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The Hazard Rate of Foreign Direct Investment: a Structural Estimation of a Real Option Model

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The Hazard Rate of Foreign Direct Investment: a Structural Estimation of a Real Option Model

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Abstract

The hazard rate of investment is derived within a real option model, and its properties are analyzed in order to directly study the relation between uncertainty and investment. Maximum likelihood estimates of the hazard are calculated using a sample of MNEs that have invested in Central and Eastern Europe over the period 1990-1998. Employing a standard, non-parametric specification of the hazard, our measure of uncertainty has a negative effect on investment, but the reduced-form model is unable to control for non-linearities in the relationship. The structural estimation of the option-based hazard is instead able to account for the non-linearities and exhibits a significant value of waiting, though the latter is independent from our measure of uncertainty. This finding supports the existence of alternative channels through which uncertainty can affect investment.

JEL classification: C4; D81; F21

Keywords: hazard rates, uncertainty, foreign investment

1   Introduction

During the last decades real option models have become increasingly popular for understanding the impact of uncertainty and sunk costs on entry. In particular, the option-theory of irreversible investment (Dixit and Pindyck, 1994) predicts that uncertainty raises the critical value at which it is optimal to invest. Therefore it has been concluded that uncertainty should have a negative effect on investment and empirical evidence of these models has been provided.

More specifically, empirical studies have employed either estimates of uncertainty derived from subjective opinions of managers in structured surveys (Patillo, 1998; Guiso and Parigi, 1999) or estimates of the variance of macroeconomic variables, such as stock prices (Leahy and Whited, 1996; Lensink, 2002), inflation (Huizinga, 1993) interest rates (Ferderer, 1993), exchange rates (Campa, 1993; Goldberg, 1993; Darby et al., 1999; Serven, 2003), oil prices (Hurn and Wright, 1994; Favero et al., 1994), copper prices (Harchaoui and Lasserre, 2001) and institutional variables (Brunetti and Weder, 1998; Altomonte, 2000). The general finding in these studies is that uncertainty depresses investment thereby claiming support for the real option theory of investment.

The option effect is actually but one of three possible channels through which uncertainty can negatively affect investment, the other two being the presence of financing constraints and the firms' attitudes towards risk[1]. In particular, Ghosal and Loungani (2000) find the negative relationship between uncertainty and investment to be substantially greater in industries dominated by small firms, a result supporting the role of financing constraints rather than the option channel in explaining the investment-uncertainty relation. In fact, should the real option argument be significant, they argue, the opposite result would have appeared in the estimations because of higher sunk costs in industries dominated by large firms.

Within the same real option literature, however, Sarkar (2000) argues that higher volatility surrounding the underlying project value also increases the probability that the trigger value of investment will be hit. He shows that the relation between uncertainty and the prob-

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[1]See the references provided in Ghosal and Loungani (2000).

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ability that investment will take place within a certain period may be non-linear. Empirical studies to explicitly test for these non-linearities in the uncertainty-investment relationship are Lensink (2002) and Serven (2003). Lensink (2002) finds that the impact of uncertainty on aggregate investment differs for low and high values of uncertainty. Serven (2003) also finds a non-linear result, pointing out that the negative effect of uncertainty only matters when uncertainty itself exceeds some critical level (threshold effects).

Although the empirical findings cannot be taken into question, their theoretical underpinnings are not solid. The analysis of the relation between uncertainty and investment in Sarkar (2000) is based on the cumulative probability of investment within a certain period after the creation of the investment opportunity; but when aggregate data are used (as in the previously mentioned empirical studies), the number of years that have passed since the investment opportunity has been created stays indeterminate. All that is measured, therefore, is the average effect of uncertainty on investment at each point in time, and not its cumulative impact once the investment opportunity has been created. Moreover, we show that the relation hinges on the length of the period chosen.

Clearly, the greatest difficulty with the empirical implementation is that, in general, it is not easy to collect data on investment delays. However, exploiting a firm-specific sample of inward investment into Central and Eastern European Countries (CEECs) by foreign transnational companies (TNCs), it is feasible to identify a unique starting date of the investment opportunity, i.e. the fall of the Berlin Wall. In fact, before 1989 foreign direct investment (FDI) in the CEECs from Western countries were virtually prohibited, with the only (partial) exception being Hungary. Starting from 1990, instead, the sudden removal of restrictions allowed FDI volumes to rise. Such a peculiar institutional context is also confirmed by the data, showing how FDI inflows in the CEECs passed from an average of 59 million of US$ in the period 1985-1989, to 300 US$ million in 1990 and 2,448 in 1991[2].

Hence, in the context of the 'natural experiment' of transition, it becomes possible to measure the time spell occurred between the creation of the investment opportunity (in principle, end of 1989) and the investment undertaken by the first TNC entering in a given market. In particular, the collected sample allows us to directly test the link between un-

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[2]The main source of macroeconomic data on FDI is UNCTAD, *World Investment Report*, various years.

certainty and investment through the hazard rate, i.e. the probability of investment given that the firm has not invested yet. In fact, since uncertainty is one of the parameters in the calculated hazard function, it can be directly estimated with maximum likelihood. In addition, the hazard approach not only enables a test of the effect of uncertainty on investment in Eastern Europe, it also gives the opportunity to estimate the impact of other explanatory variables on the hazard rate of FDI, such as gravity-type variables (population, market size and distance), labor cost, industry size, minimum efficient scale, speed of liberalization and the impact of trade agreements.

As a result, rather than testing the implications of a real option model, the aim of this paper is to test the real option model itself, together with its relevant implications, by deriving an explicit function for the hazard rate of investment and structurally estimating it through microeconomic data on inward investment in Eastern Europe. At this purpose, the paper is organised as follows. Section 2 derives the hazard rate of investment in a standard real option model and briefly explains its properties. In section 3 we set up the estimation models and discuss the data. Section 4 examines the empirical results, with section 5 providing some refinements of the original model specifications. Implications and conclusions follow.

2   The Hazard Rate of Investment

The theory of investment under uncertainty states that a firm should invest when the value of investment exceeds its cost by the (option) value of waiting to invest. Following Sarkar (2000), we normalize the cost of investment to 1 and assume that the earnings stream x follows a geometric Brownian motion,

$$dx_t = \mu x_t dt + \sigma x_t dz_t \tag{1}$$

where μ is the (constant) drift rate, σ is the (constant) standard deviation and dz the increment of a standard Wiener process. Denoting the correlation of the project with the market portfolio with ρ, the market price of risk with λ and a constant r as the risk free rate, Sarkar (2000) shows that the project value (i.e. the NPV of the project when accepted) can

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be written as $(x/\psi - 1)$ where $\psi = r + \lambda\rho\sigma - \mu$, while the value of the option to invest is the solution to an ordinary differential equation and can be written as $\Upsilon(x) = Ax^\alpha$, where

$$\boldsymbol{\alpha} = \frac{1}{2} - \frac{\mu - \lambda\rho\sigma}{\sigma^2} + \sqrt{\left(\frac{1}{2} - \frac{\mu - \lambda\rho\sigma}{\sigma^2}\right)^2 + \frac{2r}{\sigma^2}} \quad \text{and} \quad A = (x^*)^{1-\alpha}/\psi\alpha$$

The optimal investment rule therefore is to invest when $x \geq x^*$ (the value of earnings that triggers the investment decision), where $x^* = \boldsymbol{\alpha}\psi/(\boldsymbol{\alpha} - 1)$. Since the option value increases with uncertainty, the critical value of investment increases when uncertainty gets higher. So, firms will normally require a higher profitability when uncertainty increases. Intuitively, people have hence assumed that a higher uncertainty also induces a longer period of waiting to invest. Sarkar (2000) points out instead that a higher uncertainty also changes the probability that the critical value x^* will be reached before a specific date, thus generating non-linearities in the relationship between investment and uncertainty.

