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Introduction

Floro Ernesto Caroleo and Luca Pennacchio

Annals of CRISEI 2016 comprises selected contributions of some scholars of the Centro di Ricerca Interdipartimentale in Sviluppo Economico e Istituzioni (CRISEI) for the year 2016. This year the research activity carried out by CRISEI scholars has covered a variety of topics, including innovation, financial markets, natural resources and foreign aid for economic growth. Therefore, the important role played by institutions and some other factors in enhancing economic development represents the common theme of this volume.

In the last few decades, public policies to promote research and development (R&D) in several advanced countries have attached increasing emphasis on the formation of innovation networks, which are considered as an ideal context to foster knowledge creation and dissemination. The paper entitled "*Inter-firm R&D cooperation within Italian technological districts: A microeconometric analysis*" by Ardovino, Carillo and Pennacchio investigates the determinants of inter-firm R&D cooperation within a particular type of innovation network, the technological districts created in Italy under a specific public policy to promote innovation and economic growth at local level. The authors show that the structural characteristics of innovation networks have an important role in determining the propensity to cooperate. The presence of universities in the technological districts, for example, promotes collaboration among the participating firms. Moreover, the management mode of the districts, or in other terms the type of governance, plays the major impact: districts characterized by governance with a market approach are more successful in fostering inter-firms cooperation than district with hierarchical governance. Further findings confirm the importance of network effects, as well as of other factors indicated by the industrial organization literature. In addition, the authors provide empirical evidence that the governance of the districts have also a relevant moderating effect on other determinants of R&D cooperation, such as geographical proximity and absorptive capacity. When the collaborations are spontaneous, or in other words are formed without a clear guide of the governance authority that manage the districts, firms tend to cooperate with other firms which are localized in the same province; contrary, if technological districts have a more hierarchical type of governance, geographical proximity is not a relevant driver of collaborations. Finally, absorptive capacity appears an important determinant of the R&D cooperation most of all in the districts managed under governance oriented towards market logic.

The ability to address financial resources to the most dynamic and innovative firms with higher growth potential represents a crucial factor for the national economic development. In this view,

stock exchange segments with low listing requirements are a fundamental source of capital for small and medium sized firms. On this topic, the paper "*Graduation and sell-out strategies in the Alternative Investment Market*" by Revest and Sapio tackles the issue of why companies undertake the decision to go public. In particular, the authors analyze the strategic motivations behind quotation on the Alternative Investment Market (AIM), a sub-market of the London Stock Exchange (LSE) and one of the most successful market in the world supporting stock market financing of small and medium-sized firms. Their empirical analysis shows that the probability of acquisitions by other firms and graduations to the LSE main market is higher among the largest AIM-listed companies. Other findings indicate that technology acquisitions are not more likely than acquisitions of companies in less technology-intensive sectors, and that graduations of companies in science-based sectors are mainly due to the "new economy" fad of the late Nineties. Then, the AIM has mainly acted as a "show room" for the sale of larger and older companies and it has not been a facilitator for the growth of young and small innovative firms. Based on such findings, the authors cast doubt on the general idea that companies' going public decision is driven by growth motives, while they emphasize the importance of entrepreneurial exit opportunities.

The effectiveness of foreign aid in fostering economic development and efficiency in resource use has long been debated, but still no consensus is found among researchers and policy makers. There is little evidence of a positive effect of aid on the long-term growth of poor countries, which despite the massive delivery of aid by the richest countries are still embroiled in slow growth paths. Recent studies have emphasized that the quality of institutions of recipient countries is a key determinant of aid effectiveness. The third contribution entitled "*Women in Parliaments and Aid effectiveness in Sub-Saharan African countries*" by Carillo, Chiariello and De Siano contributes to this stream of literature, by evaluating whether aid effectiveness depends upon a particular characteristic of institutions in recipient countries, namely the Parliament gender composition. More in details, the authors consider the relationship between the share of women in parliaments and the effectiveness of aid in a sample of 46 Sub-Saharan African countries observed over the period 1995-2012. The main findings of the empirical analysis point out that foreign aid has a negative effect on economic growth and that the presence of women in parliament mitigates such negative effect. Taken together, these results support the view that if the institutional context of a country is not adequately structured, aid flows may be unable to stimulate economic growth. In this respect, however, a large presence of women in national institutions may lead to a more efficient use of external resources through, for example, the improvement of health and education conditions which, in turn, may have a positive impact on economic development.

The final two works expand our understanding on the use and conservation of some natural resources. The paper by Freni, "*Order of resource extraction and factor intensity*", examines theoretically the order of extraction of an exhaustible resource from different deposits. The author proposes a model for the optimal time paths of extraction and production of an energy sector in which two non-specific primary factors of production are required to exploit the reserves and to produce the substitute. The main implication of the model is that the incentive to procrastinate extraction in response to monotonic factor price dynamics can lead to discontinuous extraction of lower cost deposits along the optimal path, even if the resource can be converted into productive capital.

Finally, Aprile and Fiorillo in their contribution entitled "*Water Conservation Behavior and Environmental Concerns*" provide an empirical assessment of the relationship between general water conservation behaviors and environmental concerns. Water is considered as one of the most important natural resources because it is viewed as a key to prosperity and environment sustainability. Using a large dataset of individuals from Italy, the authors find that pollution and resource exhaustion are positively related to individual water conservation behavior, while alteration of environmental heritage exhibits a negative relationship with water saving behavior. The former result suggests that individuals will save water if they perceive general environmental issues as a threat for their own welfare. On the other hand, the latter finding may indicate that when individuals believe that general environmental issues are a threat for their own group's welfare but not for other groups, then they will not have a water saving behavior.

R&D cooperation within Italian technological districts: A microeconometric analysis*

Otello Ardovino, Maria Rosaria Carillo and Luca Pennacchio

Abstract

The purpose of this paper is to investigate the determinants of inter-firm R&D collaborations in a particular type of innovation network, the technological districts created in Italy under a specific public policy to foster innovation and economic development at the local level. Using an original database containing information on the collaborative research projects activated by the districts, we find that the structural characteristics of the individual districts play an important role upon firms' collaboration choices: the probability of cooperating is higher in districts in which universities have a major weight and in districts with governance more oriented towards market logic. As regards the governance, the estimates also reveal a strong moderating effect on other important determinants of R&D cooperation, such as geographical proximity and absorptive capacity.

JEL Classification: L14, O31, O32

Keywords: R&D cooperation, innovation networks, firm behaviour, dyadic regression model

* The authors are solely responsible for the content of the paper. The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the AGCOM

1. Introduction

In the last few decades, public policies to promote research and development (R&D) of several advanced countries have attached increasing emphasis on the formation of innovative networks, which are considered as an ideal context to foster knowledge creation and dissemination. In Italy, a particular state intervention has been implemented to create technological districts (TDs henceforth), that is innovative networks geographically concentrated in specific areas and in which various types of organisations (financial institutions, private and public research institutions, local authorities, private firms, etc.) carry out intense R&D activities. The *raison d'être* of such policy is the agglomeration of innovative firms and other institutions that can foster innovation, generating competitive advantages and economic development of local areas.

This paper sets out to use econometric analysis based on a sample of Italian TDs in order to identify the factors that promote cooperation among firms in the collaborative projects implemented by the various TDs. Then, our research contributes to the literature on the microeconomic choice to collaborate in R&D within innovative networks.

Our analysis differs from previous studies because it considers the strategies of collaboration within innovative networks that are characterized by two main peculiarities: *i)* their creation is conditioned on public funding and requires a decision-making process which starts from the *top*; *ii)* R&D activities implemented within them are managed according to a well-defined governance model; in this respect, the organisational and management structure may have an active role in the formation of partnerships for R&D activities. The existing literature, instead, appear chiefly centred on spontaneous collaborative relations between firms which are not driven and managed by external governance.

Such particular characteristics suggest the analysis should include not only the factors already identified in the literature as determinants of cooperation, but also the elements characterising individual districts. Thus, our research question concerns whether the drivers highlighted by the literature and/or the particular features of the districts are relevant in the context of Italian TDs to explain the formation of partnerships among firms.

Using a sample of collaborative research projects implemented in six TDs during the period 2005-2010, we estimate a logistic regression model for dyadic data. The results of our econometric analysis indicate that the structural characteristics of TDs play an important role in determining the propensity to cooperate. Estimates show that the presence of universities in a TD promotes collaborations among firms. Moreover, the management mode of a TD, in other words the type of governance, has a major impact: governance with a market oriented approach increases the propensity to cooperate. Further findings confirm the importance of network effects, as well as of

other factors indicated by the industrial organisation literature. In addition, we find that the governance of a TD plays a moderating effect on the relationship between the probability of cooperating and both geographical proximity and firms' absorptive capacity.

The paper is structured as follows: Section 2 provides a selected review of the theoretical and empirical background related to innovation networks. Section 3 describes the specific policy adopted in Italy to promote the creation of TDs. Section 4 presents the data and the econometric model, while Section 5 discusses the empirical results. Section 6 concludes the paper.

2. Theoretical and empirical background for technological districts

From a theoretical point of view, the modern innovation theory has emphasized that knowledge creation and dissemination is a localized process (Lundvall and Johnson, 1994; Storper, 1995). In line with this idea, the concept of regional innovation system (RIS) - introduced in the policy debate in the late 1990s as a regional interpretation of national innovation system (Cooke et al., 2004) - has attracted a growing importance in innovation policy. The RIS framework, defines innovation as a cumulative and non-linear process, resulting from formal and informal, voluntary and involuntary interactions between different local agents (such as firms, universities, research centers and local governments). According to this concept, the Triple Helix Model of innovation, which considers the close collaboration between University, Government and Industry as the essential engine of development for the local economy (Etzkowitz and Leydesdorff, 1995; Etzkowitz and Leydesdorff, 2000), is considered as the state of the art in the literature concerning regional innovation policies. It emphasizes that regional governments assume the key role of coordinator among different stakeholders involved in knowledge generating processes, because they have important competences and budgets in the field of innovation as well as a geographical proximity to local agents. Then, they can be considered as the most appropriate actors in order to align the interests of different local agents, fostering the creation of local innovation networks and the connectivity among different types of shareholders.

This model may be aptly combined with other approaches derived from the systemic view of the firm (Freeman, 1984; Golinelli, 2005), and with social network analysis (Granovetter, 1985; Burt, 1992; Gilsing, 2005) to highlight the positive effect of cooperation within innovative networks on technological progress and hence on the growth and competitiveness of local production systems.

Despite the extensive studies on technological clusters and regional innovation systems worldwide, empirical analyses of Italian technological districts are very scant. Patrucco (2003) using the case study of a TD in northern Italy shows that the number and heterogeneity of firm relationships positively impact on the innovation capabilities and growth of firms participating in the district.

Further contributions mainly evaluate the coherence between the economic specialization patterns of the Italian regions and the activity of the future district. To this end, some authors have sought to identify the key variables for suitable assessment of an area's technological potential. Lazzeroni (2010) identifies two methodological approaches: the first, starting from a large number of variables, uses multivariate analysis techniques (Bonavero, 1995; Miceli, 2010) or composite indicators such as the EU's European innovation scoreboard to measure the degree of local technological specialisation; with the second approach, variables are chosen a priori which might be representative of research potential in the areas in question (see, for example, Capuano and Del Monte, 2010). It is precisely this second approach, albeit more radical insofar as it is based on the construction of theoretical models, which would appear more suitable for analysis in local contexts where data are often unavailable. In this case, the factors deemed important are often identified through a comparison of existing situations, measuring the technological potential of various geographical areas also by means of qualitative variables (Monni and Spaventa, 2009). Lastly, a recent paper (Bertamino et al. 2016) sought to assess the economic performance of firms that participate in Italian technological districts. By using impact evaluation methods, the authors find that the performance of firms that joined a TD did not differ significantly from that of similar firms that did no. Similar results are shown by Liberati et al. (2015) on a sample of firms operating in science and technology parks: their business performance and propensity to innovate are not improved compared with external counterparts.

3. The public intervention for technological districts in Italy

As an instrument able to produce development and growth, TDs was first introduced into Italy with the Guidelines for Scientific and Technological Policy of the 2002 and then bolstered under the 2005 – 2007 national research programme (PNR). These planning documents stress the need to create, in certain areas of Italy, science parks in research and innovation able to promote collaboration between the various actors in the R&D production chain, drawing particular benefits from '*…public-private collaboration, supported by a process of institutional understanding between central, regional and local administration*'.[1] TDs receive public funds from European Union as well as central and local Italian governments; funds provided by the central government are prevalent.[2]

The area dimension of scientific research and technological development assumes a crucial role in such a policy: the creation of a TD in most cases requires a decision-making process which starts

[1] Italian Ministry of Education, University and Research (MIUR): National Research Programme 2005-2007, pp. 41.

