)
Coefficient of variation of worker inflow rate$_{t-1}$	-0.043	-0.042	-0.042
	(-0.032)	(-0.032)	(-0.032)
Coefficient of variation of worker outflow rate$_{t-1}$	0.024	0.024	0.020
	(-0.031)	(-0.031)	(-0.031)
Dummy R&D$_{t-1}$	0.0377*	0.036	0.0380*
	(-0.023)	(-0.023)	(-0.023)
Revenues$_{t-1}$	0.0076***	0.0076***	0.0077***
	(-0.001)	(-0.001)	(-0.001)
Squared revenues$_{t-1}$	-0.0000***	-0.0000***	-0.0000***
	(0.000)	(0.000)	(0.000)
Dummy corporations	0.7163***	0.7168***	0.7100***
	(-0.194)	(-0.194)	(-0.194)
Dummy large firm	0.4117***	0.4185***	0.4103***
	(-0.087)	(-0.087)	(-0.087)
Dummy medium firm	0.1396***	0.1457***	0.1436***
	(-0.047)	(-0.048)	(-0.047)
Pavitt sector: technological	0.3663***	0.3543***	0.3556***
	(-0.102)	(-0.102)	(-0.102)
Pavitt sector: special	0.1155**	0.1127**	0.1132**
	(-0.057)	(-0.057)	(-0.057)
Northern firms	0.039	0.037	0.038
	(-0.060)	(-0.060)	(-0.060)
Share of executives$_{t-1}$	0.279	0.265	0.253
	(-0.425)	(-0.424)	(-0.423)
Share of high level white collars$_{t-1}$	0.553	0.562	0.551
	(-0.349)	(-0.349)	(-0.348)
Share of low level white collars$_{t-1}$	0.4354**	0.4271**	0.4182**
	(-0.182)	(-0.182)	(-0.181)
Share of blue collars$_{t-1}$	-0.018	-0.029	-0.045
	(-0.172)	(-0.172)	(-0.172)
Investment in physical capital$_{t-1}$	0.0145***	0.0146***	0.0145***
	(-0.004)	(-0.004)	(-0.004)
Constant	-1.0456***	-1.0464***	-1.0258***
	(-0.251)	(-0.250)	(-0.250)

Notes: The dependent variable is the R&D expenditure. ***, **, * denote, respectively, significance at 1%, 5% and 10%. Standard errors are in parenthesis. The sample corresponds to 800 firms observed over the period 2000-2003. Among the 1859 firm-year observations, 461 are left-censored. Nominal variables are in millions of euros. Uncertainty has been measured by the standard deviation of past two-years sales per-employee, where firm's sales per-employee are normalised by the average sales per-employee in firm's operating industry. The interaction term is the product of the share of temporary workers times the uncertainty. The size of firms is proxied by a dummy for small (lower than 51 employees), medium (from 51 to 250 employees) and large firms (more than 250 employees). Worker inflow (outflow) rate is the ratio of hirings (separations) over the workforce.

Figure 1: Patterns of R&D, uncertainty and flexible labour



on the R&D expenditure. We plot the patterns of R&D for increasing levels of flexibility (measured on the $x-$axis as the share of fixed-term contracts over the firm workforce); each line is drawn for a given level of uncertainty. In the absence of flexibility, an increase in uncertainty is associated to a decrease of the R&D level. With increasing flexibility, first we observe that the effect of uncertainty on R&D is gradually less intense, but still negative. Then, after a threshold (around 11% of flexibility) the effect of uncertainty becomes positive. At the same time, if we keep constant the level of uncertainty, we notice that there is always a hump-shaped relation between flexibility and the amount of resources allocated to R&D. Finally, the optimal level of flexibility is increasing in the level of uncertainty.