In particular, when current time is zero, the probability of reaching the trigger value x^* within some time period t can be written as

$$F(t, x_0) = \Phi\left(\frac{\ln[x_0(1 - 1/\boldsymbol{\alpha})/\psi] + \zeta t}{\sigma\sqrt{t}}\right) + \left(\frac{\psi}{x_0(1 - 1/\boldsymbol{\alpha})}\right)^\gamma \Phi\left(\frac{\ln[x_0(1 - 1/\boldsymbol{\alpha})/\psi] - \zeta t}{\sigma\sqrt{t}}\right) \tag{2}$$

where x_0 is the value of x at $t = 0$, $\Phi(.)$ is the cumulative density of a standard normal distribution, $\boldsymbol{\zeta} = (\mu - \frac{1}{2}\sigma^2)$ and $\gamma = (2\mu/\sigma^2) - 1$. By differentiating (2) we derive the density function

$$f(t, x_0) = \varphi\left(\frac{\ln[x_0(1 - 1/\boldsymbol{\alpha})/\psi] + \zeta t}{\sigma\sqrt{t}}\right) \frac{\frac{1}{2}\{\boldsymbol{\zeta}t - \ln[x_0(1 - 1/\boldsymbol{\alpha})/\psi]\}}{\sigma t\sqrt{t}}$$

$$- \left(\frac{\psi}{x_0(1 - 1/\boldsymbol{\alpha})}\right)^\gamma \varphi\left(\frac{\ln[x_0(1 - 1/\boldsymbol{\alpha})/\psi] - \zeta t}{\sigma\sqrt{t}}\right) \frac{\frac{1}{2}\{\boldsymbol{\zeta}t + \ln[x_0(1 - 1/\boldsymbol{\alpha})/\psi]\}}{\sigma t\sqrt{t}} \tag{3}$$

Given the density and the cumulative density of investment at time t, the hazard rate of

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investment at time t, $h(t, x_0)$ is defined as[3]

$$h(t, x_0) = \frac{f(t, x_0)}{[1 - F(t, x_0)]} \qquad (4)$$

In our specific case, then, the hazard rate is calculated by plugging equation (2) and (3) into equation (4).

A numerical simulation of (2), reported in Figure 1, replicates the result of Sarkar (2000). However, it also shows that the shape of the relation between uncertainty and the cumulative probability of investment within τ years depends very much on the choice of τ. Although ancillary parameter values are as in Sarkar (2000), that is $\mu = 0$, $r = 0.1$, $\rho = 0.7$, $\lambda = 0.4$, and $x_0 = 0.1$, his result of a non-linear relationship between uncertainty and the probability of investment only holds for intermediate values of τ, such as $\tau = 5$. For sufficiently low (high) levels of τ there is a positive (negative) relationship between uncertainty and the probability of investment.

For an empirical analysis, it is more useful to investigate the same relationship through the hazard rate, since the latter only depends on an observable variable (elapsed time since the creation of the investment opportunity), rather than an arbitrary choice variable (τ).

[Figure 1 about here]

Figure 2 plots the hazard rate of investment calculated in (4) for different values of uncertainty, where parameter values are as above. The hazard rate is actually humped for all levels of uncertainty. When the investment opportunity has just been created, the hazard increases in volatility. When the investment opportunity exists for a longer period, instead, the hazard decreases in volatility. The reason is that, if uncertainty is low, then the probability that the investment trigger has not been reached over time is relatively low. On the contrary, a higher uncertainty in early periods increases the chances of immediately reaching the value of earnings that triggers the investment decision. The latter is the line of argument

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[3]See Kiefer (1988) or Greene (1999) for a general treatment of duration data and hazard functions.

put forward by Sarkar (2000), here reproduced within a more general result.

[Figure 2 about here]

Moreover, there is another source of non-linearity in the investment-uncertainty relationship, since the shape of the hazard rate also depends on the initial value of the profitability variable x_0. When x_0 is increased from 0.1 to 0.14, for example, the hazard function is decreasing for all levels of uncertainty while increasing in volatility (see Figure 3). Decreasing x_0 to levels < 0.1 preserves the humped shape of the hazard rate, but the peak shifts to the right for lower x_0s. Therefore, with a low uncertainty we would observe relatively later investments in low profit (low when the investment opportunity was created) industries, while in a situation of high uncertainty high profit industries would be the object of postponed investments.

[Figure 3 about here]

3   Data description and econometric approach

The empirical literature has tested the effect of uncertainty on investment, expecting a negative relation between both variables. By explicitly calculating the hazard rate of investment we have instead shown that the relation between uncertainty and investment critically depends on the amount of time during which the firm has the option to invest at its disposal. So the relation between uncertainty and investment is far from clear when analyzing aggregate investment data.

Moreover, in analysing the effect of uncertainty on investment there have been only indirect attempts to estimate real option models using reduced-form equations. In this paper we instead directly estimate a structural model of the hazard rate of investment from the basic real option model of a lumpy investment (see Dixit and Pindyck, 1994). Given the arguments above, such a structural estimation seems to be a daunting task, but the sudden market liberalisation in the CEECs at the end of the eighties provides us with a clear starting date for creating a sample of investment opportunities. Given a set of 48 industries in

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7 Central and Eastern European countries included in the PECODB database[4], we generate a sample of 336 investment opportunities for TNCs within the period 1990-1998. For each country/industry pair it is possible to measure the investment spell, i.e. the time elapsed from the start of the liberalisation process to the moment in which the first investment has been undertaken. Endowed with this information, we are then able to estimate the hazard function of the first investment by a TNC in a particular industry within one of these countries.

Let x_{ij0}, the profitability of investment in country i in industry j at time $t = 0$, be a monotonic function of exogenous variables y_{ij0}, i.e. $x_{ij0} = 2\exp(y_{ij0}\theta)/[1 + \exp(y_{ij0}\theta)]$[5]. The vector y_{ij0} includes variables extensively employed in the empirical literature on foreign investments such as GDP per capita (*gdppc*), population (*pop*), distance (*dist*), all taken in logs, and the comparative advantage of the host country in terms of labor costs (*relwage*)[6].

Since in the paper the model is tested at the industry level, while the theory is based on a single project partial equilibrium model, we have to address the issues of functional form mis-specification and heterogeneity. The latter may arise because investments in different industries may have different distributions, due to differences in the minimum efficient scale, industry sizes or sunk costs. In order to control for this aggregation problem (see Kiefer, 1988), we include among the exogenous variables the (log) average size (*indsize*) of each industry in each country, and the (log) minimum efficient scale (*MESdom*) of domestic firms in each industry (see Annex for a detailed description of the data).

Another possible bias derives from the fact that the dependent variable in our estimates (the investment spell) critically depends on the choice of the initial year in which the investment opportunity was created. Although, in principle, the natural experiment of transition points to 1989 as the initial year from which one should start measuring the investment

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[4]The PECODB database is a firm-specific collection of 4,200 FDI operations in the CEECs in the period 1990-1998. The database excludes small marketing ventures, including only actual production units controlled by TNCs. In terms of validation, the database is able to account for almost 70 per cent of the region's total FDI inward stock as registered by official statistics. The countries included in the present analysis are Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovak Republic, Slovenia. A list of the considered industries is reported in Annex.

[5]In order to be consistent with the normalisation of costs to 1, we bounded the profitability of investment x_{ij0} to the $[0, 2]$ interval. The main results are however not affected by different values of the upper bound, as long as the relation between x_{ij0} and y_{ij0} is monotonic.

[6]At this purpose, the 1998 *World Investment Report* from UNCTAD provides a good survey of the main FDI trends and determinants.

spell, there is evidence that in Eastern Europe different countries opened up to FDI establishing different modalities of privatization/liberalization in different years. Therefore, in order to control for this further source of heterogeneity, we interact the variable *indsize* with a variable measuring the pattern of liberalization in each country in a given year (*lib*). The latter variable, previously employed by Holland and Pain (1998) and Carstensen and Toubal[7] (2004), is an index with a scale from 1 to 5 representing the method of privatization, where 1 is the most impeding method for TNCs (vouchers) and 5 is the most favourable (sales to outside owners only). As a result, the interaction variable is a country, industry and time dependent variable measuring the size of each industry corrected for the legal entry barriers.