[2] The Ministry of Education, University and Research (MIUR) estimates nearly in 500 million of euros the public resources distributed to the TDs until the end of 2011.

from the *top.* The initiative to establish TDs lies with the individual regions which have to present a project to the Italian MIUR so as to promote collaboration on specific innovative sectors between large, small and medium enterprises on the one hand, and public and private research institutes on the other. It is thus a matter of creating science parks for research and innovation. A prerequisite for the establishment of a TD is also identifying a geographical area that has substantial resources and technological skills that are consistent with the activity of the future district. The local variation in socio-economic structures in Italy has led to the creation of somewhat different TDs (Bossi *et al.*, 2006). However, we may identify a series of activities common to all TDs, namely: *i*) cooperation among the actors (networking), *ii*) local supply of high-level training, *iii*) support and assistance for start-ups through specialised finance, chiefly in the form of venture capital.

Starting from area technological specialisations (in many cases in areas at a sub-regional scale), such districts should be able to trigger a virtuous process between the world of research and industry that may lead to the development of high scientific skills of importance even at the international level.

Thus TDs are intended to combine the advantages of spatial agglomeration (closeness) of high-tech activities, typically knowledge spillovers, and creation of specialised labour and services, with the advantages of establishing networks, such as sharing the costs and risks associated with R&D. Moreover, thanks to the creation of collaboration networks it is also possible to incentivise SMEs, decoupling from the classic view that sees mainly large firms as the driver behind innovation and development processes.

Another fundamental criterion established by the government for setting up TDs is the creation *ad hoc* of a legally empowered governance authority to represent the TD and undertake the task of managing its activities according to a well-defined governance model.[3] The Articles of Associations of these authorities explicitly specify that the aim is to foster the development of the district as an integrated system of research and technological innovation. To that end governance authorities carry out "*all possible activities they deem necessary*", including the promotion of collaborative networks for the co-production and transfer of knowledge, according to the specific mission to manage and coordinate whole districts.

4. Data and econometric model

4.1 Sample description

[3] By governance authority or governance body we mean the legally established entity, created ad hoc, responsible for the management and coordination of the district and relative activities. It is usually a cooperative society or foundation whose members are also considered members of the district.

The empirical analysis considers six of the most important technological districts recognised by the MIUR. Most of the data were initially collected via the internet sites of the TDs and the Ministry. This information was subsequently verified and supplemented by interviews with those in charge of, or representing, the various districts. The availability of certified data and the degree of collaboration established with each district were essential elements for choosing the six TDs analysed herein. The sample in question, though only referring to some of the TDs operating in Italy (27 at the end of 2014), appears representative of the reference population both as regards the sectoral specialisation and with reference to geographical location: the districts considered belong to different technological sectors and to different regions, with a homogeneous split among the various areas of the country. Starting from the creation of various districts, mostly occurring in the two-year period 2005-2006, we collected data on research projects activated by the year 2010 using regional national or European public funds, in which the district governance authority played a leading and/or coordinating role. For each district, the information available concerns the projects undertaken during the period 2005-2010 and the participants. The amount of funds dedicated to such projects is around 100 million euros and is mostly provided by public sources.

In addition, the empirical analysis is based on two further sources of data: Bureau van Dijk for accounting variables of all companies participating in the TDs, whether domestic or foreign, and OECD for information on patent applications to the European Patent Office.

4.2 Dependent variable and econometric model

We measure R&D cooperation by the joint participations of firms in TD projects that are in the execution phase or already completed. For each district we constructed an actor-project matrix (affiliation matrix) containing the value 1 if the actor participated in the various research projects, and 0 otherwise; such a matrix, multiplied by its transpose (project-actor matrix), yields an actor-actor matrix (adjacency matrix) containing for each possible pairs of actors the number of collaborations in the research projects of the DT. Importantly, we consider each district as an individual network. Since only three firms (which we exclude from the sample) participated in more than one district and gave rise to cross-district collaborations, our choice seems appropriate.

The actor-actor matrix thereby created is thus a square symmetric matrix of dimension $n \times n$ whose elements on the main diagonal indicate the number of projects undertaken by each actor, and other elements indicate the collaboration links between each pair of actors. Given that more than 98% of pairs has 0 or 1 collaboration, we create a dependent variable equal to 0 for pairs with no collaborations and 1 for pairs with at least one collaboration. Therefore the variable in question may

be used as dependent variable to estimate the probability of collaboration between firms in the districts using what is known in econometrics as *binary regression models for dyadic data*.[4]

As pointed out above, in our model the observations are dyads and refer to possible collaborative links between firms in the technological districts. The dyadic regression models conceived to deal with such data involve two major econometric issues: *i)* specification of regressors and *ii)* non-independence of observations. Due to the nature of our data, the order of the actors within the pair is unimportant, i.e. $y_{i,j} = y_{j,i}$ for every i and j or, expressed in words, the values of the dependent variable are the same irrespective of the direction of the link. Consequently, also the independent variables are calculated so as to respect the symmetry of the relations and have the same value for pairs (i, j) and (j,i).[5] Following the approach of Fafchamps and Gubert (2007) the variables referring to the characteristics of the actors making up the various pairs (i, j) are calculated either as the absolute value of the difference or as the sum of values of each actor forming the link. This ensures that the regressors do not depend on the order of the i's and j's. The coefficients of variables expressed in absolute values are interpreted as the effect of differences in attributes on $y_{i,j}$ while those of variables expressed as the sum capture the effect of the combined level of attributes. As regards the second issue, the observations are not independent due to the presence of individual-specific factors common to all dyads sharing the same individual. In such cases, the estimates will still be consistent and not asymptotically biased but the standard errors will be inconsistent, cause the presence of heteroscedasticity, with the consequence of an incorrect inference. Lindgren (2010) suggests that all econometric analysis involving dyadic data should handle the heteroscedasticity issue appropriately. To obtain robust standard errors we rely on the method of Fafchamps and Gubert (2007) which corrects not only for the presence of heteroscedasticity but also for the presence of a correlation among the observations involving similar individuals. The method is a two-way clustering extension of the standard heteroscedasticity variance estimator proposed by Conley (1999) and White (1980).[6] The reduced form of the estimated model is as follows:

$$\Pr(Y_{i,j}=1) = \Lambda[\beta_0+\beta_1(District_{i,j})+ \beta_2(Traditional_{i,j})+\beta_3(Network_{i,j})+\beta_4(Control_{i,j})+\varepsilon_{i,j}]$$

The maximum likelihood method is used to estimate the coefficients.

[4] For in-depth treatment of econometric models with discrete dependent variables, see Maddala (1983) or Long and Freese (2006).

[5] Summing the observations of the districts included in the sample and only considering the unique pairs between firms yields 3042 possible pairs of actors. Of these observations, about 32% have the value 1. In other words, about 32% of the pairs established at least one collaboration in the district projects.

[6] The formal discussion of the method is beyond the scope of this paper; for more details see Fafchamps and Gubert (2007) or Lindgren (2010).

The motivations underlying the choices of collaboration among firms have been analysed in many theoretical and empirical studies. Following Belderbos *et al.* (2004) reference can be made to two approaches: the Industrial organization approach on firms' cooperation choices, chiefly of a theoretical nature, emphasised technological knowledge, identifying knowledge spillovers (Jaffe, 1986; Cassiman and Veugelers, 2002) and imperfect appropriability (d'Aspromont and Jacquemin, 1988; Shapiro and Willig, 1990) as the main factors leading to collaboration choices among firmschiefly; the second analyses the factors determining cooperation from the angle of transaction costs and Resource-Based Theory, and is more interested in aspects concerning the sharing of costs and risks which are typical of R&D.

Recently, another strand of contributions has suggests the importance of two new dimensions able to affect cooperation in R&D, derived from social network theory and geography of innovation (Maggioni and Uberti, 2011). Of the former, Bala and Goyal (2000) state that the involvement of actors within social networks, thanks to the creation of positive externalities, entails greater benefits than the case of bilateral links. From this point of view, the positioning of organisations within innovative networks is considered the decisive key to cooperation insofar as it increases the benefits of knowledge transfer and appropriability. In relation to innovation geography, Audretsch and Feldman (2004) stress that geographical proximity has a positive effect on cooperation among organisations as it enables closer and more frequent interpersonal relations which, in turn, boost knowledge transfer, especially of a tacit nature. To support such theoretical propositions, some studies which analyse research projects funded by the European Union Framework Programmes (Paier and Scherngell, 2011; Autant-Bernard et al., 2007; Defazio et al., 2008) provide empirical evidence on the importance both of geographical aspects and network effects.

The explanatory variables of the model proposed in this work were chosen *i)* as to take account of the specific nature of the phenomena being studied, i.e. the peculiarities of TDs, *ii)* in line with the literature cited above.

4.3 Explanatory variables

4.3.1 Characteristics of technological districts

The first group of regressors ($District_{i,j}$), which may be considered as that including the main variables of interest, refers to the characteristics of each TD. Mele *et al*. (2008) elaborate a theory to interpret the evolution of TDs based on the importance of governance: to promote the development of the district, the governance authority plays a decisive role in setting out a common policy for the various stakeholders involved which, by their very nature, bring divergent objectives to the district. Further, Wincent *et al.* (2012), in analysing government-funded innovative networks in Sweden,

provide empirical evidence concerning the important role played by governance in determining the innovative performance of enterprises. Leven et al. (2014) show the importance of network configuration and orchestration of partnerships between participants for the effectiveness of a large-scale government sponsored program that was designed to increase competitiveness and accelerate economic growth in Northern Sweden.

To allow for the importance of governance, we thus constructed a dichotomous variable (*Governance*) which takes the value 1 if the occurrence of collaboration in district projects is left mainly to the spontaneous action of the various actors (market logic), and 0 if the choice of actors to involve in projects is chiefly guided by the specific will of the governance authority (hierarchical logic). More in details, each TD was assigned to one of the two categories by combining the following information: i) availability on the part of the TD of their own research structures, ii) management characteristics emerging from reading the Articles of Association, iii) information emerging from interviews with TD directors. Indeed, what clearly differentiates the TDs is how the networking activity among participants is implemented. Some governance authorities operate to create strong leadership in order to exert well-defined supervision over all activities in the district. Such districts represent knowledge integrators that design and develop specific network mechanisms to promote links between scientific research and companies, selecting organisations and promoting partnerships to steer the path of development. Districts adopting such a governance of relations among stakeholders are classified as TDs with hierarchical governance. Instead, other governance authorities manage the district in more general terms, focusing on resources and activities rather than on the formation of relationships among actors: they predict the main trends regarding research, support government authorities in planning public financing for R&D and sponsor research projects. Such districts do not carry out ex-ante coordination mechanisms of stakeholders' relations and much less choose the individual actors that will participate in research projects. Districts in which relations are based on individual and spontaneous actions of stakeholders are classified as TDs with market-oriented governance.

A second variable (*University)* measures the weight of university institutions within the various technological districts. The positive effect of collaboration with universities on firm innovation is stressed by much of the economics literature. Establishing collaboration with universities allows firms both to reduce the costs and risks of conducting R&D, and to acquire new knowledge able to further boost their own innovative capacity. Brostrom and Loof (2008) also find empirical evidence that cooperation with university institutes allows firms to strengthen links with other firms, thanks to an improvement in their human capital and their capacities to internalise external opportunities.

4.3.2 Traditional factors

The second vector of covariates $Traditional_{i,j}$ chiefly refers to the characteristics of the individual firms forming the various pairs. An important aspect in determining cooperation choices, which falls within traditional factors, is the complementary nature of knowledge and skills of the various actors (Arora and Gambardella, 1990), especially in high-tech content. Such heterogeneity may promote diffusion of information and the sharing of indispensable resources for the innovative process.

Besides, a low level of heterogeneity could establish competitive dynamics among firms and limit their cooperation (Katz, 1986) in the moment in which there may be competition among such firms on the product market.

Such considerations suggest the existence of a positive link between the propensity to collaborate and the heterogeneity of the firms involved. However, such an effect does not appear generally to hold either at the theoretical or empirical level. For example, Cantner and Meder (2007) find the opposite effect, i.e. that technological proximity, hence greater homogeneity among firms, has a positive effect on collaboration in research in high-tech sectors.

We believe it is worth making a distinction between the concepts mentioned above. For this purpose, to measure the degree of technological and product market proximity between firms participating in TDs we introduced the variables *Technological Proximity* and *Market Competition.* The former is a proxy of sectoral proximity and is calculated as in Caloffi *et al.* (2013). In particular, the variable assumes the value 1 if firm *i* operates in the same two-figure Ateco sector as firm *j*, and 0 otherwise.[7]

By contrast, the *Market Competition* variable aims to take into account the firms' retail market proximity and is the interaction term between the proxy of technological proximity and the variable *Geographical Proximity*, a dichotomous variable which is equal to 1 if the firms of the pairs have their head office in the same province (NUTS 3 level). Hence, the category encoded with 1 of the *Market Competition* variable comprises firms that could compete with one another since they are localized in the same province and belonging to the same industry.