As far as the coefficients of the control variables are concerned, several of

Table 3: Tobit regressions: three- and all-years measure of uncertainty

	(a)			(b)		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Uncertainty$_{t-1}$	-0.1520***	-0.1509***	-0.1640***	-0.1659***	-0.1653***	-0.1797***
	(-0.043)	(-0.043)	(-0.044)	(-0.048)	(-0.048)	(-0.048)
Share of temporary workers		0.7543*	0.555		0.7549*	0.5607
		(-0.403)	(-0.420)		(-0.403)	(-0.419)
Squared Share of temporary workers		-1.2042**	-1.2480**		-1.2085**	-1.2534**
		(-0.571)	(-0.569)		(-0.571)	(-0.419)
Interaction term			1.3762*			1.3549*
			(-0.759)			(-0.747)

Notes: The dependent variable is the R&D expenditure. ***, **, * denote, respectively, significance at 1%, 5% and 10%. Standard errors are in parenthesis. The sample corresponds to 800 firms observed over the period 2000-2003. Among the 1859 firm-year observations, 461 are left-censored. Nominal variables are in millions of euros. In panel (a) uncertainty has been measured by the standard deviation of past three-years sales per-employee, where firm's sales per-employee are normalised by the average sales per-employee in firm's operating industry. In panel (b) the uncertainty measure refers to all previous available years. The interaction term is the product of the share of temporary workers times the uncertainty. Since there were not substantial differences in terms of sign, magnitude and statistical significance of the estimated coefficients of the control variables with respect to table 2, the table reports only the information concerning the variables for which we have formulated specific hypotheses. Complete tables are available upon request.

them are significant and have the expected signs. The Tobit results indicate that past revenues and physical capital investments have a positive impact on firms' R&D effort. The positive effect of past revenues might reflect an increasing capability of carrying out investments in R&D because of better cash flows, but it could also be an indicator of successful performances linked to past innovation. Consistent with previous empirical studies, we also find that the effect of firm size is positive and significant. Larger firms show a higher commitment to innovating strategies because of easier access to finance, scale economies and differences in the organisation of work. We also reach the conclusion that higher investments are achieved in special and technological Pavitt sectors as compared to the reference sector, namely the traditional sector. Finally, corporations tend to invest more.

Table 3 summarises the results based on the two variants of our measure of uncertainty. It is straightforward to see that the results are in line with those already presented in table 2.

To be confident that the estimates presented so far describe real options investment behaviour, we also show the results where we add a control variable

Table 4: Tobit regressions: check for firm's risk preferences

	Model 1	Model 2	Model 3
Uncertainty$_{t-1}$	-0.1096***	-0.1091***	-0.1258***
	(-0.040)	(-0.040)	(-0.041)
Share of temporary workers		0.5576	0.4427
		(-0.405)	(-0.410)
Squared Share of temporary workers		-0.9483*	-1.0031*
		(-0.566)	(-0.566)
Interaction term			1.1300**
			(-0.569)
Average R&D intensity$_{t-1}$	1.2430**	1.2184**	1.2035**
	(-0.538)	(-0.538)	(-0.537)

Notes: The dependent variable is the R&D expenditure. ***, **, * denote, respectively, significance at 1%, 5% and 10%. Standard errors are in parenthesis. The sample corresponds to 800 firms observed over the period 2000-2003. Among the 1859 firm-year observations, 461 are left-censored. Nominal variables are in millions of euros. Uncertainty has been measured by the standard deviation of past two-years sales per-employee, where firm's sales per-employee are normalised by the average sales per-employee in firm's operating industry. The interaction term is the product of the share of temporary workers times the uncertainty. Average R&D intensity is defined as the two-years average of the ratio of R&D expenditure over revenues from sales. Since there were not substantial differences in terms of sign, magnitude and statistical significance of the estimated coefficients of the control variables with respect to table 2, the table reports only the information concerning the variables for which we have formulated specific hypotheses. Complete tables are available upon request.

for firm's risk preferences. In particular, we expect each firm's past innovation strategies to be related to its risk aversion[19]. Therefore, we proxy past innovation strategies with the average R&D intensity of the previous two years, and we assume that risk-aversion is inversely related to R&D intensity. Table 4 reports the estimated coefficients. The average R&D intensity is always positive and significant, meaning that firms that have invested heavily in the past are those that invest more today. In this way, we believe that this variable is able to capture risk preferences and that the coefficient of the uncertainty measure reflects real options investment behaviour.