Finally, given our theoretical setup, we also have to control for the different impact of industry structure on the investment decisions. We have introduced a set of dummies partitioning industries into high, medium and low sunk costs, based upon the Davies and Lyons (1996) classification reported in Annex. In particular, industries are classified as having *high* sunk costs when, based on their NACE code, the industry is both advertising and R&D-intensive. They are considered as having *medium* sunk costs when the industry is either R&D or advertising intensive, and as having low sunk costs otherwise.

Under the parameter restrictions $r = 0.1$, $\rho = 0.7$, and $\lambda = 0.4$, parameters μ, θ and σ can be estimated by maximum likelihood estimation[8]. After the (conventional) start of transition in 1989, the first investments have taken place in our sample in 1990, which hence represents $t = 1$. Industries in countries where no investment has taken place before 1999 are (right) censored observations. Let $T = 9$ denote the last year (1998) for which data are available in the PECODB database. Since our data are not continuous, a discrete version of the continuous density function is taken. Following Kiefer (1988), the integrated hazard of investment in sector j in country i can then be written as

$$H_{ij}(t \mid \theta, \sigma) = \sum_{s=1}^{t} h_{ij}(s \mid \theta, \sigma) \tag{5}$$

where $h_{ij}(s \mid \theta, \sigma)$ are the hazard rates calculated given the distribution of x_{ij0} as from

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[7]We are grateful to Farid Toubal for making the variable available to us.

[8]Parameters r, ρ and λ can be considered as scaling constants; a change in their value does not significantly affect the estimated hazard rate of investment.

equation (4). The associated log-likelihood function is

$$\ln L(\theta, \sigma) = \sum_i \sum_j d_{ij} \ln \left[h_{ij}(t \mid \theta, \sigma) \right] - H_{ij}(T \mid \theta, \sigma) \tag{6}$$

where $d_{ij} = 1$ for uncensored observations and $d_{ij} = 0$ if instead the observation is censored. Inference about the parameter values can be done in the usual way.

The structural estimation of the model implies a time-invariant volatility, an assumption which is not necessarily at odds with the empirical evidence. In fact, although one might intuitively think that uncertainty decreases over time during the transition period, the empirical evidence from volatility in emerging markets that opened up to foreign investments shows that uncertainty is actually fairly constant over time. To the best of our knowledge, only Bekaert and Harvey (1997) find a downward trend in stock market volatility when emerging markets open up to foreign investors. Later studies (Han Kim and Singal, 2000; De Santis and Imrohoroglu, 2000) argue however that their result is based on a sample of countries out of which only three showed a significant decrease in volatility, while one an increase. Using a much richer sample of countries, the later papers do not find a significant overall effect of liberalization on volatility up to five years after the liberalization date. As a result, given the aim of a structural estimation, it is possible to consider σ_{ij} as a constant (e.g. as the 'implied volatility' of the option value, σ_{const}) or rather to estimate it as a function of time-invariant exogenous variables which are proxies for the uncertainty surrounding the movements in the profitability of investment, and hence

$$\sigma_{ij} = \sigma_{const} + \beta \ indunc \tag{7}$$

where β is a parameter to be estimated. In particular, in this last case we have proxied uncertainty through the average coefficient of variation[9] of the EBIT (earnings before interest and taxes) of a sample of firms (both domestic and multinationals) currently operating in the seven countries / 48 industries considered (*indunc*). The data source for the uncertainty variable is the AMADEUS dataset, provided by the Bureau Van Dijck, a consulting firm operating in Brussels, and containing balance sheet data of a sample of roughly 5,000,000

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[9]Note that the coefficient of variation, defined as the standard deviation over the mean, is dimensionless.

companies operating in Europe. Of the almost 180,000 companies recorded in the seven countries considered, we have restricted our analysis to the 32,083 firms for which data are available for at least four consecutive years, in order to have a meaningful estimate of each firm's EBIT standard deviation. Hence on average the EBIT coefficient of variation is calculated with 95 firms per observation[10].

The method of a structural estimation of the hazard rate in a real option framework, via the maximisation of the associated likelihood function (6), can be compared to more traditional reduced-form estimations of the hazard, which do not directly test the investment-uncertainty relationship but rather impose an arbitrary function on the 'baseline' hazard, or leave the same baseline unspecified. More specifically, the hazard can be written as

$$\lambda(t) = \lambda_0(t) e^{\beta_1 x_1 + \ldots + \beta_k x_k} \tag{8}$$

where $\lambda_0(t)$ is the baseline hazard. The Cox-proportional model leaves the baseline hazard unspecified, providing estimates of the coefficients $\beta_1, \ldots, \beta_k$, but no direct estimate of $\lambda_0(t)$, hence maximising a partial log-likelihood function corrected for censoring. Since $\partial \ln \lambda(t)/\partial x = \beta$, the coefficients can be interpreted as the constant proportional effect of x on the conditional probability of investing within a certain period[11]. A parametric model for the baseline hazard is instead more efficient if the assumed function is correctly specified, but can lead to inconsistent estimates in case of misspecification.

In the option-related literature, Hurn and Wright (1994) and Favero et al. (1994) use a hazard model approach using data on the time between the development of an oil field and its discovery. They write the hazard as the product of the baseline hazard (both non-parametric and parameterized as a Weibull function) and the covariates (including uncertainty), so they

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[10]To the best of our knowledge the quoted studies cited in the Introduction do not report the correlation between uncertainty in the macro variables employed as proxies and uncertainty in entrants' profits. Hence, in order to rule out a systematic difference between the average uncertainty employed in the estimates, measured at the industry level, and the uncertainty actually faced by the first movers TNCs, we have checked the correlation between our measure of industry-specific uncertainty and the coefficient of variation of the EBIT of the investing TNCs, with respect to which the investment spell has been measured. The figure we obtained revealed a positive and significant correlation of .23 (calculated on 111 available observations, with a p-value of .016 for the two-tailed test).

[11]As noted by Kiefer (1988), this is the analog, in a hazard function setting, of the usual partial-derivative interpretation of a linear regression coefficient.

examine the effect of uncertainty on the waiting period.

Among the few empirical studies that have looked at the entry timing of FDI using a hazard function approach, Tan and Vertinsky (1996) analyse the timing of foreign direct investment by Japanese electronics firms in the United States and Canada. Using a non-parametric hazard model they find, among other results, that strong market growth in the host country leads to a more rapid undertaking of inward FDI. A related study is given by Kogut and Chang (1996), who consider the spell between sequential investments by Japanese firms in the U.S. They show that initial investments serve as platforms for subsequent investments. More recently, Garcia Blandon (2001) studied the timing of foreign direct investment in the banking sector in Spain using an hazard approach.

Specification analysis in both our duration models (4) and (8) can be undertaken by examining the generalized residuals, ε, which equal the integrated hazard $H_{ij}(t \mid \theta, \sigma)$ of equation (5). If the model is correctly specified, the generalized residuals are exponentially distributed. Therefore, in the absence of censoring, the population moments expectations, $E\left[\varepsilon^p\right]$, equal $p!$. The conditional moment approach to specification testing exploits the fact that if the model is correctly specified the sample average moments (evaluated at the estimated parameters and the observed explanatory variables) should be close to the population moments expectations. For censored observations the centered moment conditions are $r_p = 0$. Let $\widehat{r}$ be the vector with the observed centralized moments, then the elements of the vector are

$$\widehat{r}_p = \frac{1}{N \cdot M} \sum_i \sum_j m_{ij}^p$$

with N and M being the number of countries and industries, respectively, and

$$m_{ij}^p = \left(\varepsilon_{ij}^p - p! + (1 - d_{ij}) \sum_{k=0}^{p-1} \frac{p!}{k!} \varepsilon_{ij}^k \right) \quad \text{with } p \geq 2$$

Pagan and Vella (1989) show that under some regularity conditions $\sqrt{NM}\widehat{r}$ is asymptotically normal with mean 0 and covariance matrix Σ. Hence, a Wald specification test-statistic for $\widehat{r} = 0$ is given by $NM\widehat{r}'\Sigma^{-1}\widehat{r}$, which is χ^2 distributed with the dimension of the vector

of moments as the degree of freedom[12].