The regressor *Geographical Proximity* also allows for the effect of spatial proximity on the probability of collaboration. Indeed, the importance of geographical proximity is highlighted by several studies which, in various forms, point to localized knowledge spillovers, i.e. the existence of

[7] The classification used is Ateco 2007 at the division level. It should be pointed out that the classification in question does not contemplate all the business sectors in which our sample of firms operates (for example, there is no category for biotechnology). However, this does not generate practical problems for our purposes where what concerns us is whether both components of the pairs operate in the same sector and not the specific sector as such.

positive externalities in space, as an important factor to promote and boost the innovative activity of firms (Breschi and Lissoni, 2001).

The ability of TDs to foster R&D cooperation between small firms is represented by *Small Firms*, a dichotomous variable equal to 1 if both firms of the pair are small organisations with an annual turnover below 10 million euro.

The vector of covariates also comprises the variable *Research Potential* with which allowances are made for the fact that individual actors, in order to obtain a greater transfer of information, seek to collaborate with others that have high research potential, hence a possible baggage of knowledge. By contrast, the *Research Gap* variable refers to the absorptive capacity, i.e. the capacity of organisations to recognise the value of external knowledge and to assimilate it, thereby maximising the benefits derived from technology transfer. This learning process is not without its costs and usually presupposes resources that already exist within the firm (Barney *et al.*, 2001). As stressed by Cohen and Levinthal (1990), an organisation's learning capacity depends greatly on its previous level of specific knowledge. Moreover, the two authors provide empirical evidence for the negative effect of the gap between each organisation's learning capacity on the benefit derived from cooperation in R&D. Both regressors are calculated according to Autant-Bernard *et al.* (2007), i.e. as the sum of the projects in which firms *i* and *j* participated (*Research Potential*), and as the difference in absolute value, the second (*Research Gap*). On the basis of previous considerations, we expect a positive sign in the first case and negative in the second. In order to examine in greater depth the relationship between absorptive capacity and probability of collaboration, we introduce in the model further variables that refer to the gap between firms in age (*Age Gap*), size (*Size Gap*) and patent applications (*Patent Gap*). The latter variable, used in Nooteboom *et al.* (2007), can be considered a proxy of firms' technological capital.

4.3.3 Network effects

The third group of explanatory variables ($Network_{i,j}$) refers to network effects and concerns the variables relative to the position of firms within their own cooperation network. The network graph for each TD is shown in Appendix B. To date there are few studies which verify whether the characteristics of a network affect the collaboration choices of firms on the same network or, to use a term from social network analysis, of their own nodes. Goyal *et al.* (2006), for example, show that the degree of involvement of organisations within their own network, what in the literature is called structural embeddedness (Granovetter, 1985; Uzzi, 1997), is a key factor in explaining cooperation choices. Underlying this result is the idea that knowledge transfer may be achieved not only through

direct collaboration between two actors, but also through indirect links which involve all the actors of a whole collaboration network.

To allow for the position of the firms within the network we use three indicators from social network analysis: betweenness centrality, degree centrality and closeness. Betweenness centrality identifies an organisation's position within a network in terms of its ability to make connections with other pairs or groups in a network. An actor with a high degree of betweenness generally holds a favoured position in the network and has greater influence. Degree centrality indicates to what extent an actor is connected via direct links with other actors and is generally the hallmark of active players on the network that often assume the role of hub (Bonaccorsi and Giuri, 2001; Powell *et al*., 1996). In innovative networks degree centrality could be interpreted as a measure of the propensity of each actor to cooperate. In other words, a high degree centrality at time *t* may result in a higher collaboration probability at time *t+1* (Borgatti, 2005).

The third indicator, closeness, measures for each actor the closeness to other network actors (Freeman, 1979). A high level of closeness indicates that an actor is able to reach other network actors more rapidly; in the context of R&D collaboration, this concept means that actors with a high closeness value have a greater probability of receiving knowledge flows and hence, as stressed by Borgatti (2005), of developing innovations before others. The regressors are calculated both as the sum (variables *Betweenneess*, *Degree*, *Closeness*) and absolute difference (*Betweenneess Gap*, *Degree Gap*, *Closeness Gap*) of the values of firms *i* and *j* forming the pairs. The indicators have some similarities with the variable that refers to research potential. Indeed, indicators of centrality can be thought of as further proxies, in terms of position within their network, of firms' research potential and absorptive capacity. In addition, from the standpoint of social network analysis, *Research Potential* is a measure of centrality in two-mode networks, while degree centrality and closeness measure the centrality of actors in a one-mode network. A positive sign is expected for the variables expressed as the mean while a negative sign is expected when their expression is the absolute difference.[8] We also note that the indicators of centrality are highly correlated. Thus in the next section we present only the estimates obtained with *Betweenness* and *Betweenness Gap*, the estimates being very similar with degree and closeness indicators. Moreover, Paier and Scherngell (2011) provide empirical evidence concerning the positive effect of long-term relations and mutual knowledge on trust between organisations, and hence, on their propensity to establish strategic collaboration in R&D. To capture this aspect we inserted in the model the dichotomous variables

[8] To limit the possible distorting effect on the estimates due to endogeneity problems, the indicators refer to the networks originating from collaboration in projects on the part of all district stakeholders. Such networks are thus broader than those considered in our sample, which refers only to collaboration between firms. In addition, only projects started in the first two years of the whole period are considered.

Interlocks and *Shareholding*. The former refers to interlocking directorates, i.e. the practice of members of a corporate board of directors serving on the board of multiple corporations. Mizruchi (1996) argue that interlocks are a powerful indicator of network ties between firms and yield significant insight into the behaviour of firms. The variable assumes the value 1 if the firms in the pair share a director or an executive, and 0 otherwise. The second variable is equal to 1 if a firm owns a stake in the other firm of pairs. Since long-term relations favour reciprocal learning and enhance the degree of trust between organisations, we expect a positive sign.

4.3.4 Controls

Finally, the group of control variables ($Controls_{i,j}$) includes: *Actors* representing the number of actors that participate in the districts and that can be considered as a proxy of network size; *Projects* which measures the number of projects activated by each district, and hence the number of potential collaborations that each actor i may establish with the other actors j of the district; *Funds* which refers to the amount of financing distributed to each district for research projects. The latter variable is built using information provided by the districts that, in many cases, are estimates of the total resources available and cannot be attributed to individual projects. Most of the financing is public but the data do not allow distinction between private and public sources. Table 1 provides summary statistics of variables used in the econometric model.

Table 1. Descriptive statistics of variable used in the econometric analysis

	Mean	Std. Dev.	Min.	Max.
Panel A: variables related to pairs				
Y	0.32	0.46	0	1
Research Potential	2.48	1.48	0	12
Research Gap	0.83	1.05	0	7
Technological Proximity	0.83	0.37	0	1
Market Competition	0.54	0.49	0	1
Small Firms	0.37	0.48	0	1
Size Gap	0.73	3.52	0	37.73
Age Gap	2.36	1.10	0	5.16
Patent Gap	-0.07	2.56	-9.13	9.2
Interlocks	0.05	0.07	0	1
Shareholding	0.01	0.11	0	1
Betweenness	0.61	1.18	0	9.04
Betweenness Gap	0.52	1.01	0	5.17
Geographical Proximity	0.33	0.47	0	1
Panel B: variables related to technological districts				
Governance	0.54	0.49	0	1
University	0.26	0.18	0.15	0.43
Projects	9.77	2.72	7	15
Actors	81.15	24.30	26	135
Funds	56.66	21.25	24.72	80.20

5. Results

It may be noted from the correlation matrix reported in Appendix B that centrality indicators are highly correlated with variables *Research Potential* and *Research Gap*. We therefore estimate alternatively their effects on the probability of collaboration: the first column refers to the specification with *Research Potential* and *Research Gap* while Column (2) includes *Betweenness* and *Betweenness Gap*. Lastly, Column (3) reports the estimates of the more parsimonious specification where network indicators, as well as *Research Potential* and *Research Gap,* are excluded. Such model specification avoids any possible problem of milticollinearity incidental to the network indicators. Column (4) reports the coefficients of the standardised explanatory variables. The latter have a more straightforward interpretation than logit coefficients and allow us to capture the importance of the regressors in explaining the dependent variable.[9]

Sectoral and geographical proximity show a positive sign of coefficients but are not statistically significant. With respect to the first result, it seems that the propensity to collaborate is unaffected by the technological proximity of firms. This is at odds with other empirical studies (Caloffi *et al*., 2013; Paier and Scherngell, 2011) that show that research spillovers are greater among firms operating in the same sectors. The result, however, could be due to the lack of appropriateness of our measure. Previous analyses compute the technological proximity in terms of distance between patent portfolios of firms. However, the patenting activity of Italian firms is very low: in our sample 107 out of 179 firms (59%) had no patents, making it impossible to compute the variable of technological proximity in this way.

With respect to size, the variable *Small Firms* is statistically significant, indicating that if both the firms in the pairs are small-sized, then the probability of collaborating increases. This means that districts are successful when encouraging SMEs to cooperate in R&D. In addition, by looking at the *Size Gap* variable, it emerges that districts also play a key role in fostering cooperation between large and small firms. Hence, such results could be interpreted as the effective capacity of districts to create collaborative networks both among small firms and large and small firms. The latter type of cooperation seems of particular interest because, without the intermediation role of governance authorities, large firms would probably be unwilling to form research partnerships with small firms.

The variable *Market Competition* is not statistically significant and presents alternation of signs in the various specifications, excluding that competition on the product market may limit cooperation

[9] The coefficients of the logit model indicate the variation in the log odds of having collaboration after a unit increase of the relative regressors while the standardised coefficients indicate the log-odds variation after a unit increase in the standard deviation of the relative regressors.

between firms.[10] The explanation could lie in the specific nature of TDs compared with other phenomena considered in the economic literature. The latter typically refer to collaborations between firms for individual funding competitions and hence to the forming of temporary consortia. By contrast, a characteristic element of districts is to promote and encourage cooperation between local actors in a long-term perspective. In addition, various projects undertaken by the districts may be classified as basic research projects which, by their very nature, are less subject to generating competitive tensions on the part of finished products. Lastly, technological districts can be thought as precompetitive innovation networks, which participants are not engaged in market competition.

The regressors *Research Potential* and *Research Gap* show the expected sign and strong statistical significance. Both R&D potential and absorptive capacity of *i* and *j* matter. The effect of absorptive capacity is confirmed also looking at variables *Age Gap* and *Patent Gap* that are statistically significant and with the negative signs. The more two firms differ in R&D potential, age and patenting activities, the less they collaborate.

As regards to network variables, the coefficients of *Betweenneess* is statistically significant, with the expected signs, indicating that within innovative networks the firm i draws benefits not only from bilateral relations with other firms j, but also from its own network of collaborations and indirectly from those of each firm j. In addition, the negative sign associated to *Betweenness Gap* further supports the role of similarity between firms, in terms of their position within the network, in fostering the probability of forming a link. Previous knowledge between firms (prior acquaintance) positively affects the probability of collaboration. As shown by the *Interlocks* variable, firms that share a director or an executive have a higher probability of collaborating in the research project of the district. This finding underlines the important role of personal ties in strengthening R&D collaborations. By contrast, the variable *Shareholding* is not statistically significant.

The variables referring to district characteristics provide interesting indications for the particular phenomenon in question. *Governance* has a positive sign and high statistical significance. This could suggest that the activity of intermediation on the part of the governance authority plays a non-secondary role upon firm propensity of collaborating if it is more oriented towards market logic. For example, districts characterised by sizeable redistribution of public funds have a higher capacity to promote cooperation among participating firms.

[10] A negative link, albeit not statistically significant, between market proximity and research output was found by Branstetter and Sakakibara (2002) with regard to Japanese research consortia. Our result, however, could be due to the inappropriateness of the proxy that we use to account for the market competition.

Moreover, the presence of universities also serves to promote collaboration among actors of the district. The interpretation is twofold. On the one hand, R&D cooperation with universities entails strong advantages in terms of cost and risk reduction, as well as in terms of knowledge creation and transfer. On the other hand, the participation of large and prestigious universities in the districts may attract more financing, whether public or private, thereby increasing the probability of collaboration among firms.

The standardised coefficients reported in Column (4) indicate that districts variables, and *Governance* in particular, have the highest explanatory power within the model. Therefore, the characteristics of individual districts play a fundamental role in determining the cooperation propensity among network firms.

Finally, control variables are statistically significant. The regressors *Actors* and *Funds* have a positive sign, showing that in larger districts with more research funds the firms have a higher probability to cooperate in R&D activities. By contrast, the variable *Projects* has a negative effect on the propensity to collaborate, which is surprising since one might expect that the greater the number of projects, the greater would be the probability of forming partnerships among firms.