4.1 Endogeneity check

Table 5 presents the results from the two-stage Smith-Blundell procedure outlined in section 3.2, which is intended to check for the potential endogeneity of the share of flexible labour contracts. In particular, both panel (a) and (b) report the

Table 5: Two-stage Tobit model: endogeneity check

	(a)	(b)
First stage residual	-0.0702	-0.0901
	(-0.149)	(-0.148)
Uncertainty$_{t-1}$	-0.1295***	-0.1254***
	(-0.04)	(-0.04)
Share of temporary workers	0.7075*	0.5184
	(-0.428)	(-0.428)
Squared Share of temporary workers	-1.2805**	-1.0219*
	(-0.572)	(-0.567)
Interaction term	1.1146*	1.1187*
	(-0.581)	(-0.578)
Average R&D intensity$_{t-1}$		1.1999**
		(-0.537)

Notes: The dependent variable is the R&D expenditure. ***, **, * denote, respectively, significance at 1%, 5% and 10%. Standard errors are in parenthesis. The sample corresponds to 800 firms observed over the period 2000-2003. Among the 1859 firm-year observations, 461 are left-censored. Nominal variables are in millions of euros. First stage residuals are obtained after the Tobit estimation of a reduced form equation in which the share of flexible contracts is explained by its lagged value, lagged uncertainty, lagged outflow and inflow turnover rates, lagged revenues and its squared value, firm size and industry, location and workforce composition. Uncertainty has been measured by the standard deviation of past two-years sales per-employee, where firm's sales per-employee are normalised by the average sales per-employee in firm's operating industry. The interaction term is the product of the share of temporary workers times the uncertainty. Average R&D intensity is defined as the two-years average of the ratio of R&D expenditure over revenues from sales. Complete tables and the first stage results are available upon request.

coefficients of the variables referring to our research questions and the coefficients of the second stage residuals. Panel (b) adds the results of the estimates including the average R&D intensity. It is straightforward to notice that, in both panels, the first stage residuals are not statistically different from zero. Moreover, we obtain large p-values, 0.637 for the residuals in panel (a) and 0.543 in panel (b). Thus, we do not reject the exogeneity of the share of temporary workers in the R&D equation. It is also worth noting that once we include the first stage residuals in the second stage regression, the estimated coefficients are in line with the ones presented in table 2.

5 Conclusions

This paper documents empirical evidence of the effects of uncertainty and flexible labour relations on the R&D outlays of a sample of Italian manufacturing firms over the period 2000-2003. Coherently with real options investment theory, the irreversible nature of R&D implies a negative relation between uncertainty and R&D expenditure. Uncertainty has been measured by the standard deviation of past sales per-employee, where firm's sales per-employee are normalised by the average sales per-employee in firm's operating industry. This study also extends previous empirical works by including a firm level measure of workforce flexibility and its interaction with product market uncertainty. We identify a non-monotonic impact of flexible labour on R&D and a positive impact of the interaction term.

While this study provides evidence that flexible labour mitigates the effect of product market uncertainty on private R&D effort, there are some caveats to bear in mind. First, our measure of uncertainty is build on past firm experience and does not take into account other mechanisms that might influence the process through which firms formulate the expected level of market uncertainty. If these mechanisms are larger than we believe, then our measure is weakened and the estimation results are less accurate. Second, due to available data, we can not distinguish between new and existing product sales. Also, the data allow us to estimate the overall effect of flexible contracts on R&D investments without distinguishing whether temporary workers are employed as research personnel or in the production process.

However, we believe that our results are informative for the ongoing debate on labour market reforms. From one standpoint, policy makers should be aware that firms' innovation performance may be restrained by rigid personnel structure and that labor market flexibility may be an additional route to foster R&D investments. As another standpoint, excessive deregulation could result in efficiency gains achieved through short-run employment practises dominating the gains from long-run innovation strategies, leading to lower innovative efforts and, consequently, to lower innovation, welfare and growth.