4 Results

The estimation of several specifications of the hazard function through a Cox-proportional hazard model yields (see Table 1) the traditional result reported by the estimations of the investment-uncertainty link: uncertainty is significantly and negatively related to the investment probability through the effect it generates on the mean of profits. Market variables (population and per capita GDP) as well as the comparative advantage of the country in terms of labor costs positively and significantly affect the probability of undertaking an investment. The average size of the industry also significantly increases the probability of an earlier investment, while the distance to the host country significantly decreases it. The results take into account differences in industry, being robust for different specifications of the sunk costs (Column 1 vs. 2-4). Minimum efficient scale, measured by the (log of) median firm's employment of domestic firms in each industry calculated on the set of considered countries, is not significant (Column 3)[13] and its inclusion does not change the results. Finally, the results are robust to the inclusion of the interaction term between the average industry size and the variable measuring the pattern of liberalization in each country in a given year.

All the estimated model pass the specification test, being the higher order central moments m_{ij}^p of the generalised residuals centered around zero, as confirmed by the joint χ^2 test statistic reported in Table 1. However, a further specification test available for Cox proportional models evaluates the nonzero slope in a generalised linear regression of the scaled residuals on functions of time (Grambsch and Therneau, 1994), and hence explicitly takes into account eventual non-linearities arising in the estimation of the hazard function. The test of zero slope is in fact equivalent to testing that the baseline hazard $\lambda_0(t)$ is constant over time; thus, rejection of the null hypothesis of a zero slope indicates deviation from the

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[12]In particular, as noted by Greene (1999), $\Sigma = (B'B - B'D(D'D)^{-1}D'B)/NM$, where B is the matrix whose ith row is the vector of central moments and D is the matrix of the scores of the likelihood function.

[13]As in Geroski (1991) we use median employment at the firm level to calculate minimum efficient scale. We use domestic and not TNCs' employment to avoid introducing endogeneity in the estimates, although the two measures turned out to be highly correlated.

proportional hazard assumption. The test statistic is χ^2 distributed, and the null hypothesis is strongly rejected, for all the Cox proportional model specifications, at the 95% level of significance. This result indirectly confirms our theoretical assumption of non-linearities in the relation between investment and uncertainty (see Figure 2), which thus lead to a mis-specification of standard non-parametric models of the hazard.

[Table 1 and 2 about here]

For a better understanding of the investment-uncertainty relationship, it is therefore worth moving from a reduced-form specification to the structural estimation of our theoretical real option-based hazard rate of investment (4) through the maximisation of the likelihood function (6).

Table 2 reports the results of this exercise on the basis of covariates measured at initial conditions x_{ij0}. As it can be seen, for all the model specifications the covariates related to profitability are correctly signed and significant, with minor changes from one specification to the other. This is an indication that, controlling for sunk costs, industry size, minimum efficient scale and heterogeneity in the start of the liberalization process across countries (Columns 1 to 5), the theoretical model is able to properly fit the data explicitly taking into account the non-linearities previously mentioned. The drift rate μ at the basis of the stochastic evolution of profits over time (see Eq. 1) can be endogenously estimated and takes the value $\mu = 0.047$ with a very low standard deviation, i.e. an implied average growth rate in the countries considered of 4.7 per cent per year, which does not seem unreasonable for transition countries[14].

Contrary to the previous studies, where the effects of uncertainty were measured on the mean value of profits (i.e. among the profit-related regressors), structurally estimating the 'true' real option specification allows us to directly relate the standard deviation σ_{ij} of the stochastic evolution of profits to our measure of country and industry-specific uncertainty (*indunc*), as from Eq. (7). We find this proxy to be correctly signed in our model speci-

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[14]For technical reasons linked to the convergence algorithm, the estimated parameter reported in the Tables is $\widetilde{\mu}$, defined as $\widetilde{\mu} = \ln[\mu/(1-\mu)]$, where $0 < \mu < 1$. Hence, once estimated $\widetilde{\mu}$, the actual μ can be otained by the inverse transformation $\mu = \exp(\widetilde{\mu})/[1 + \exp(\widetilde{\mu})]$.

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fications but not significant. Rather, the data show support for the assumption, typical of
real option models, of a constant 'implied volatility' in the stochastic evolution of profits
(positive and significant σ_{const}), with a value in our sample of countries/industries of around
10 per cent[15]. Most importantly, our estimations of the real option-based hazard show that
the central moments (II-V) of the generalized residuals are, but one, all within one standard
deviation from zero, and hence the model is correctly specified[16].

Insofar, the result suggests that the negative effect of uncertainty on investment works
through its effect on profitability rather than on the value of waiting to invest and that non-
linearities are likely to be present in the relationship. The result therefore supports the view
of Ghosal and Loungani (2000) that the investment-uncertainty relationship may depend on
other channels than the option one. There is a value of waiting, though, but it is not related
to our measure of uncertainty.

A final, technical but non trivial point. Given the theoretical properties of the real
option-based hazard rate, trying to proxy σ through the traditional country-specific mea-
sures of uncertainty employed in the literature would yield (and has indeed yielded in our
estimates) an identification problem. This is due to the collinearities arising in the max-
imisation of the likelihood function among variables related to profits and variables related
to uncertainty, once these are all measured along the ith (country) dimension of the data.
The intuition comes from a comparison of Figure 2 and Figure 3: a variation along the
profitability dimension has *ceteris paribus* a non linear effect on the uncertainty or, better,
different combinations of initial profit conditions and uncertainty can yield the same hazard
rate. Hence, a likelihood function where these two variables are measured along the same
(country) dimension is likely to present points of local optima or saddle points.

5   A refinement: time-varying covariates

The hazard rate calculated insofar has allowed us to measure the effects of uncertainty on
investment taking into account initial conditions x_{ij0}. However, it is interesting to check

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[15]As in the case of μ, for technical reasons linked to the convergence algorithm the actual value of σ_{ij} can
be derived by the transformation $\sigma_{ij} = \exp(\tilde{\sigma}_{ij})/[1 + \exp(\tilde{\sigma}_{ij})]$, where $\tilde{\sigma}_{ij}$ is estimated as from Eq. (7).

[16]However, the χ^2 test statistic weakly rejects the joint moments mean to be equal to zero for some model
specifications. We will address the issue in the next paragraph.

whether our results also hold when profit-related covariates are time-dependent. Through this refinement it is possible to take into account eventual pro-cyclical effects of FDI and, in our specific case, to better measure the ongoing transition of the considered countries towards a market economy. Let x_{ijt}, the profitability of investment in country i in industry j in year t, be a monotonic function of exogenous variables y_{ijt} as in the previous case, where y_{ijt} includes as before our profit-related variables, now allowing them to vary over time. Again, under the same parameter restrictions for r, ρ and λ as in the previous section, parameters μ, θ, σ_{const} and β can be estimated by maximum likelihood estimation. The discrete version of the the integrated hazard with time-varying covariates of investment in sector j in country i can then be written as

$$\Lambda_{ij}(t \mid \theta, \sigma) = \sum_{s=1}^{t} \lambda_{ij}(s \mid \theta, \sigma) \tag{9}$$

where $\lambda_{ij}(s \mid \theta, \sigma) = f(s, x_{ijs}) / \left[1 - \sum_{t=1}^{s-1} f(t, x_{ijt}) \right]$ is the (discrete) hazard given the density function calculated in (3) and for $s > 1$, while $\lambda_{ij}(1 \mid \theta, \sigma) = f(1, x_{ij1})$. The associated log-likelihood function is

$$\ln L = \sum_{i} \sum_{j} d_{ij} \ln \left[\lambda_{ij}(s \mid \theta, \sigma) \right] - \Lambda_{ij}(T \mid \theta, \sigma) \tag{10}$$

where $d_{ij} = 1$ for uncensored observations and $d_{ij} = 0$ if instead the observation is censored.