Table 2. Logit estimates on the determinants of inter-firm R&D cooperation

	(1)	(2)	(3)	(4)
Technological Proximity	0.10	0.17	0.20	0.07
	(0.173)	(0.191)	(0.195)	
Geographical Proximity	0.59	0.31	0.05	0.02
	(0.243)	(0.332)	(0.252)	
Small Firms	0.38*	0.39*	0.36**	0.06
	(0.215)	(0.232)	(0.212)	
Market Competition	-0.17	0.09	-0.03	-0.01
	(0.287)	(0.294)	(0.243)	
Size Gap	0.04**	0.02*	0.03*	0.10
	(0.021)	(0.012)	(0.018)	
Age Gap	-0.01*	-0.01**	-0.01*	-0.07
	(0.006)	(0.004)	(0.006)	
Patent Gap	-0.04**	-0.03*	-0.05*	-0.14
	(0.020)	(0.018)	(0.030)	
Governance	1.70**	1.59*	1.65**	0.83
	(0.722)	(0.950)	(0.789)	
University	2.67*	2.33*	2.57*	0.28
	(1.541)	(1.39)	(1.512)	
Interlocks	1.55*	1.97**	1.94**	0.14
	(0.901)	(0.975)	(0.960)	
Shareholding	-0.45	-0.61	-0.64	-0.07
	(0.544)	(0.520)	(0.454)	
Research Potential	1.41***	-	-	
	(0.191)			
Research Gap	-0.90***	-	-	
	(0.209)			
Betweenness	-	2.46***	-	
		(0.478)		
Betweenness Gap	-	-1.65***	-	
		(0.494)		
Projects	-0.36***	-0.22**	-0.27**	-0.74
	(0.110)	(0.108)	(0.118)	
Actors	0.02***	0.01*	0.01**	0.39
	(0.006)	(0.007)	(0.007)	
Funds	0.03**	0.05**	0.05**	1.20
	(0.014)	(0.023)	(0.024)	
Observations	2923	2923	2923	
Pseudo R^2	0.27	0.23	0.18	
Wald χ^2 (p-value)	0.00	0.00	0.00	

***, **, * Statistically significant at 1, 5 and 10% level. Constant not reported.
Standard errors corrected for dyadic correlation of errors in parenthesis.

Having found that the *Governance* variable has a strong direct effect in fostering R&D collaborations, we also investigate whether the variable affects the relationship between the other regressors and the probability of cooperation. To this aim, we split the sample in two subsamples: one for collaborations implemented in districts with governance oriented towards market logic (estimates in Column 2 of Table 3), and one for collaborations implemented in districts with a more hierarchical governance (estimates reported in Column 1 of Table 3). The check is based on the model specification of Table 2 - Column (1), which has the major advantage to avoid multicollinearity and endogeneity problems between networks indicators and other regressors.[11]

[11] Given that in each of the subsamples there are only 3 TDs, the controls *Projects*, *Actors* and *Funds* have been dropped from the model. We also exclude the variable *University*, concentrating the analysis only on factors related to firms.

The most interesting differences emerge with respect to geographical proximity and the proxies of absorptive capacity. Geographical proximity between firms is not statistically significant in Column (1), while it is significant, with a positive coefficient, in Column (2). Such finding indicates that when the collaborations are more spontaneous, or in other words are formed without a clear guide of the governance authority that manage the districts, firms tend to cooperate with other firms which are localized in the same province. Instead, TDs with hierarchical governance seem to stimulate R&D cooperation also between firms localized far away.

As regards the proxies of absorptive capacity, the variables *Patent Gap* and *Age Gap* are statistically significant only in the subsample of market-oriented governance, while in the subsample of hierarchical governance they are not. This suggests that absorptive capacity is an important determinant of the probability of cooperation most of all in the TDs managed under a governance oriented towards market logic.

On the other hand, in TDs managed with governance of hierarchical type personal ties between firms appear more relevant than in other TDs. The variables *Interlocks* and *Shareholding* are significant at the 1% level and positively correlated with the dependent variable.

Lastly, it is interesting to observe that the variable *Size Gap* is statistically significant in both subsample, but has a positive impact on the probability of cooperation in the case of hierarchical governance, while it has a negative impact in the case of market-oriented governance. Then, firms tend to cooperate with similar partners, in term of size, if the collaborations are spontaneous, while the TDs characterized by a hierarchical type of governance seem to be able to foster research partnerships also between firms of different size.

Table 3. Moderating effect of the district governance on the relationship between individual determinants and the probability of cooperation

	(1)	(2)
Technological Proximity	0.32	-0.00
	(0.213)	(0.190)
Geographical Proximity	-0.49	1.01***
	(0.423)	(0.280)
Small Firms	0.64***	0.35**
	(0.178)	(0.177)
Market Competition	-0.17	-0.11
	(0.275)	(0.387)
Size Gap	0.07***	-2.96***
	(0.025)	(0.434)
Age Gap	-0.00	-0.00
	(0.006)	(0.003)
Patent Gap	-0.00	-0.13***
	(0.028)	(0.036)
University	-0.51	7.41***
	(0.819)	(2.902)
Interlocks	3.51***	0.63
	(1.36)	(1.345)
Shareholding	1.15***	-0.39
	(0.415)	(0.598)
Research Potential	1.71***	1.44***
	(0.126)	(0.118)
Research Gap	-0.77***	-0.94***
	(0.142)	(0.121)
Observations	1608	1315
Pseudo R^2	0.24	0.31
Wald χ^2 (p-value)	0.00	0.00

6. Conclusions

The present paper has analysed the factors that lead to R&D cooperation among firms in Italian government-sponsored TDs. In particular, the analysis has considered firms' participation in some collaborative research projects implemented within TDs. To this aim, a sample of TDs has been investigated by means of a logistic regression model for dyadic data. The main results indicates that the structural characteristics of each district greatly affect the behaviour of the actors concerned. Indeed, estimates showed that the presence of universities may boost cooperation among the firms and that district governance has a major role, in the sense that TDs with market-oriented governance are more successful in fostering cooperation than districts with hierarchical governance. Such a result, although lacking a clear theoretical basis, could indicate that market logic for the coordination of stakeholders participating in TDs has to be preferred if, as stated by the Articles of Association of some TDs, a key goal is to promote the creation of collaborative networks in R&D activities.

Moreover, our findings in part confirm what has been stressed by the traditional literature on the subject. Knowledge transfer and absorptive capacity of firms are important factors in explaining

decisions to cooperate. However, these aspects have less direct impact than the structural characteristics of individual districts. Such evidence suggests that, within innovation networks where there is a governance body, such as Italian TDs, the latter's intermediation may attenuate in part the importance of factors that explain cooperation in spontaneous research networks. Given such consideration, we have analysed more in-depth the role of governance and its moderating effects on other determinants of R&D cooperation. In this respect, relevant differences emerge when we compare TDs with different types of governance. In the TDs characterized by a governance oriented towards market logic, the determinants of inter-firms R&D cooperation within TDs are consistent with the traditional literature. For example, geographical proximity and absorptive capacity have a significant impact on the probability of cooperation. On the other hand, in the TDs with hierarchical governance the collaborations between firms seem to be driven by other factors, such as personal ties; geographical proximity does not have any effects, while absorptive capacity affects the probability of collaboration to a lesser extent.

In addition, other findings shed light on several interesting features of TDs. Technological proximity does not appear to affect the probability of collaborating among firms, contrasting with part of the empirical and theoretical works concerning cooperation in high-tech activities. Finally, also network effects, captured in the estimates with position indicators from social network analysis and prior acquaintance, play a key role in determining collaboration among firms.

Some interesting considerations about TDs as an instrument of public policy also emerge from the analysis. The estimates showed that TDs, by setting up collaborative networks in research projects, are able to promote the collaboration of small firms both with one another and, in the case of TDs characterized by hierarchical governance, with large firms. From this point of view the districts seem to achieve one of their main objectives concerning the engagement of small firms in research and development. Furthermore, small firms can draw considerable advantage from research partnerships with large firms which, without the intermediation role of the districts, would be unlikely to take place. Based on the present analysis, it could be argued that if one of the main object of a TD is to foster R&D cooperation between small and large firms, then a governance of hierarchical type may be preferred. On the other hand, if the main object is to stimulate collaborations among small firms, then a market-oriented governance may be more appropriate.

Our analysis is the first stage in the characterisation of R&D cooperation and in the identification of its drivers within Italian TDs. The individual determinants considered here still need to be investigated in depth. However, in our opinion, the results constitute a useful starting-point for analysing the complex reality of TDs. Future studies could – and should – also deal with assessing their achievements and those of the public policy which led to their birth. This undertaking appears

both stimulating and arduous. Indeed, it should not be forgotten that technological districts represent an experience which is still evolving and that the effects of R&D, as well as the economic returns tied to innovations, are only fully achieved in the long term.

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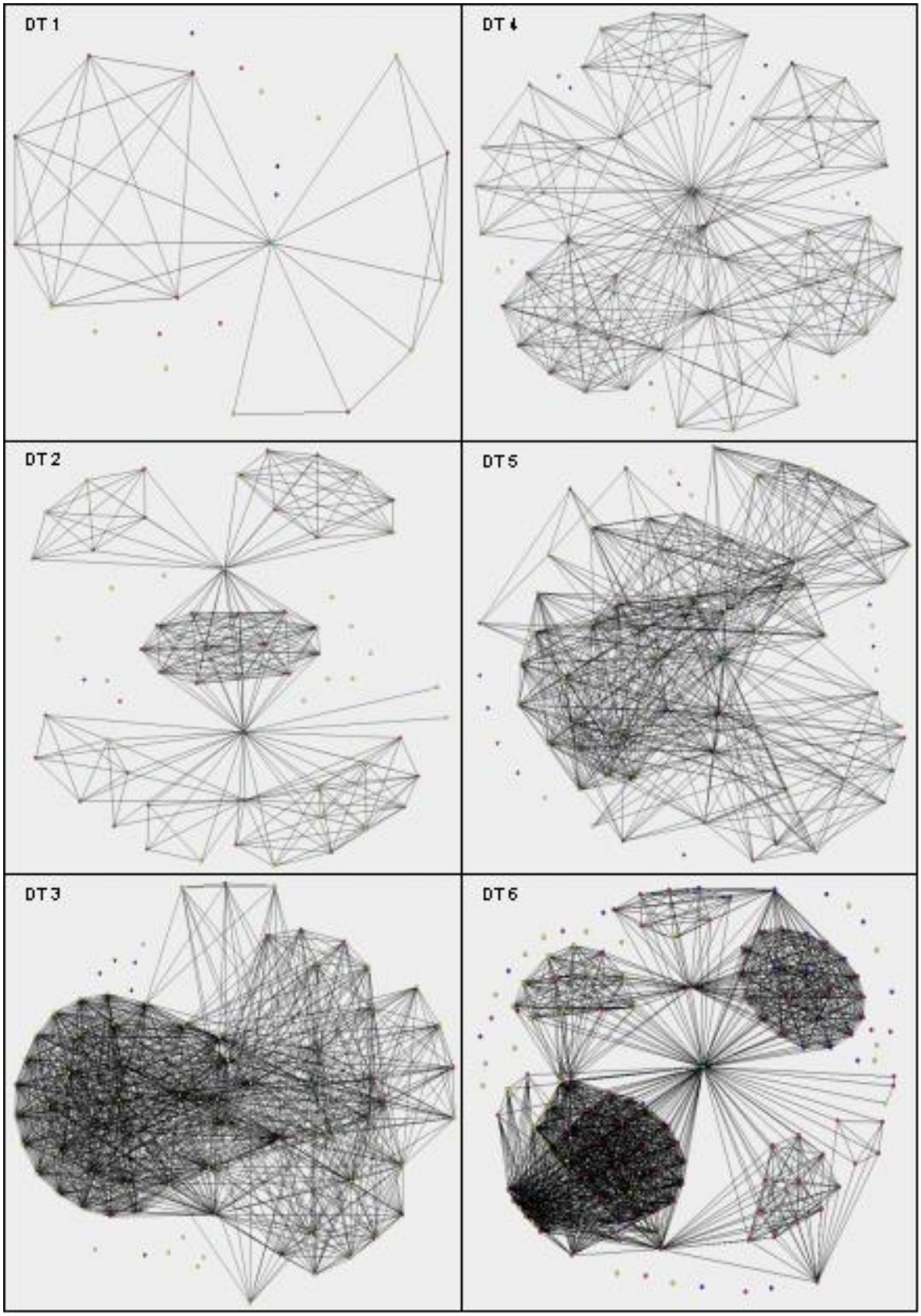
Appendix A – The collaborative research networks within the TDs included in the sample