Notes

[1]To use Pindyck's (1991) terminology, irreversible expenditures are sunk costs that cannot be recovered.

[2]Even in a world with uncertainty, a theory based on completely reversible investments is not able to generate this feature because every investment could be in principle recoupable at a later date.

[3]Empirical evidence of a negative relationship between uncertainty and irreversible investment can be found, among others, in Episcopos (1995) and Bulan (2005). For a comprehensive survey, see Carruth et al. (2000).

[4]See, for instance, Barbosa and Faria (2011).

[5]See, among others, Lucidi and Kleinknecht (2010) and Kleinknecht et al. (2006).

[6]See Hopenhayn and Rogerson, 1993, Bertola, 1994 and Samaniego, 2006for different formal approaches.

[7]Originally, the survey was undertaken by *Mediocredito Centrale*. It was a bank specialised in international finance and industrial finance. In 2002, Mediocredito Centrale was taken over by the Capitalia group, the third largest banking group in Italy.

[8]Representativeness has been preserved through stratification by gross product per employee, size, industry, and location.

[9]It is worth noting that our observational window does not include substantial changes in regulations. Relatively to our observational window, even if two main reforms of the Italian labour market passed in 2001 and in 2003, they were implemented only starting in 2005.

[10]Unfortunately, the data do not contain information to build output-based measures of R&D, such as the number of patents.

[11]All nominal variables have been corrected for inflation according to the official Italian Consumer Price Index

[12]In order to identify firms' operating industries, we make use of Pavitt and ATECO taxonomies. First, the classes of economic activities are disaggregated according to Pavitt's taxonomy.

They include: traditional sectors, scale sectors, specialised sectors and high-technology sectors. Then, among these classes, we rely on the three-digit ATECO classification to define the set of industries. The ATECO classification is the Italian version of the European NACE codes (*Nomenclature Statistique des activités économiques dans la Communauté Européenne*) adopted by the Italian Institute of Statistics (ISTAT) to produce internationally comparable economic data.

[13]For instance, differences in the speed of adoption of a new product can vary a lot among industries because of differences in consumers and producers behaviour. By normalising firm's revenues per employee by the average revenue from sales per employee in firm's operating industry, we restrict the variability of our uncertainty measure to industry specificities.

[14]It is worth noting that we use both time-invariant regressors to reduce the error variance (Wooldridge, 2002) and lagged values of time-varying variables in order to treat regressors as predetermined. See Czarnitzki and Toole (2011) for a similar approach.

[15]We construct dummies for small (lower than 51 employees), medium (from 51 to 250 employees) and large firms (more than 250 employees).

[16]Since taking the log of R&D at zero is unfeasible, we prefer to carry out our estimates on the level of R&D. Even if some authors set the zeros to the minimum observed positive R&D, we prefer not to proceed to this data manipulation. Moreover, we do not use the R&D intensity as dependent variable because changes in the numerator could cancel out with changes in the denominator, making difficult to identify the effects on R&D.

[17]R&D intensity is defined as the ratio of R&D expenditure over revenues from sales.

[18]With respect to the three measures of uncertainty, the p-values of the coefficient of the share of temporary workers are, respectively, 0.113, 0.186 and 0.164.

[19]See Czarnitzki and Toole (2007) for a similar check.

References

Abel, A., Dixit, A., Eberly, J., and Pindyck, R. (1996). Options, the value of capital, and investment. *The Quarterly Journal of Economics*, 111(3):753.

Arvanitis, S. (2005). Modes of labor flexibility at firm level: Are there any implications for performance and innovation? Evidence for the Swiss economy. *Industrial and Corporate Change*, 14(6):993.

Barbosa, N. and Faria, A. (2011). Innovation across Europe: How important are institutional differences? *Research Policy*, 40:1157–1169.

Bertola, G. (1994). Flexibility, investment, and growth. *Journal of Monetary Economics*, 34(2):215–238.

Bloom, N. (2007). Uncertainty and the dynamics of R&D. *The American Economic Review*, 97(2):250–255.