Table 3 shows how the results of this model specification are remarkably similar to the one without time-varying covariates, for both the profit-related variables and the estimates of the parameters μ and σ, always controlling for sunk costs, industry size, minimum efficient scale and heterogeneity in the start of the liberalization process across countries (Columns 1 to 3). The specification test does not initially support the hypothesis of a joint zero mean for the moments reported in Table 3, but, apart from the second, the higher order centered moments relative to their standard deviation display a rapid convergence towards zero, as confirmed by the associated T-statistic.

In the search for a better model specification, we use the time dimension of the covariates, which allows us to include in the estimation (Columns 4 to 6) also a dynamic effect linked

to the trade liberalisation across the CEECs and the European Union. In particular, the $EU - FTA$ and $CEEC - FTA$ dummies take value 1 if, in the considered year, a bilateral free trade agreement has been signed by the CEECs respectively with the EU or with other CEECs, as reported in Annex. The alternative model design aims at taking into account the different strategies (vertical vs. horizontal FDI) that have been undertaken by the TNCs investing in the area, a relevant issue for the purposes of this paper, since the two types of FDI might behave differently with respect to the investment-uncertainty relationship.

Since horizontal FDI tend to be market-driven, they should respond positively to a liberalisation among the CEECs (the CEEC-FTA dummy), because this increases the market access for the local TNCs' affiliates. Although vertical FDI might be captured in the previous model specification by the significance of the relative wages, a better control for this kind of TNCs' strategies is the explicit inclusion of a variable measuring the removal of trade barriers between the home and the host economy (the EU-FTA dummy), a factor to which vertical FDI are particularly sensitive. It is not surprising that both dummy variables are significant (Columns 4 and 5). More importantly, the general relationship between investment and uncertainty is robust to this richer model design, which tend to display consistent and significant signs for all the control variables (Column 6) and also passes more easily the specification tests.

Hence we have an indication that the methodology of directly estimating the hazard rate of a real option model is robust to different model designs, and can yield interesting results in the analysis of the investment-uncertainty relationship under different theoretical setups.

[Table 3 about here]

6 Implications

The model also gives additional insights in our understanding of the patterns of FDI in Eastern Europe. According to Sinn and Weichenrieder (1997) foreign direct investment has been disappointingly low in Eastern Europe. We show that irreversible investment in the form of FDI can still be expected due to trade liberalization especially in industries that after the fall of the Berlin wall were characterized by low expected profitability and low

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uncertainty (e.g. regulated industries such as utilities) and in industries with high expected profitability and high uncertainty.

In order to provide some evidence of this finding, and as an example of the prediction power of our model, we have calculated the average hazard rates of foreign investment for specific industries j and countries i on the basis of our estimated coefficients of initial profitability x_{ij0} and variance σ_{ij} reported in Table 2, with the same parameters value for r, ρ and λ employed throughout the paper. At this purpose, Figure 4 (top) shows how a low expected profitability/low uncertainty industry (electricity and gas), and a high expected profitability/high uncertainty industry (finance) both display on average a predicted hazard rate higher than a "standard" industry such as electronics.

[Figure 4 about here]

Furthermore, at the country level, while the high hazard rate of Poland is not unexpected, there is for example an evident discrepancy in the ability of attracting future FDI between Bulgaria and Romania (Figure 4, bottom), the two countries currently not joining the European Union in its first wave of Eastern enlargement. If adequate policy measures for encouraging FDI will not be implemented by the Bulgarian government, there is the risk of a progressive widening in the integration path of this country with respect to the Romanian counterpart and, ultimately, to the same European Union.

7 Conclusion

This paper sheds new light on the investment-uncertainty relationship within the literature on irreversible investments, directly estimating the implied hazard function of a real option model. We find a direct support for the hypothesis of a non-linear relation between investment and uncertainty, with the non-linearities being of an even more complex nature than the theory had originally predicted. As such, any empirical study not taking all these interactions into account leads to an approximate, indirect assessment of the investment-uncertainty relationship. Within this respect, the study provides some evidence that the negative impact of uncertainty on investment reported in the literature has to be attributed

to its effect on expected profits, rather than to the value of waiting option. More specifically, we find that there is a value of waiting to invest, but its value appears not significantly related to our measure of industry and country uncertainty. In the analysis we also controlled for several variables, and found that the expected profitability is positively related to the population size, the market power, the comparative advantage of the host country in its cost of labor, the average industry size and bilateral trade agreements.

In terms of future lines of research, recent papers (e.g. Lambrecht and Perraudin, 2003; Grenadier, 2002) show that sustained competition among firms reduces the value of the waiting option significantly. Since erosion in the value of waiting leads to a lower trigger value while leaving unchanged the standard deviation (hence leading to earlier investments), the competition effect itself does not work directly through the standard deviation. On the contrary, we showed that the hazard rate may be an increasing function of uncertainty. As a result, in order to test for the effect of competition, the function incorporating the trigger value should model not only the investment spell relative to the first TNC entering the market, but also the timing of further investments, explicitly including in the functional form a measure of competition, as in the previously quoted papers. We leave such a test for future research. However, we think that the estimation method proposed in this paper can serve as a good starting point for further empirical work on this issue.

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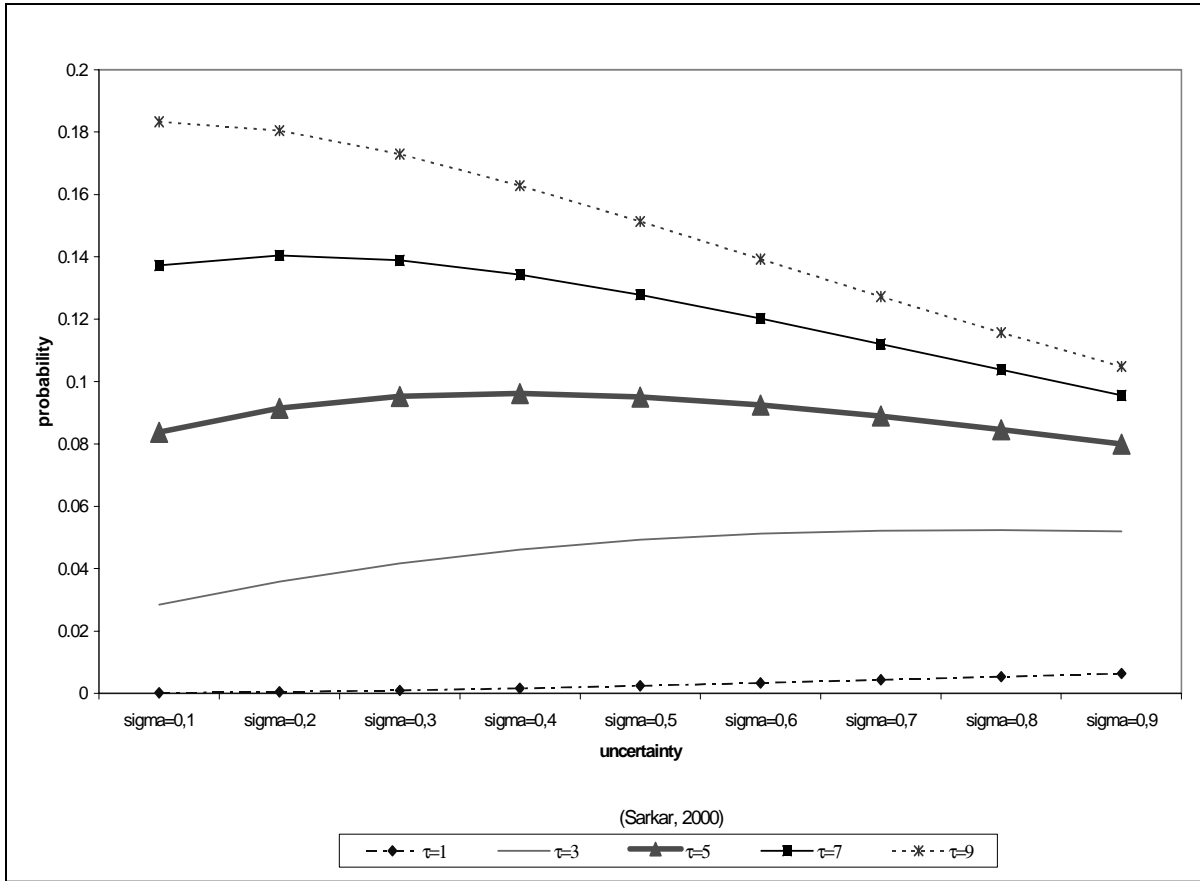**Figure 1. The probability of investment before τ**