Appendix B – Correlations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
(1) Technological Proximity	1.00																	
(2) Geographical Proximity	0.06*	1.00																
(3) Small Firms	0.10*	0.20*	1.00															
(4) Market Competition	0.21*	-0.38*	-0.33*	1.00														
(5) Research Potential	0.08*	0.11*	-0.01	-0.02	1.00													
(6) Research Gap	0.00	-0.04*	-0.14*	0.05*	0.33*	1.00												
(7) Size Gap	0.05*	0.00	-0.16*	0.08*	-0.02	0.02	1.00											
(8) Age Gap	-0.01	-0.12*	-0.28*	0.11*	0.03	0.08*	0.11*	1.00										
(9) Patent Gap	-0.02	-0.05*	0.00	-0.00	0.02	0.04*	-0.10*	0.10*	1.00									
(10) Betweenness	0.04*	0.10*	-0.01	-0.04*	0.70*	0.54*	-0.01	0.06*	-0.02	1.00								
(11) Betweenness Gap	0.05*	0.07*	0.00	-0.03*	0.63*	0.62*	-0.02	0.04*	-0.00	0.71*	1.00							
(12) Governance	-0.00	0.30*	0.13*	-0.26*	-0.32*	-0.26*	-0.01	-0.13*	-0.16*	-0.21*	-0.21*	1.00						
(13) University	-0.03	-0.12*	-0.29*	0.15*	-0.34	-0.01	0.07*	0.11*	0.02	-0.25*	-0.25*	0.11*	1.00					
(14) Interlocks	0.02	-0.00	-0.03*	0.01	0.04*	0.04*	-0.00	-0.00	-0.00	0.00	0.00	-0.02	0.00	1.00				
(15) Shareholding	0.01	-0.02	-0.06*	0.02	0.03	0.03*	-0.01	-0.01	0.02	-0.00	-0.00	-0.06*	-0.01	0.38*	1.00			
(16) Projects	-0.02	0.10*	-0.12*	-0.06*	-0.36*	-0.11*	0.14*	-0.07*	-0.09*	-0.29*	-0.29*	0.49*	0.60*	0.02	-0.02	1.00		
(17) Actors	0.01	0.09*	-0.05*	0.01	-0.21*	-0.06*	-0.09*	-0.06*	-0.09*	-0.10*	-0.09*	0.38*	0.38*	-0.03	-0.04*	0.56*	1.00	
(18) Funds	0.02	-0.15*	0.07*	0.12*	0.46*	0.21*	-0.02	0.05*	0.11	0.30	0.30*	-0.39*	-0.51*	0.02	0.07*	-0.55*	-0.36*	1.00

Graduation and sell-out strategies in the Alternative Investment Market

Valérie Revest and Alessandro Sapio

Abstract

Why have thousand companies listed on junior stock markets such as the Alternative Investment Market (AIM)? The controversial evidence on survival and productivity growth of the AIM-listed companies, together with the recent increase in post-IPO sales worldwide suggest that growth motives are far less essential than the attainment of entrepreneurial exit opportunities. Insights on the strategic motivations behind stock market quotation are provided in this article by comparing the characteristics of AIM-listed companies involved in two trajectories, namely graduation and post-IPO company sales. Estimates of discrete choice and duration models outline the relationship between the probabilities of AIM-listed companies to be acquired or to graduate to the LSE main market and their size, age, and sector between 1995 and 2009. The results show that the AIM has mainly acted as a "show room" for the sale of its larger and older companies, especially after the Internet bubble: companies in high-tech sectors featured prominently among graduates in the late Nineties, but not among takeovers. As such, the AIM has not been a facilitator for young and small innovative firms, or it has mainly attracted those wishing to retain independence.

Keywords: Technology-based small firms, Alternative Investment Market, acquisitions, graduations.

Introduction

The increasing number of stock exchange segments with low listing requirements ("junior stock markets") testifies to the political will to support stock market financing of SMEs. The tight constraints to loans that have disproportionately affected young innovative firms since 2008 have only reinforced this tendency (Cowling et al., 2012; Mina et al., 2013; Schneider and Veugelers, 2010 among others).

Nevertheless, stock markets in both US and Europe have been facing a decline in small firms IPOs in recent years, accompanied by an increase in trade sales (Ritter et al., 2013). Selling business to larger companies that can exploit innovations more effectively and generate synergies is increasingly preferred to IPOs as an entrepreneurial exit strategy (see Carpentier and Suret, 2014, regarding business angels strategies, and the theoretical model in Bayar and Chemmanur, 2012). One can however observe also an increase in post-IPO company sales (Ritter, 2013; Ritter et al., 2013), suggesting that an IPO can be seen as an intermediate stage in a sequential divestiture strategy (Reuer and Shen, 2004; Brau et al., 2010; Mantecon and Thistle, 2011). Such a "double track" strategy can be deployed on highly liquid first-tier segments of the stock exchanges only if listing requirements are satisfied. This effectively cuts SMEs and young firms out of the picture, unless a junior segment is available.

A junior stock market can then act as a "show-room" of promising acquisition targets for larger and more established companies, including those wishing to supplement traditional technology sourcing modes, such as patent licensing or contract research (Grandstrand and Sjolander, 1990). But companies listing on a junior stock market can alternatively choose to graduate to the main market in hope of reaping the benefits of stock market flotation (e.g. visibility, high-powered managerial incentives, competition among providers of finance; see Röell, 1996), that are magnified in the official list due to its greater liquidity and wider analyst coverage. Graduation represents an additional strategic options for entrepreneurs that wish to enact a multi-stage divestiture strategy.

Building on these premises, the goal of this article is to learn about the strategies of publicly listed firms by comparing the characteristics of firms that have followed different post-IPO trajectories, such as sell-out and graduation.

Junior stock markets, such as the iconic Alternative Investment Market (AIM) created in 1995 by the London Stock Exchange, pose challenges for the theory and practice of financial markets. Regulatory outsourcing is a rather controversial institutional innovation (Carpentier and Suret, 2012; Revest and Sapio, 2013a) and, perhaps relatedly, even the AIM has performed poorly in several respects, despite being the largest among junior stock markets. Negative results are highlighted regarding survival rates, operational performances, delisting rates, as well as the quality

of the firms involved in reverse mergers (Hornok, 2014; Revest and Sapio, 2014; Vismara et al., 2012), although one should not deny that listing on the AIM can also yield positive feedbacks for the listed firms, such as facilitating post-IPO capital raising (Hoque, 2011; Nielsson, 2013).

Our empirical analysis may then shed light on why thousand companies have listed on the AIM as well as in similar markets (such as Alternext in France, AIM Italy, AIM Japan). When it comes to new and small firms, light regulation (Jenkinson and Ramadorai, 2008; Rousseau, 2008) and growth motives are considered as important reasons for stock market flotation, but according to Davies (2011) and Fraser (2005), the majority of small firms seeking to go public do not view growth as a strategic goal. As suggested by the mentioned evidence on double track strategies, stronger emphasis should be placed on other corporate strategic motivations, related to the control and combination functions of stock markets, as defined by Lazonick (2007a).

If previous results of empirical studies on the AIM tend to show that the number of transferts from the AIM to the main list is sparse, and that the percentage of high-tech firms is rather low (Campbell and Tabner, 2014, and), it is compelling to know what are the characteristics of the companies that are acquired or that graduate, also for political purposes.

Drawing on data on AIM-listed companies since its inception (January 1995) to June 2009, we estimate how the probabilities of AIM-listed companies to graduate to the LSE Main Market or to be acquired change with their size and age measured at the time of introduction on AIM, as well as across sectors, conditional on aggregate trends and fluctuations that affect market valuation. Our modeling approaches encompass binary response and duration models, which are appropriate tools to analyze the probability and hazard rates of discrete events. Our findings show that the probabilities of acquisitions and graduations in a time horizon of 5 years after introduction are higher among the largest AIM-listed companies, that technology acquisitions are not more likely than acquisitions of companies in less technology-intensive sectors, and that graduations of companies in science-based sectors were almost entirely “helped” by the “new economy” fad of the late Nineties.

The remainder of the article is structured as follows. Part one reviews the empirical studies regarding the performance of the AIM as a stock market and of its listed companies. Part two discusses the graduation trajectory, i.e. a company transfer from a junior market to a main market. Part three considers the issue of post-IPO acquisitions. Part four presents the empirical analysis, including the dataset, the variables and the summary statistics. In part five, the econometric methods are briefly described and the results are interpreted. Part six concludes and illustrates some avenues for future research.

The AIM: a controversial junior stock market

The main organizational specificity of the AIM is a combination of low admission requirements with information disclosure processes centered on financial intermediaries assisting the issuers. AIM does not set any minimal initial requirements in terms of capitalization, assets, equity capital, trading history, and free float. Every company seeking admission on AIM, though, needs to appoint a Nominated Advisor (Nomad), who assesses the company's suitability for quotation by carrying out an examination of the applicants business and activities. Once the company is listed, Nomads have to ensure that the issuers supervised by them comply with the AIM listing rules. Although there are no mandatory corporate governance rules, Nomads may persuade their clients to align with the best practice. Nomads act as gatekeepers, advisers and, ultimately, regulators of AIM-listed companies (Mendoza, 2008).

Fast admission processes, as well as customized oversight and disclosure have contributed to the long term growth of the AIM in terms of issues and capitalization. During the last decade, AIM "replicas" have emerged all over the world, such as AIM Japan, AIM Italia, First North (Baltic countries), Toronto Venture Stock Exchange (Canada), New Zealand Alternative Exchange. Though, empirical works provide diverging results on the ability of the AIM to support SMEs, in regards to the survival rates of the listed companies, their financial health, as well as their real performances (e.g. growth in market shares and in productivity).

Triggered by the widespread perception of AIM as a "casino" (Roël Campos, quoted by Bawden and Waller, 2007), Espenlaub et al. (2012) find that between 1995 and 2004, around 10% of the listed companies have been delisted within 5 years after the IPO, for voluntary and administrative reasons (see also Gregory et al., 2010). The survival rate is on average higher for the AIM-listed companies assisted by larger (and presumably more reputable) Nomads. Consistently, the results in Gerakos et al. (2013) highlight the shorter time-to-failure of companies introduced on AIM with respect to those listing on other markets. Vismara et al. (2012) shed light on a 42% failure rate for the AIM, as compared to 20%-28% for other stock markets. Recent studies on the failure rates of UK firms include also spatial and industry effects: the AIM is dominated by London-based IPOs (Amini et al., 2012) and a higher failure rate is observed for financial companies in or near London (Amini and Keasey, 2013).

In parallel, relatively low stock returns and liquidity by AIM firms were underlined by Gerakos et al. (2013), Vismara et al. (2012), and Hoque (2011). Over the period 1995-2010, the post-listing returns in the 5 years after IPO, on average, was negative in AIM for all years, and positive for the main market of the London Stock Exchange. In addition, AIM companies produce lower dividends, are less likely to make acquisitions and more likely to be cancelled (Hoque, 2011). Along the same

lines, the results in Gerakos et al. (2013) for the period 1995-2008 were less than encouraging, finding lower post-listing returns than for similar companies listed on other markets, be it the LSE Main List, the Nasdaq, or the OTCBB (see also on this point Vismara et al., 2012). Even the AIM-listed fast growing firms were less likely to enjoy extra positive outcomes than firms listing on other exchanges. Yet, more promising and homogeneous results appear in regards to capital raising. AIM companies would encounter a higher probability to proceed to a capital increase than similar companies on the main list (Hoque, 2011; Vismara et al., 2012). The funds raised during one year by either IPO or capital increase on the AIM are shown to be larger on average than on markets in the USA or continental Europe (Nielsson, 2013).

Few empirical works deal with the influence of the AIM on company-level real performances. Colombelli (2009) found that the growth rate of companies listed on AIM between 1995 and 2006 is positively affected by the presence of intangible assets, as well as by the educational level and experience of the managing director. A link is also established between the quality of the innovation system, symbolized by the university patenting activity, and the growth rate of the listed companies (Cassia et al., 2009). A recent study highlights the differences between the growth rates of the AIM listed companies with those of similar privately-held companies - in terms of size, age and sectoral distribution, incorporated in the United Kingdom (Revest and Sapio, 2013b) and observed in the 1997-2009 period. After accounting for a selection effect, AIM-listed companies display an additional 10.6% growth rates (in terms of employees) compared with non-listed companies. Yet, for the AIM-listed companies growth in productivity - defined as added value per employee - appears to be lower (-20.7%). Hence, higher rates of job creation do not translate into stronger productivity growth.

However poorly may this market be in enhancing social welfare (as through net job creation and productivity growth), it may still prove effective from an issuer's point of view. The key insight here is that there is usually more to the listing decision than capital raising or real growth. According to Davies (2011) and Fraser (2005), most small firms seeking to go public do not view growth as a strategic goal. Stock markets perform control and combination functions (Lazonick, 2007), i.e. they are suited to enhance the transfer of control rights as they provide liquidity to issuers and traders. We focus on two ways in which the control and combination function can be exploited by issuers in junior stock markets: graduation to the main market and post-IPO company sale. The upcoming sections will discuss the theoretical insights and evidence on both trajectories.