Boeri, T. and Garibaldi, P. (2007). Two tier reforms of employment protection: A honeymoon effect? *The Economic Journal*, 117:F357–F385.

Bulan, L. (2005). Real options, irreversible investment and firm uncertainty: New evidence from US firms. *Review of Financial Economics*, 14(3-4):255–279.

Carruth, A., Dickerson, A., and Henley, A. (2000). What do we know about investment under uncertainty? *Journal of Economic Surveys*, 14(2):119–154.

Czarnitzki, D. and Toole, A. (2007). Business R&D and the interplay of R&D subsidies and product market uncertainty. *Review of Industrial Organization*, 31(3):169–181.

Czarnitzki, D. and Toole, A. (2011). Patent protection, market uncertainty, and R&D investment. *The Review of Economics and Statistics*, 93(1):147–159.

Dixit, A. (1992). Investment and hysteresis. *The Journal of Economic Perspectives*, 6(1):107–132.

Dolado, J., García-Serrano, C., and Jimeno, J. (2002). Drawing lessons from the boom of temporary jobs in Spain. *The Economic Journal*, 112:F270–F295.

Dolado, J. and Stucchi, R. (2008). Do temporary contracts affect TFP?: Evidence from Spanish manufacturing firms. *IZA Discussion Paper*, (3832).

Episcopos, A. (1995). Evidence on the relationship between uncertainty and irreversible investment. *The Quarterly Review of Economics and Finance*, 35(1):41–52.

Goel, R. and Ram, R. (2001). Irreversibility of R&D investment and the adverse effect of uncertainty: Evidence from the OECD countries. *Economics Letters*, 71(2):287–291.

Hopenhayn, H. and Rogerson, R. (1993). Job turnover and policy evaluation: A general equilibrium analysis. *The Journal of Political Economy*, 101(5):915–938.

Kleinknecht, A., Oostendorp, R., Pradhan, M., and Naastepad, C. (2006). Flexible labour, firm performance and the Dutch job creation miracle. *International Review of Applied Economics*, 20(02):171–187.

Lucidi, F. and Kleinknecht, A. (2010). Little innovation, many jobs: An econometric analysis of the Italian labour productivity crisis. *Cambridge Journal of Economics*, 34(3):525–546.

Michie, J. and Sheehan, M. (1999). HRM practices, R&D expenditure and innovative investment: Evidence from the UK's 1990 workplace industrial relations survey (WIRS). *Industrial and Corporate Change*, 8(2):211–234.

Minton, B. and Schrand, C. (1999). The impact of cash flow volatility on discretionary investment and the costs of debt and equity financing. *Journal of Financial Economics*, 54(3):423–460.

Nese, A. and O'Higgins, N. (2007). Attrition bias in the capitalia panel. *International Review of Economics*, 54(3):383–403.

Pindyck, R. S. (1991). Irreversibility, uncertainty, and investment. *Journal of Economic Literature*, 29(3):pp. 1110–1148.

Saint-Paul, G. (2002). Employment protection, international specialization, and innovation. *European Economic Review*, 46(2):375–395.

Samaniego, R. (2006). Employment protection and high-tech aversion. *Review of Economic Dynamics*, 9(2):224–241.

Serrano, F. and Altuzarra, A. (2010). Firms' innovation activity and numerical flexibility. *Industrial & Labor Relations Review*, 63(2):22.

Smith, R. and Blundell, R. (1986). An exogeneity test for a simultaneous equation tobit model with an application to labor supply. *Econometrica*, 54(3):679–685.

Ulph, A. and Ulph, D. (1998). Labour markets, bargaining and innovation. *European Economic Review*, 42(3-5):931–939.

Wooldridge, J. M. (2002). *Econometric Analysis of Cross Section and Panel Data*. The MIT Press.

Zhou, H., Dekker, R., and Kleinknecht, A. (2011). Flexible labor and innovation performance: Evidence from longitudinal firm-level data. *Industrial and Corporate Change*, 20(3):941–968.