Note: The probability of investment before τ has been calculated according to equation (2), with $\mu = 0$, $r = 0.1$, $\rho = 0.7$, $\lambda = 0.4$, and $x_0 = 0.1$
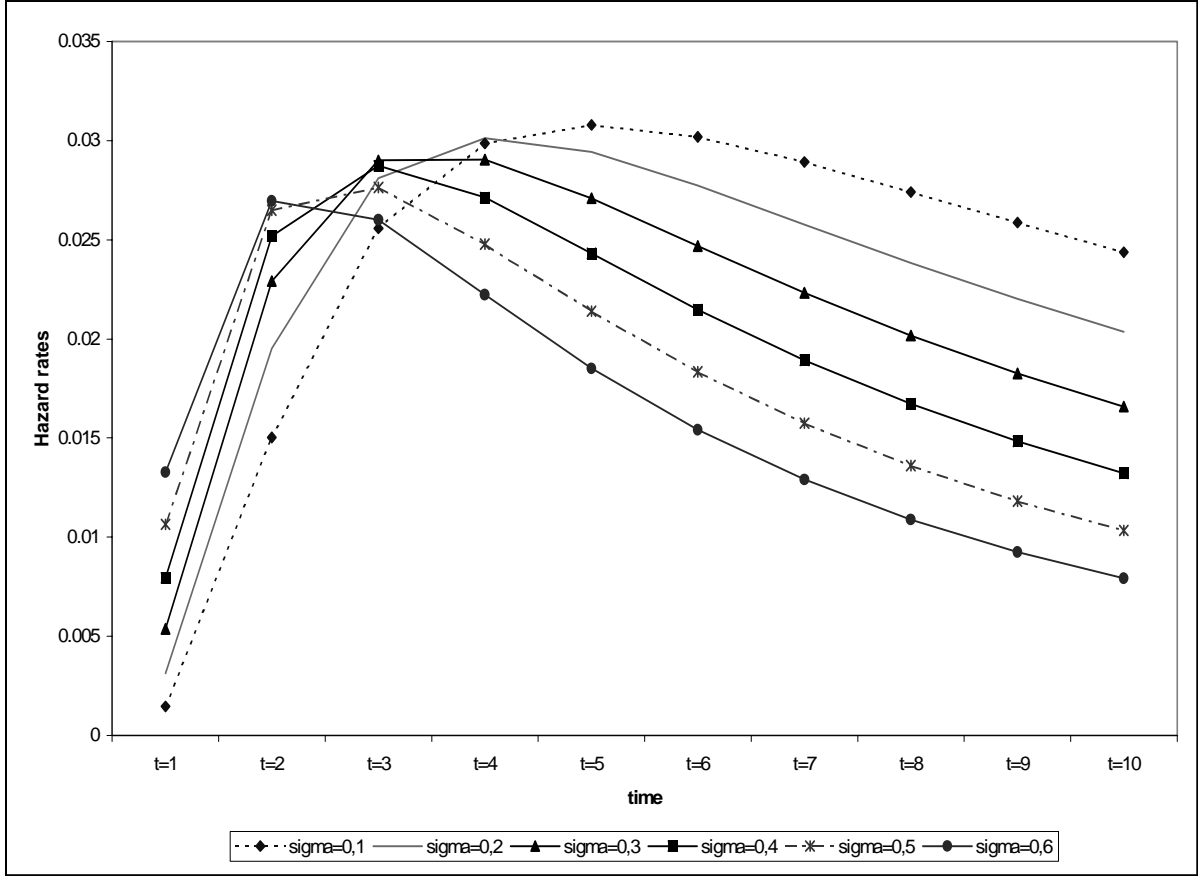
Figure 2. The hazard rate of investment based on a real option model with

$$x_0 = 0.1$$

Note: the hazard rate is calculated as $h(t, x_0) = \frac{f(t,x_0)}{[1-F(t,x_0)]}$ with $F(t, x_0)$ defined in equation (2) and $f(t, x_0)$ in equation (3)

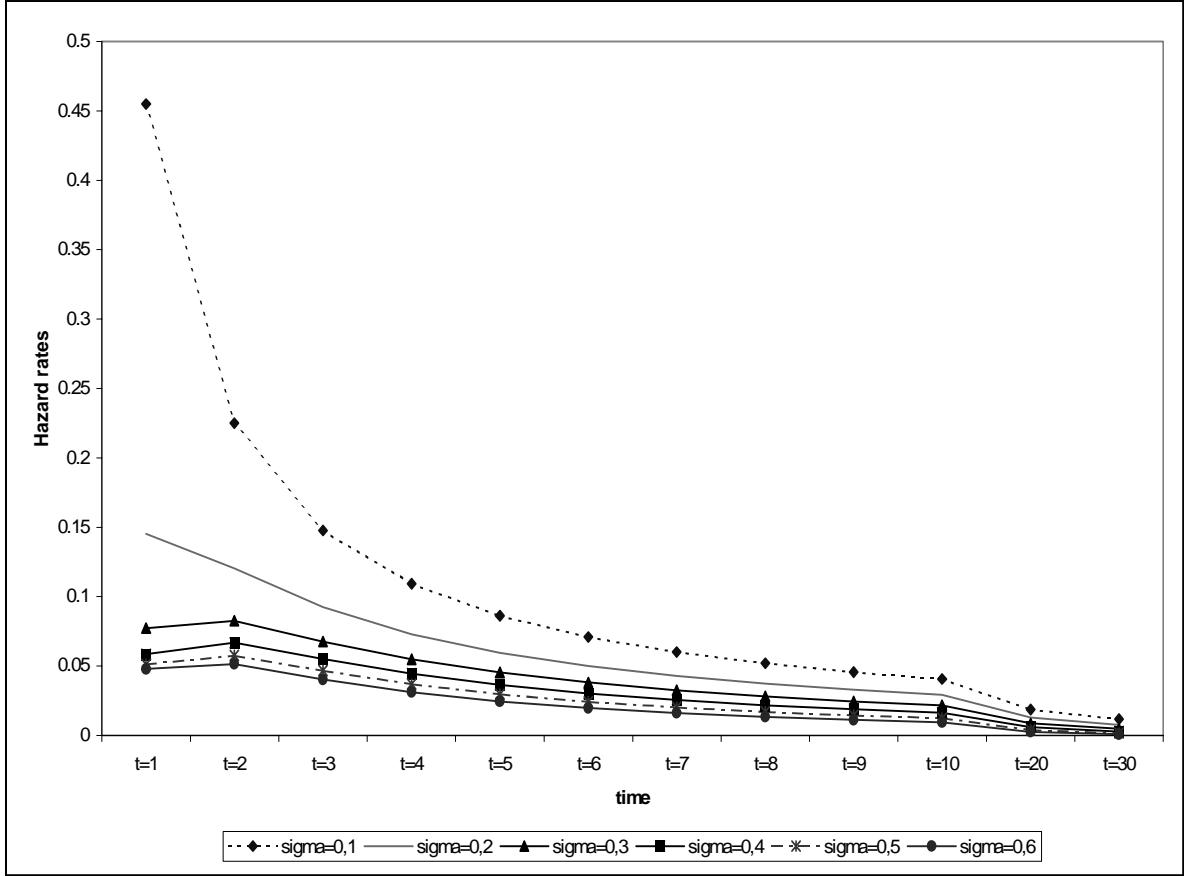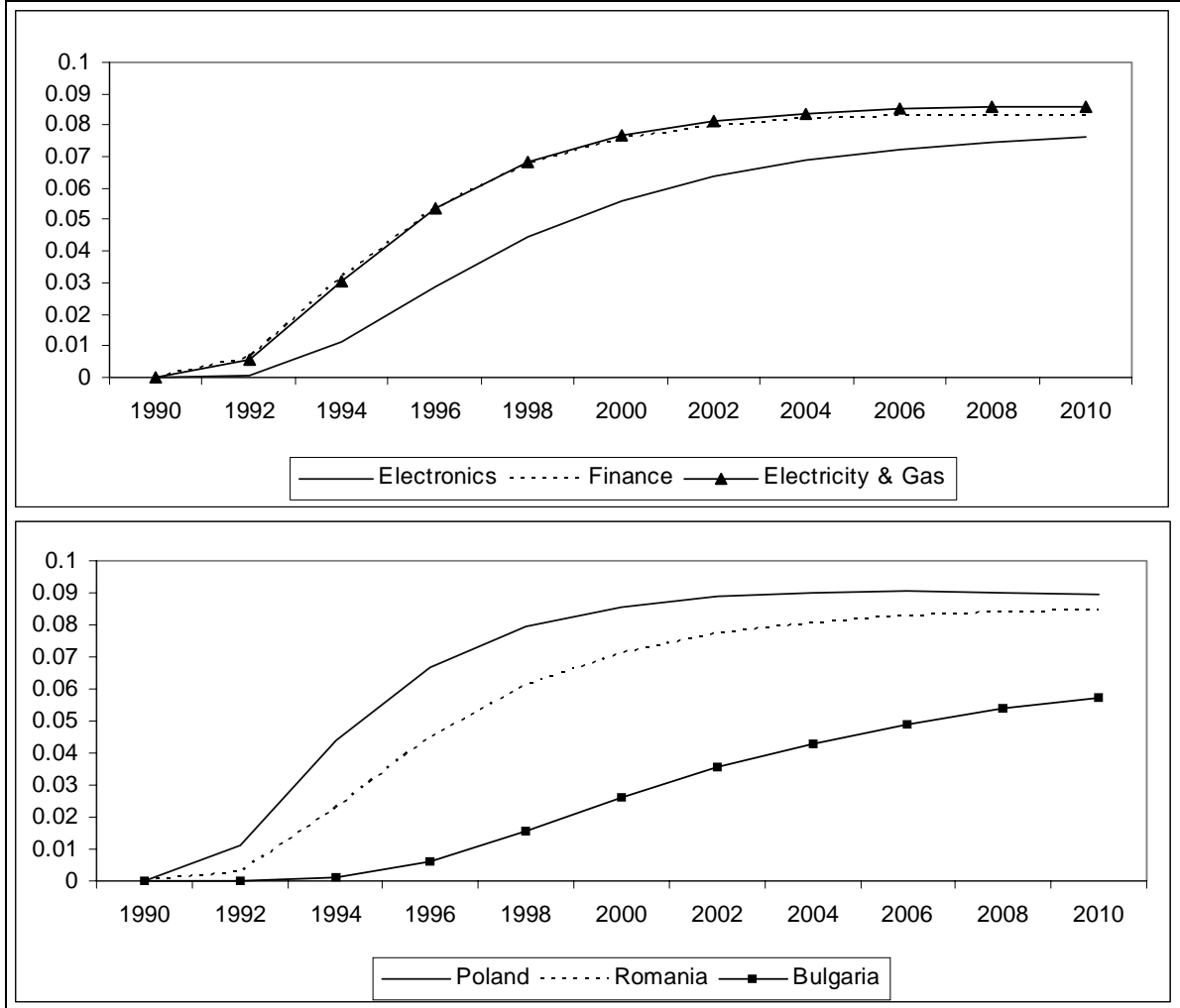**Figure 3. The hazard rate of investment based on a real option model with**