Graduations from a junior stock market

Back in 1995, the AIM was conceived as feeder for the main list of the LSE, in an attempt to learn

from previously unsuccessful experiments such as the Unlisted Securities Market: promising companies would be temporarily floated on AIM, in view of a graduation to the LSE main market (Posner, 2009). In this perspective, the graduation rate can be taken as a measure of market performance. Through graduation, a company can prove it is ready to face a tighter regulatory setting. Such a signal may translate into lower cost of capital, may attract new investors and thus increase the shareholders base. Carpentier et al. (2010) is so far the most complete empirical study on graduations from a junior market: the TSXV, a segment of the Canadian Toronto Stock Exchange (TSX) catering to companies in the pre-revenue stage. In fact, the opportunity of graduation is presented by the TSX as an advantage of listing for prospective issuers. Indeed, from 1989 to 2006 included, 802 companies migrated from the TSXV to the main market, i.e. nearly 45 companies per year on average. Estimates of a probit model for the probability of graduation showed that larger companies and companies in high-tech and minerals were better positioned for a transfer to the main market. The estimated rate of graduation from the TSXV to the TSX main market in the 1986-2006 period, was 7.67% (including IPOs and back-door listings), higher than the rate of IPOs on the main exchange, seen as the exit rate for venture capital investments.

When it comes to AIM, the graduation record looks dismal. Between 1997 and 2009, only 55 companies moved from the AIM to the LSE, while, quite surprisingly, 210 companies switched from the LSE to the AIM (Campbell and Tabner, 2014). Companies switching from the LSE main list to AIM are relatively small by main market standards, credit constrained, and generate poor cash flows (Jenkinson and Ramadorai, 2008). More broadly, light regulation, moderately low admission fees, and an organization rather favorable to SMEs are the key motivations of the companies that move from the main list to the AIM (Campbell and Tabner, 2014). When the average company moves from the AIM towards the main market, ownership concentration declines, signaling that companies may seek graduation in order to enlarge their shareholder bases (Jenkinson and Ramadorai, 2008; Campbell and Tabner, 2014).

Post-IPO company sales

In focusing on company post-IPO sales, we implicitly conceive them as positive events in the life of a company – although this view may not be widely shared. The ambiguity of company sales was clear to Fama and French (2004), who noted how acquired companies can be strong or weak. Carpentier and Suret (2010) classified all mergers and acquisitions as non-survivors. In Espenlaub et al. (2012) acquired companies are classified as survivors only if highly ranked in terms of selected financial performance measures.

Our positive assessment of company sales relies on the entrepreneurial exit literature (Wennberg et

al., 2010). The entrepreneurial process, indeed, involves the exploration of various possible exit paths, the development of exit strategies, and the identification of potential successors. Consequently, exit is not seen as a systematically negative outcome, although it may appear so from an investor standpoint (Mason and Harrison, 2002; Parhankangas and Landström, 2006). An entrepreneur might run several firms concurrently as a portfolio entrepreneur (Westhead et al. 2005), or move from one firm to another as a serial entrepreneur (Toft-Kehler et al., 2013). Exit can be considered as the beginning of a new adventure (Ucbasaran et al., 2003).[i]

In line with this insight, Reuer and Shen (2004) argue that IPOs should not be considered as a "natural end state that address a financial objective", as the standard financial theory teaches us, but rather as an intermediate step in the company life, such as the first step in a sequential divestiture (Rock, 1994; Zingales, 1995). IPOs are often considered as a part of a larger process of transferring control rights in organizations (Mikkelson et al., 1997).

The role of IPOs in stimulating acquisitions raises the following question: why should a firm decide to incur the costs of an IPO instead of just selling the firm outright? Asymmetric information and adverse selection may provide answers. Privately-held firms tend to use sequential divestitures through IPOs rather than outright sales because IPOs improve the visibility of the firm for potential acquirers, and allow to partly overcome the difficulties for the sellers to obtain a selling price that reflects the business value (Reuer and Shen, 2004). Information asymmetry and adverse selection do exist for an IPO, but are less pronounced than for a private sale. Coffee (1999) has shown that in knowledge-intensive industries, M&As are more prolonged than in other industries and buyers tend to propose lower bid premia. Hence, IPO procedures can ease the valuation a company - even if IPO prices have at times contributed to price overvaluations, as during the Internet bubble.[ii]

In this vein, Reuer and Ragozzino (2008) investigated the role of alliances and IPOs in mergers and acquisitions during the period 1992-2002. They found that both alliances and IPOs positively influence mergers and acquisitions operations, by diminishing the transactions costs in the M&A markets and the risk of adverse selection. IPOs contribute to shape the evolution of the firms and can contribute to improve the liquidity of the market for corporate control. Consequently, some private firms decide to use the "dual-track" strategy of going public before a sale (Brau and Fawcett, 2006). Brau et al. (2010) and Mantecon and Thistle (2011), focusing on US takeovers in the periods 1995-2004 and 1996-2005, respectively, showed that companies selling outright earn lower sell-out premia than companies selling after the IPO completion or even pending the IPO process. These results are only partly due to self-selection of the most promising targets into the IPO market.

Dual-track strategies rooted in information asymmetries are also appropriate for the sale of high-

tech companies, whose assets are relatively hard to evaluate. Technology sourcing through acquisitions of entrepreneurial start-ups pertain to the innovation strategy of large and mature high-tech firms facing organizational inertia, competency traps, and technology competition (Desyllas and Hughes, 2009; Dushnitsky and Lenox, 2006; Graebner et al., 2010), as acquired firms can substitute for internal R&D (Blonigen and Taylor, 2010; Danzon et al., 2004). Knowing this, high-tech companies take active steps to become attractive acquisition targets (Lindholm, 1996). Decisions to sell seem to be guided by the will to gain access to critical resources, e.g. large scale manufacturing capabilities, distribution channels, or experienced managers (Graebner and Eisenhardt, 2004; Teece, 1986).

The evidence on dual track strategies helps making sense of the changing function of the stock market highlighted by the drop in IPO activity that has occurred since the outburst of the financial crisis in 2008 (Gao et al., 2013; Ritter et al., 2013), a drop that has been driven mainly by small firms both in Europe and in the US. In the British, French, German, and Italian main markets, the percentage of small firm IPOs has dropped from 38.2% (1995-2000) to 25.4% (2001-2011) (Ritter et al., 2013). While several explanations have been advanced, e.g. in Ritter (2013) and Ritter et al. (2013),[iii] this decline was partially offset by an increase in the number of acquisitions of privately-held companies and, notably, by an increase in the number of post-IPO acquisitions (table 5 in Ritter et al., 2013).

Empirical analysis

The empirical analysis performed in this paper seeks to learn about the characteristics that make firms more likely to graduate to the main market or to sell out after an IPO, conditional on their survival and controlling for aggregate trends and fluctuations that affect market valuation. We expect graduation to be a strategic choice mainly available to the larger and older AIM-listed companies, as they are the most suited to meet the main market listing requirements. Post-IPO sell-outs, if rooted in informational asymmetries, should instead be more attractive for younger and smaller firms, whose business projects are less easy to evaluate, and even more for companies in high-tech sectors, that are potential targets for technology acquisitions. Finding the opposite would cast doubts on the informational effectiveness of the market.

Data and variables

For the purposes of this paper, a dataset has been collected including balance-sheet data on 1531 companies listed on the AIM or delisted from it between January 1, 1995 and June 30, 2009 (sources: Osiris, Amadeus, http://www.londonstockexchange.com). Financial holdings are excluded

from the sample. For each company, the LSE website provides information about the AIM introduction date, the introduction type (IPO, introduction from the official listing, private placement), the delisting date, and the delisting reason (failures, takeovers, reverse takeovers, transfers).[iv] Among delisting events, we focus on graduations and sale of business, but as it will be clear, the other delisting types are taken into account as competing risks.[v]

Company characteristics of interest are size, age, and sector. Company size is measured here by using, alternatively, sales and total assets; both are commonly used proxies of firm size in industrial economics.[vi] Values of sales and total assets are deflated using sectoral deflators (source: Eurostat). Age at introduction is defined as the number of days elapsed between the incorporation date and the date of introduction on AIM. Size and age are expected to be highly relevant determinants of graduations. One reason is that, by construction, companies that are larger and older at the time of introduction on AIM are "closer" to satisfying the stricter listing and information disclosure requirements imposed by the main market (if not already able to meet them).[vii] Thus, in a given time frame, companies that start out larger and older are more likely to fill the gap that separates them from main market eligibility. Longer trade histories provide more data on which investors can assess the risk and value of the firm, and larger companies are more ready to put collateral, making it easier to find underwriter banks for a main market offer. Age is also a proxy for knowledge accumulation (Audretsch and Lehmann, 2005). Concerning takeovers, small and young firms are often thought to be more likely takeover targets, more in need to solicit rescue bidders, and less likely to successfully enact takeover defenses (Nuttall, 1999; Powell, 1997). However, agency problems related to the ownership-control separation are more likely to emerge in large firms, where managers would enjoy greater discretion, leading to underperformance and creating incentives for more competent managers to take over. By the same token, older firms could be more likely to attract takeovers as they are affected by greater organizational inertia (Davis and Stout, 1992).

In order to capture differences in technological opportunity and appropriability conditions, we rely on an extended version of the Pavitt (1984) taxonomy. The Pavitt taxonomy paints a multi-faceted picture of technology, taking account whether the main sources of innovation are internal or external, the degree of knowledge appropriability, and cost structures. A Pavitt-based classification of sectors includes four categories: science-based, specialized supplier, scale intensive, supplier-dominated.[viii] While originally meant to cover manufacturing, the Pavitt taxonomy has been subsequently extended to services (see the reviews in Archibugi, 2001; Peneder, 2003). We build upon Bogliacino and Pianta (2010) and, following some suggestions by Bessant and Tidd (2007), we further augment their classification to include NACE Rev. 1.1 sectors not covered by them.[ix]

The science-based category includes sectors such as software, telecommunications, and pharmaceuticals, that are the most interesting for our purposes. In terms of expected impact of technological intensity on firm trajectories, the main theoretical intuition is that, all else being equal, firms in high-tech sectors are less likely to survive, due to the substantive uncertainty and the information asymmetries associated with the innovation process. At the same time, larger R&D expenses may be interpreted by the market as low (short-term) performance, attracting takeover bids. The reviewed evidence on technology acquisitions provides further reasons why high-tech companies may delist through takeovers.

Additional sources of cross-firm heterogeneity are controlled for, namely: whether a company was incorporated in the UK ("UK incorporated" dummy), whether a company switched back from the LSE Main Market ("Introduction from LSE" dummy), and whether a company's Nomad acts also as a broker for the supervised company ("NomadBro" dummy). In line with the bonding hypothesis of Coffee (1999), companies that decided to move from the LSE Main Market to the AIM would do it in order to exploit a lighter regulatory setting. If so, there would be no reason for them to re-switch. The NomadBro dummy accounts for the fact that Nomads can at the same time act as brokers (the so-called Nomad-Bros) and auditors for the companies they supervise. Nomads can use their bargaining power to get better terms and enhance the liquidity of their client companies (see Mallin and Ow-Yong, 2010). This may make it easier for companies advised by Nomad-Bros to obtain a main market transfer for their supervised companies. Weak incentives and moral hazard may arise, too, since Nomads are hired and paid by the companies that they monitor.

Finally, the timing of introduction on AIM can make a difference for the subsequent firm trajectories. As observed by Coakley et al. (2007), stock market rallies make it easier for companies with low operating quality to go public. Indeed, when prices and trading volumes are high, financial markets are more ready to accept new listings, since underwriters are less hard to find in expansionary times. This should be even more true during financial bubbles, when market valuations drift away from fundamentals. The timing of AIM introduction may affect also the relationship between size, age, and the probability of transfers and takeovers. Size and age should matter less during expansionary times: capitalization growth inflated by speculative activities would benefit even firms with relatively small sales and assets. Finding relatively high graduation rates among smaller and younger companies that were introduced on AIM during a downturn would tell something about their quality. Indeed, it may be argued that companies entering shortly after a market crash, who nevertheless graduated before the setting of a new bubble, could avail themselves of high-potential projects or managerial abilities that allow them to survive despite the bearish market.

We therefore build two dummies: one for companies that had their AIM introduction between 1995 and 2000 (i.e. during the Internet bubble), and another for companies that had their AIM introduction right after the stock market crash of 2000 and before the on-set of the housing bubble (i.e. between 2001 and 2004 included). Such periods are identified by looking at the 3-year returns of the FTSE 100 Index, which was positive between 1995 and 2000 and between 2005 and 2008, negative between 2001 and 2004 and in 2009 (our calculations on LSE data). We use such dummies to build interaction terms with size and age. Yearly dummies and 3-years FTSE100 returns are also used as time controls to capture time variation in graduation and acquisition rates.