$\mathbf{x_0} = \mathbf{0.14}$

Note: the hazard rate is calculated as $h(t, x_0) = \frac{f(t,x_0)}{[1-F(t,x_0)]}$ with $F(t, x_0)$ defined in equation (2) and $f(t, x_0)$ in equation (3)

Figure 4. The predicted avarage hazard rates of investment in specific industries and countries

Note: the reported hazard rates are the average over selected industries and countries of the ij hazards calculated on the basis of the estimated initial profitability x_{ij0} and variance σ_{ij}. In particular, $x_{ij0} = 2\exp(y_{ij0}\theta)/[1 + \exp(y_{ij0}\theta)]$, where y_{ij0} includes the parameter estimates and covariates given in column (1) of the real option model in Table 1. Similarly, σ_{ij} is calculated from equation (7) given the parameter estimates for σ_{const} and *indunc* in the same column of the same Table. The parameters value for r, ρ and λ are the same used throughout the paper.

Table 1. Estimation of the Cox proportional hazard

	(1)	**(2)**	**(3)**	**(4)**
pop	1.74** (6.64)	1.73** (6.61)	1.73** (6.62)	1.71** (6.31)
gdppc	3.06** (4.71)	3.02** (4.67)	3.03** (4.68)	2.96** (4.44)
relwage	.42** (3.50)	.42** (3.52)	.43** (3.53)	.43** (3.54)
dist	-1.34** (-4.61)	-1.35** (-4.66)	-1.36** (-4.67)	-1.37** (-4.65)
indsize	.18** (2.60)	.17** (2.52)	.18** (2.53)	.21* (1.94)
*indsize*lib*	-	-	-	-.02 (-.41)
indunc	-.13* (-1.86)	-.14* (-1.93)	-.14* (-1.95)	-.14** (-1.96)
MESdom	-	-	.02 (.28)	.02 (.26)
med	-.16 (-1.10)	-	-	-
high	-.17 (-.94)	-.09 (-.52)	-.10 (-.56)	-.10 (-.58)
Log likelihood [a]	-1263.39	-1263.99	-1263.96	-1263.87
N M	336	336	336	336
Specification tests				
Cen. Moment II	-.11 (-.77)	-.11 (-.78)	-.11 (-.80)	-.11 (-.80)
Cen. Moment III	-.42 (-.73)	-.42 (-.74)	-.44 (-.77)	-.44 (-.79)
Cen. Moment IV	-1.73 (-.62)	-1.74 (-.63)	-1.81 (-.66)	-1.81 (-.68)
Cen. Moment V	-8.72 (-.58)	-8.97 (-.58)	-9.10 (-.61)	-9.10 (-.65)
Ho: joint moments mean = 0 X^2 (4)	8.23	8.35	8.41	8.51
Ho: zero-slope coefficients X^2 (n. of var)	30.16**	30.10**	31.27**	31.73**

Note: T-statistics in parentheses

** significant at the 5 per cent level or more; * significant at the 10 per cent level

[a] The Cox proportional specification estimates a partial log-likelihood function

Table 2. Estimation of the real option hazard model with initial covariates

	(1)	**(2)**	**(3)**	**(4)**	**(5)**
const	-19.34** (-2.07)	-17.96** (-2.18)	-16.57** (-2.00)	-14.79* (-1.79)	-18.34* (-1.71)
pop	2.74** (2.87)	2.60** (3.03)	2.49** (2.88)	2.31** (2.65)	2.68** (2.71)
gdppc	4.97** (2.54)	4.69** (2.69)	4.45** (2.54)	4.06** (2.31)	4.83** (2.37)
relwage	.24 (1.45)	.22* (1.94)	.18 (1.30)	.17 (1.25)	.22 (1.38)
dist	-1.20** (-4.69)	-1.18** (-4.71)	-1.16** (-4.57)	-1.13** (-4.41)	-1.17** (-4.59)
indsize	.24* (1.72)	.21* (1.94)	.17 (1.56)	.25 (1.59)	.35* (1.73)
*indsize*lib*	-	-	-	-.06 (-.80)	-.08 (-.88)
MESdom	-	-	-.08 (-.92)	-.07 (-.88)	-.14 (-1.21)
med	.08 (.37)	-	-	-	.26 (.96)
high	.36 (1.24)	.31 (1.22)	.31 (1.27)	.31 (1.28)	.48 (1.55)
σ_{const}	-2.10** (-10.71)	-2.09** (-11.02)	-2.07** (-11.29)	-2.08** (-10.62)	-2.09** (-10.63)
indunc	.04 (.48)	.03 (.45)	.02 (.28)	.02 (.28)	.03 (.37)
$\tilde{\mu}$	-3.01** (-80.90)	-3.01** (-79.58)	-3.01** (-74.09)	-3.02** (-67.80)	-3.00** (-80.16)
Log likelihood	-590.10	-590.18	-589.76	-589.45	-588.88
N M	336	336	336	336	336
Specification test					
Cen. Moment II	.07 (1.48)	.07 (1.51)	.08 (1.52)	.09 (1.56)*	.08 (1.54)
Cen. Moment III	.17 (.67)	.17 (.67)	.23 (.78)	.25 (.80)	.25 (.79)
Cen. Moment IV	.76 (.61)	.85 (.63)	1.17 (.71)	1.29 (.72)	1.26 (.72)
Cen. Moment V	4.64 (.64)	5.11 (.65)	6.91 (.70)	7.65 (.71)	7.35 (.69)
Ho: joint moments mean = 0 X^2 (4)	9.22	9.53*	10.43*	10.55*	10.12*