Summary statistics

For each year between 1995 and 2008, Table 1 (Appendix) reports the number of companies introduced on AIM, the average log-total assets, log-sales, and age of the new issuers, the composition of entrants by Pavitt sectors (in shares), and the shares of each year's entrants that, within 5 years of admission on AIM, were acquired and graduated.[x] All these data refer to our available sample. The time fluctuations of the variables can be made sense of by recalling that the observation period was characterized by two bubbles (the Internet bubble of the late Nineties and the housing bubble of 2007-2008). Consistently, the number of new admission on AIM boomed in 2000, then dropped when the bubble burst, only to reach even higher counts in 2004-2005. The recent decline is again explained with recessionary times. Average size and age values reported in the table suggest that, as the bubbles came near to their peaks, new entrants where younger and smaller. A clear decrease in average age occurred in 1999 and 2007. Average sales seem to drop more than average assets (e.g. in 1999-2000), perhaps because a fair share of new listings was made of companies still unable to generate enough sales from their assets.

The science-based and supplier-dominated are the most represented sectors. Unsurprisingly, the share of science-based entrants peaked at 40% in 2000, while new admissions from supplier-dominated sectors are apparently more frequent when the stock market goes down, e.g. 48% in 2002 and 58% in 2008. Finally, the time trends in company sales and graduations suggest an interesting characterization of the two bubbles. For companies that joined AIM in 1995, 1996, and 1997, it was more likely to subsequently transfer to the LSE main market (19% to 20% graduation rates), whereas being acquired was a more likely fate for firms introduced on AIM in the 2000s (31% of the 2005 entrants sold out eventually). The sectors more frequently involved in transfers were telecommunications, pharmaceuticals, software publishing, computer programming, and real estate agencies. All these sectors were among the main drivers in the last two bubbles. An interesting observation is that, while acquisitions of high-tech companies boomed during the

Internet bubble in most stock markets (see Inkpen et al., 2000; Lazonick, 2007a, 2007b), the same was not true for acquisitions of AIM-listed companies.

Results

Goal of the econometric analysis presented here is to understand the characteristics of AIM-listed companies that have been acquired or that have graduated to the LSE Main Market. Operationally speaking, we investigate the question of what characteristics of AIM-listed companies are able to statistically explain the probability of the events "AIM-listed company *i* was acquired within τ years after introduction" and "AIM-listed company *i* was granted admission to the LSE official list within τ years after introduction". In our analysis, we observe companies from the time of introduction on AIM onwards; we also assume that each firm experiences no more than one event, and that all events within a category can be treated as identical. The probabilities of acquisition and graduation are evaluated over a time horizon of 5 years. Considering a shorter window would increase the rarity of the events of interest, whereas more than 5 years would aggravate the censoring problems.

Binomial logit and single-event duration models

Tables 2 and 3 display Maximum Likelihood estimates of logit and duration models of acquisitions and graduations, respectively.[xi] In the logit model we relate the odds-ratio of a given event (acquisition, graduation) to a number of explanatory variables.[xii] Estimates of duration models, instead, provide information on the hazard function of the time-to-graduation and of the time-to-acquisition, i.e. the rate at which companies are acquired or graduate at a certain time, given that they were on the AIM list before (Van den Berg, 2000).[xiii] Time-to-graduation (time-to-acquisition) is defined as the number of days elapsing between introduction on AIM and graduation (acquisition). We focus on proportional hazard models, such as the Weibull model and the Cox model. Hazard functions in the proportional hazard models are shifted upwards or downwards depending on the values of the covariates, but have the same shape for different firms. An advantage of using the Weibull model is that it also belongs to the family of Accelerated Failure Time models, hence its coefficients admit an interpretation as marginal effects of the explanatory variables on the time-to-event.

According to the results on takeovers, size, age, and sectors all appear as important determinants. In particular, the coefficients of total assets and sales are positive and significant, with higher point estimates for companies that joined AIM in 2001-2004 (see columns (1) and (2) of Table 2, and all estimates of Table 3). This might suggest that the Internet bubble supplied the market with smaller takeover targets. When the FTSE returns are used as time controls (Table 2, columns (3) and (4)),

size variables retain their significance, but coefficients in the 1995-2000 and 2001-2004 periods are comparable in magnitude.[xiv] Older companies that entered in 1995-2000 seemed more likely to be acquired: Table 2 (first 2 columns) and Table 3 report positive and significant coefficients for age, 1995-2000. Age turns out to be not statistically significant in the specifications with FTSE returns. The coefficients for all the three sector classes that we consider are positive, with varying significance. Since we have left out scale-intensive sectors, one concludes that acquisitions on AIM were quite diversified across sectors, with the exception of firms in sectors characterized by economies of scale, with intermediate degrees of appropriability of new knowledge. In a way, such evidence indicates that AIM patterns of acquisitions were rather diversified, with no specific focus on technology acquisitions, such as those in science-based sectors.

Results on graduations are displayed in Table 4 (logit) and Table 5 (Weibull and Cox). Size is a key determinant of graduations too, as expected. Also here, the estimates suggest that the advantage of larger entrants in achieving transfers was larger during the downturn of 2001-2004, which is consistent with the intuition that, when the economy slows down, it is much harder for smaller companies to grow. Yet again, changing the time control from yearly dummies to FTSE returns blurs the results. Bad news for young companies is brought by the estimates of the age coefficients, which are never significant. On the contrary, the science-based sector dummy is the only significant one, consistent with the technological origin of the late Nineties bubble. Interestingly, the NomadBro dummy is significant and positive in one instance, albeit weakly (Table 4, column (3)). Notice that the "Introduction from LSE" dummy is dropped because, in our sample, none of the companies that switched to AIM from the LSE main market would eventually go back.

All the estimated logit models perform nicely, as they correctly predict a high percentage of cases, and the results of the Hosmer-Lemeshow tests for model specification are positive. The tests on the Weibull shape coefficients reject the null of an exponentially-distributed baseline hazard. It is worth noting that, since the Weibull model admits also an accelerated time failure representation, the reported estimates also mean that larger companies spent less time on AIM before being acquired or before graduating.

Robustness I: multiple events and competing risks

The foregoing results are based on the untested assumption that the companies not involved in either takeovers or transfers – that is, those that stayed listed and those involved in reverse takeovers, bankruptcy, and voluntary delistings - share the same characteristics. One can however consider all the latter events as competing with graduations and takeovers. In other words, at each time a company is potentially subject to more than one event, and the occurrence of any of those

events prevents the occurrence of the others (in the most trivial example, bankruptcy prevents transfers and takeovers). More general models are called for, such as the Multinomial Logit model (MNL) and a duration model with competing risks.

The MNL model treats the delisting events as belonging to separate categories, namely transfers, takeovers, reverse takeovers, failures, and a residual category including companies that stay listed until the end of the sample period. Duration models with competing risks answer to the following question: What is the probability that companies stay listed on AIM until time *t* and then, when they are delisted, it is because of graduation or takeover?

Tables 6 and 7 show the estimates of the multinomial logit model and the competing risk model, respectively. Table 6 only focuses on a specification with total assets and yearly dummies, for the sake of brevity. Size is again a positive and significant influence on acquisitions and graduations, and its increasing weight after the 2000 bubble crash is confirmed (the size, 2001-2004 estimates are larger than the size, 1995-2000 estimates). Reverse takeovers, on the contrary, are more frequent among small firms, while surprisingly no negative size effect is found for failures.[xv] Age is positive and significant for acquisitions for companies that joined AIM during the Internet bubble (1995-2000), and does not affect graduations. Since the age coefficients are negative and significant for reverse takeovers and failures, we have an explanation why younger firms are not more likely than older ones to graduate. Sectoral results found in logit and models are confirmed. Table 7 reports results on acquisitions and graduations together, for both size proxies, using yearly dummies. These results are in line with those based on basic Cox and Weibull models.

Robustness II: separation, rarity and censoring

Further robustness checks are proposed hereby, with a view to taking care of some econometric problems: complete separation of the sample, rarity of the graduation events, censoring, and unobserved heterogeneity. Complete separation of the sample occurs because companies that switched from the LSE Official List to AIM did not switch back during our observation period. Hence, the probability of graduation, conditional on entry from LSE, is zero for all companies, and maximum likelihood algorithms fail to converge. Instead of dropping the LSE dummy from the logit specification, we keep it and use the penalized likelihood estimator introduced by Firth (1993) as suggested by Heinze and Schemper (2002). The results in Table 8, which refer to graduations only, confirm the evidence of size effects increasing during the 2001-2004 downturn, the lack of age effects, and the prominence of science-based firms among transfers. Thus, the main difference with previous specifications is that now the "Introduction from LSE" dummy is estimated, and its coefficient is negative as expected.

Rarity of the graduation events (as testified by Table 1) can have a number of unpleasant implications for the estimates, such as: low power, as the standard error of the log of relative risk of an event, for a given sample size, increases with its rarity, especially if occurrence falls below 5% (Cunningham and Lindenmayer, 2005); amplification of small-sample biases in estimated coefficients, and downward bias of the probability of the rare event (King and Zeng, 2001). We therefore implement King and Zeng's (2001) correction (relogit package in Stata) when the dependent variable is the graduation probability. Estimates are in Table 9. Notice that the FTSE returns variable is used as a time control instead of yearly dummies that had to be dropped because of computational problems. Nevertheless, the increasing size effect is confirmed in three out of four specifications. Most interestingly, now the age variable for companies admitted in 2001-2004 is negative and significant. We have checked companies admitted in that period, to find that among them, 12 managed to graduate. Out of such 12 companies, 7 graduated after 2004, in a period when the housing bubble made life easier, while 5 graduated rather quickly even before the on-set of the new bubble. The ability of listing on AIM shortly after the burst of the Internet bubble and of graduating to the LSE main market even without benefiting from the overvaluations of the subsequent bubble may testify to the good quality of those companies or to the strategic use of graduation – at least at a conjectural level.

Finally, a censoring problem arises because some of the sampled companies may have experienced delisting events after the end of our observation period (i.e. after June 2009). Furthermore, any company introduced on AIM after June 2004 was observed for less than 5 years, that is, for less than the window used in our logit analysis. Following Dubin and Rivers (1989), this would under-

represent delistings that occurred in the 2000s. The ensuing biases and inconsistency of the estimates are cured by means of a Heckman probit model. This is a two-stage estimation method: in the first stage, one regresses a dummy (1 if for uncensored, 0 for censored observations) on a set of variables, in our case size and time dummies ("selection equation"); in the second stage, the inverse Mill's ratio from the first stage is included as an explanatory variable in a probit model of the probability of the event of interest ("outcome equation"). Results are in Tables 10 (acquisitions) and 11 (graduations).[xvi] While results for acquisitions are basically confirmed, we again find negative coefficients for age during 2001-2004 when time is controlled for by yearly dummies. Interestingly, NomadBros exert a positive influence on graduations positive for (see columns (3) and (4) in Table 11).

Conclusion

For some time, European policy-makers have hoped to find a European Nasdaq. Regulatory outsourcing and the deregulation of the flotation process may have shown the way by allowing essentially any firm to go public. This is the core concept of the AIM, the largest junior stock market in Europe. Firm types that were traditionally out of the stock market have thus been offered an additional option for their financial sourcing, but there may be more to the listing decision than capital raising. Analyzing the trajectories of the AIM-listed companies in the form of post-IPO company sales and graduations to the LSE main market can be very informative on the strategic motives behind stock market flotation. Estimates of binomial and multinomial logit models, as well as duration models, show that the probabilities of graduations and post-IPO company sales in a time horizon of 5 years after introduction are higher among the largest AIM-listed companies, that post-IPO company sales are not more likely in high-tech than in less technology-intensive sectors, and that graduations of companies in science-based sectors were almost entirely "helped" by the "new economy" fad of the late Nineties.

A number of lessons can be learned from this study. First, younger and smaller AIM-listed companies are not likely to graduate, suggesting that a graduation strategy, if any, is pursued over relatively long horizons. However, the AIM is characterized by a lower number of graduations than other junior markets, such as the TSXV (Carpentier et al., 2010), casting doubts on the very adoption of graduation strategies by AIM-listed companies. The institutional reasons why AIM and TSXV behave so differently with respect to graduations are worth inquiring. One may argue that unfavorable macroeconomic scenarios may have discouraged graduations; indeed, during the expansionary years, graduations were more frequent, at least for companies belonging to the science-based sectors; and size was an advantage during the 2001-2004 downturn. Yet, we are

unsure whether this can be generalized to any macroeconomic expansion, or there was something to the Internet bubble that made graduations particularly suitable.