Note: T-statistics in parentheses

** significant at the 5 per cent level or more; * significant at the 10 per cent level

Table 3. Estimation of the real option hazard model with time-varying covariates

	(1)	(2)	(3)	(4)	(5)	(6)
const	-2.90 (-1.33)	-2.01 (-1.01)	-2.01 (-1.02)	-1.99 (-1.01)	-1.17 (-.59)	-.91 (-.44)
pop	1.16** (4.16)	1.09** (4.03)	1.09** (4.33)	1.09** (4.32)	1.13** (5.26)	1.14** (5.07)
gdppc	1.58** (3.94)	1.51** (4.02)	1.52 (4.05)	1.51** (4.04)	1.32** (3.89)	1.26** (3.36)
relwage	.47** (2.67)	.44** (2.73)	.44** (2.74)	.44** (2.74)	.37** (2.42)	.25 (1.24)
dist	-1.03** (-5.44)	-1.00** (-5.47)	-1.00** (-5.48)	-1.00** (-5.50)	-1.11** (-6.60)	-1.14** (-6.48)
indsize	.17 (1.53)	.15 (1.47)	.15 (1.52)	.15 (1.54)	.18* (1.65)	.19* (1.71)
*indsize*lib*	-.04 (-1.18)	-.04 (-1.24)	-0.04 (-1.23)	-.04 (-1.26)	-.05 (-1.24)	-.05 (-1.25)
MESdom	-	-.12* (-1.89)	-0.12** (-2.08)	-.12** (-2.07)	-.13** (-2.02)	-.13** (-1.96)
med	-.11 (-.81)	.01 (.05)	-	-	-	-
high	.27 (1.24)	.31 (1.51)	0.31 (1.61)	.30* (1.66)	.37* (1.79)	.42** (2.02)
EU-FTA	-	-	-	.48** (2.41)	-	.27 (1.24)
CEEC-FTA	-	-	-	-	.77** (2.17)	.56 (1.54)
σ_{const}	-2.46** (-8.31)	-2.29** (-6.86)	-2.29** (-6.95)	-2.41** (-9.20)	-2.25** (-8.35)	-2.3** (-8.82)
indunc	-.02 (-.14)	-.10 (-.75)	-.10 (-.76)	-.06 (-.57)	-.14 (-1.32)	-.12 (-1.13)
$\tilde{\mu}$	-2.99** (-105.2)	-3.00** (-103.6)	-3.00** (-104.2)	-2.98** (-144.2)	-2.98** (-149.8)	-2.98** (-151.4)
Log likelihood	-587.85	-586.01	-586.01	-581.12	-580.25	-579.38
N M	336	336	336	336	336	336
Cen. Moment II	.47 (1.69)*	.64 (1.67)*	.62 (1.69)*	.18 (.77)	.35 (1.21)	.17 (.73)
Cen. Moment III	1.19 (1.14)	2.79 (1.13)	2.75 (1.17)	.30 (.45)	.83 (.81)	.17 (.35)
Cen. Moment IV	4.01 (.91)	17.60 (.88)	16.97 (.89)	.79 (.35)	2.80 (.65)	0.01 (.00)
Cen. Moment V	17.57 (.77)	30.03 (.79)	30.29 (.79)	3.47 (.31)	11.77 (.57)	-1.23 (-.09)
Ho: joint moments mean = 0; X^2 (4)	16.34**	16.51**	16.56**	8.77	11.11*	7.12

Note: T-statistics in parentheses

** significant at the 5 per cent level or more; * significant at the 10 per cent level

Annex Table – Data description

The model includes a total of 48 NACE 2 and 3 digits industries, grouped as follows.

No advertising and no R&D – low sunk costs: 10-11-12-13 and 14 (mining of coal, metals and stone; extraction of petroleum and natural gas); 151 and 152 (production and transformation of meat and fish); 156 (grains); 158 (fabrication of bread, tea, coffee and other alimentary products); 17 (textiles); 18 (clothing); 19 (leather); 20 (wood); 21 (paper and pulp); 22 (publishing and press); 252 and 262 (plastics and ceramics); 26 (other non-metallic products); 27 (metallurgy); 28 (metals); 292 (general machinery); 351 (ship building); 361 and 362 (furniture); 366 (other general manufacturing)

Advertising intensive – medium sunk costs: 153 and 155 (vegetables, milk and dairy products); 157 (pet food); 159 (drink and beverages); 16 (tobacco); 363 and 365 (musical instruments and toys)

R&D intensive – medium sunk costs: 241 and 242 (basic chemicals and agro-chemicals); 246 and 247 (other chemical products and synthetic fibres); 251 (rubber products); 291 (mechanical machinery); 294 and 295 (machine tools); 30 (office machines); 31 (electrical appliances, excluding domestic); 321 (electronics); 331 and 332 (medical and precision instruments); 343 (car components); 352 and 354 (railways; motorcycles)

Advertising and R&D intensive – high sunk costs: 243, 244 and 245 (paintings, pharmaceuticals and soaps and detergents); 293 (agricultural machines); 297 (domestic appliances); 322 and 323 (communication equipment); 334 and 335 (optics, photography, clocks); 341 (car production); 401 and 402 (electricity and gas); 642 (telecommunications)

Services – medium sunk costs: 45 (construction); 55 (hotels and restaurants); 65 and 66 (financial intermediation and insurance); 72 (computer and related activities); 73 (research and development); 92 (cultural and sporting activities)

Data refer to the following *countries*: Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia.

The source of macroeconomic data is the WIIW Database on Eastern Europe (www.wiiw.ac.at), 1990-2001. Other data derive from the AMADEUS dataset. The variables employed are the following:

gdppc: per capita Gross Domestic Product in US$ of the countries considered

pop: population in thousands of the countries considered

dist: distance in Km. from each country's capital city and an "average" European location, chosen as the city of Frankfurt

relwage: inverse of the average monthly gross wage of each country with respect to the average of the countries considered

indsize: share of each industry considered in each country gross value-added

MESdom: median domestic firm's employment of each industry calculated on the set of considered countries

lib: an index with a scale from 1 to 5 representing the method of privatization, where 1 is the most impeding method for TNCs (vouchers) and 5 is the most favourable (sales to outside owners only). See Carstensen and Toubal (2004) for further details.

The *year* at which each variable has been measured is 1990 for Table 1-2 and the year at which the first investment has been recorded in each country/industry pair for Table 3. The EU-FTA and CEEC-FTA dummies take value 1 if in the considered year a bilateral free trade agreement has been signed respectively with the EU (Europe agreement) or with other CEECs (CEFTA), according to the following table.

Country	Signature of Europe Agreement	Membership of CEFTA
Bulgaria	1 March 1993	1 January 1999
Czech Rep.	6 October 1993	21 December 1992
Hungary	16 December 1991	21 December 1992
Poland	16 December 1991	21 December 1992
Romania	8 February 1993	1 July 1997
Slovakia	6 October 1993	21 December 1992
Slovenia	10 June 1996	1 January 1996