Second, post-IPO sales are relatively frequent on AIM, consistent with evidence in Reuer and Shen (2004) and Ritter et al. (2013). Thus he dual track strategy of going public before a sale finds application on junior stock markets, too. Despite the alleged lack of transparency of the junior market architecture, it still manages to provide visibility valuable enough for relatively opaque companies. Information produced by the junior stock market, however, is probably not enough to overcome the uncertainty surrounding high-tech projects. Indeed, acquisitions of AIM-listed companies are diversified across sectors, so there is no bonus for high-tech sectors. AIM-listed companies may have been acquired within a technology sourcing strategy, but overall this does not seem to be the prevailing motive. It may as well be that founders of high-tech companies quoted on AIM are control averse, i.e. they prefer to retain independence. Notice also that age is a stronger determinant of post-IPO company sales than of graduations, suggesting that, although companies may go public *in order to* sell out, a dual track strategy is not adopted early in the company life cycle, i.e. when information asymmetries are wider.

It can be useful to interpret these results in light of recent studies on reverse takeovers, which tend to show that a lemon market can emerge if the regulation is not binding enough (Carpentier and Suret, 2011; Kashefi-Pour and Lasfer, 2011; Roosenboom and Vasconcelos, 2010). Our evidence is also consistent with existing accounts of the shifting balance between innovation support and financialization, a hot issue in these years (Lazonick, 2007a; Dore, 2008; Lazonick and Mazzucato, 2013). The link between the innovative firm and stock markets has been analyzed in detail by O'Sullivan (2000) and Lazonick (2007a, 2007b), showing that "new economy" start-ups of the Eighties and Nineties had little resort, if any, to the stock market as a source of funds.

All in all, the AIM appears to be mostly a show-room for company sales in which, however, smaller, younger, and high-tech companies are not prominently featured. This may call for a rather pessimistic view on the ability of AIM to support new and small firms, unless we recall that the freedom to go public, guaranteed by junior stock markets, does not undermine the freedom of smaller, younger, and high-tech companies to pursue their strategic goals *outside* of the stock market.

Our results lead us to focus on the demand side and on the quality of small high-tech firms that go public. The most promising high-tech SMEs must be acquired before the IPO (Carpentier et al., 2014). This calls for more in depth reflection on policy support. Firstly, not all the so-called start-ups should be sustained by public policies, only the "true" gazelles (Nightingale and Coad, 2014). Secondly, following Mason and Brown (2013), current forms of public support must be

reconsidered in order to better take into account the firm specificities and heterogeneity, and to best adapt the financing by stock markets for preserving the independence of SMEs.

Future research may enlarge the scope to some more recently established junior stock markets, rooted in widely different financial systems than the UK (e.g. markets in Scandinavian countries and in Japan) and, in addition, track the post-IPO evolution of size, age, technological intensity, and capital structure of the listed companies. Indeed, firms after going public undergo significant organizational changes, which may improve (or diminish) their likelihood to transfer or be acquired with respect to the chances they had at introduction time. Panel methods could be employed in order to capture the time-changing weight of company sale and graduation determinants.

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Appendix A

An extended Pavitt taxonomy for manufacturing, agriculture, and services (building on Bogliacino and Pianta, 2010).

	NACE Rev. 1.1 2-digit Codes
Science-Based	
Chemicals	24
Office machinery	30
Manufacture of radio, television and communication equipment and apparatus	32
Manufacture of medical, precision and optical instruments, watches and clocks	33
Communications	64
Computer and related activities	72
Research and development	73
Specialised Suppliers	
Mechanical engineering	29
Manufacture of electrical machinery and apparatus n.e.c.	31
Manufacture of other transport equipment	35
Real estate activities	70
Renting of machinery and equipment	71
Other business activities	74
Scale intensive	
Pulp, paper and paper products	21
Printing and publishing	22
Mineral oil refining, coke and nuclear fuel	23
Rubber and plastics	25
Non-metallic mineral products	26
Basic metals	27
Motor vehicles	34
Financial intermediation, except insurance and pension funding	65
Insurance and pension funding, exc, compulsory social security	66
Activities auxiliary to financial intermediation	67
Supplier Dominated	
Agriculture, hunting, and forestry	01-02
Fishing	05
Mining and quarrying	11-12-13-14

Food, drink and tobacco	15-16
Textiles	17
Clothing	18
Leather and footwear	19
Wood and products of wood and cork	20
Fabricated metal products	28
Furniture, miscellaneous manufacturing; recycling	36-37
Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel	50
Wholesale trade and commission trade, except of motor vehicles and motorcycles	51
Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods	52
Hotels and catering	55
Inland transport	60
Water transport	61
Air transport	62
Supporting and auxiliary transport activities; activities of travel agencies	63
Public administration and defence; compulsory social security	75
Education	80
Health and social work	85
Sewage and refuse disposal, sanitation and similar activities	90
Recreational, cultural, and sporting activities	92
Other service activities	93

Table 1. Summary statistics by year: number of AIM introductions; average log-size, average age, sectoral composition of the entrants; percentages of entrants that were acquired and graduated within 5 years of AIM introduction.

Years	Entrants	Log Tot. assets	Log Sales	Age	Sc.-based	Scale-intens.	Spec.-supplier	Supplier-dom.	Acq.	Grad.
	(n.)	(avg.)	(av.g)	(avg. yrs)	(%)	(%)	(%)	(%)	(%)	(%)
1995	40	n.a.	n.a.	11.32	0.25	0.18	0.13	0.45	0	0.2
1996	57	9.02	8.34	7.42	0.32	0.19	0.18	0.32	0	0.19
1997	47	8.83	8.32	9.82	0.38	0.15	0.11	0.36	0	0.19
1998	44	9.08	9.04	6.45	0.30	0.02	0.21	0.48	0.05	0.05
1999	41	8.87	8.12	4.95	0.39	0.15	0.22	0.24	0.07	0.05
2000	165	9.08	7.73	7.57	0.40	0.09	0.18	0.33	0.09	0.01
2001	120	9.00	8.25	12.83	0.24	0.14	0.23	0.39	0.08	0.02
2002	103	8.94	8.12	14.56	0.23	0.14	0.16	0.48	0.13	0.01
2003	102	9.13	8.82	17.55	0.26	0.17	0.12	0.46	0.17	0.05
2004	203	8.99	8.56	6.24	0.32	0.12	0.20	0.36	0.13	0.03
2005	270	9.12	8.47	6.82	0.27	0.14	0.18	0.41	0.31	0.02
2006	196	9.48	8.33	7.81	0.26	0.19	0.25	0.30	0.21	0.02
2007	115	9.95	8.55	4.63	0.24	0.20	0.24	0.31	0.11	0
2008	26	10.47	10.04	19.06	0.19	0.12	0.12	0.58	0.15	0

Table 2. Logit estimates of the acquisition probability: AIM-listed companies.

Acquisitions, logit	**(1)**	**(2)**	**(3)**	**(4)**
Total assets	0.886***		0.586***	
	(7.30)		(9.46)	
Total assets, 1995-2000	0.221***		0.502***	
	(8.00)		(9.46)	
Total assets, 2001-2004	0.479***		0.477***	
	(8.04)		(7.35)	
Sales		0.572***		0.493***
		(8.42)		(8.35)
Sales, 1995-2000		0.250		0.370***
		(0.63)		(7.34)
Sales, 2001-2004		0.461***		0.077
		(9.93)		(0.71)
Age	0.193**	0.093	0.206**	0.125
	(2.46)	(1.44)	(2.51)	(1.47)
Age, 1995-2000	0.205***	0.235***	0.125	0.077
	(2.67)	(2.86)	(1.38)	(0.71)
Age, 2001-2004	0.010	-0.093	0.032	-0.094
	(0.08)	(0.80)	(0.31)	(-0.88)
Science-based	1.737**	1.781*	1.670**	1.726*
	(2.25)	(1.87)	(1.99)	(1.76)
Specialized supplier	1.359**	1.506*	1.302**	1.420*
	(2.19)	(1.91)	(2.17)	(1.93)
Supplier-dominated	1.675***	1.856**	1.476***	1.682**
	(3.03)	(2.32)	(2.72)	(2.22)
UK incorporated	-0.228	-0.772***	-0.240	-0.588**
	(-0.99)	(-3.77)	(-0.73)	(-2.05)
LSE	0.246	0.279	0.155	0.242
	(0.38)	(0.39)	(0.21)	(0.31)
1998	12.234***	12.493***		
	(11.66)	(11.85)		
1999	13.605***	13.861***		
	(12.89)	(13.08)		
2000	13.492***	13.805***		

	(12.83)	(12.99)		
2001	12.534***	12.417***		
	(9.03)	(9.79)		
2002	12.956***	12.512***		
	(9.15)	(9.78)		
2003	13.070***	12.807***		
	(9.04)	(9.97)		
2004	12.995***	12.720***		
	(9.57)	(10.08)		
2005	9.202***	11.846***		
	(5.92)	(8.84)		
2006	7.934***	10.829***		
	(4.84)	(7.96)		
2007	6.099***			
	(3.32)			
2008	9.693***	12.704***		
	(5.50)	(7.94)		
FTSE 3-year returns			-2.545***	-2.204***
			(-4.59)	(-3.57)
NomadBro			0.020	0.077
			(0.08)	(0.35)
Constant	-20.669***	-18.871***	-8.345***	-6.516***
	(-12.53)	(-10.95)	(-7.96)	(-5.03)
Observations	798	662	661	561
Hosmer-Lemeshow test	6.97 (0.540)	5.88 (0.661)	7.88 (0.445)	6.33 (0.610)
% correct prediction	86.3	85.7	85.9	84.9
Predicted prob(acq.)	0.174 (0.191)	0.201 (0.208)	0.196 (0.175)	0.208 (0.193)

Robust z-statistics in parentheses, except: Hosmer-Lemeshow test (p-value), predicted probability (standard error). Legend: *** p<0.01, ** p<0.05, * p<0.1

Table 3. Duration models of the acquisition hazard: AIM-listed companies.

Acquisitions, duration models	**Cox**	**Cox**	**Weibull**	**Weibull**
Total assets	0.654***		0.652***	
	(5.08)		(5.00)	
Total assets, 1995-2000	0.188***		0.188***	
	(6.08)		(6.49)	
Total assets, 2001-2004	0.479***		0.485***	
	(8.71)		(9.47)	
Sales		0.410***		0.410***
		(8.63)		(8.33)
Sales, 1995-2000		0.044		0.044
		(1.34)		(1.30)
Sales, 2001-2004		0.427***		0.433***
		(14.10)		(13.94)
Age	-0.03	-0.150*	-0.031	-0.149*
	(-0.35)	(-1.85)	(-0.33)	(-1.82)
Age, 1995-2000	0.178***	0.192***	0.181***	0.195***
	(2.77)	(2.47)	(2.78)	(2.46)
Age, 2001-2004	-0.005	-0.098	-0.007	-0.102
	(-0.05)	(-1.03)	(-0.07)	(-1.07)
Science-based	1.366***	1.322**	1.370***	1.329**
	(2.69)	(2.02)	(2.67)	(2.02)
Specialized supplier	0.940**	0.941	0.940*	0.947
	(1.98)	(1.64)	(1.95)	(1.63)
Supplier-dominated	1.079**	1.196*	1.081**	1.208*
	(2.55)	(1.94)	(2.53)	(1.94)
UK incorporated	0.052	-0.332	0.050	-0.340
	(0.18)	(-1.39)	(0.17)	(-1.38)
Introduction from LSE	0.203	0.247	0.196	0.236
	(0.36)	(0.38)	(0.34)	(0.36)

1997	-18.056***	-17.129***	-0.054	-0.126
	(-9.43)	(-13.76)	(-0.04)	(-0.09)
1998	21.997***	23.015***	12.425***	14.849***
	(13.56)	(32.31)	(11.91)	(14.21)
1999	23.418***	24.524***	13.862***	16.371***
	(14.43)	(37.80)	(13.18)	(15.58)
2000	23.188***	24.327***	13.636***	16.175***
	(14.20)	(34.41)	(13.06)	(15.45)
2001	21.987***	23.268***	12.404***	15.091***
	(13.15)	(45.26)	(9.72)	(12.34)
2002	22.212***	23.161***	12.634***	14.984***
	(12.85)	(44.32)	(9.65)	(12.35)
2003	22.453***	23.584***	12.894***	15.439***
	(12.77)	(43.46)	(9.74)	(12.68)
2004	22.303***	23.429***	12.736***	15.266***
	(13.30)	(45.09)	(10.07)	(12.49)
2005	20.576***	23.766***	11.059***	15.610***
	(100.49)	(227.24)	(6.18)	(12.36)
2006	19.388***	22.773***	9.855***	14.600***
	(99.27)	(289.77)	(5.48)	(11.63)
2007	17.424***	-18.293***	7.889***	-1.321
	(98.23)	(-17.51)	(4.34)	(-0.80)
2008	18.524	22.142	8.989***	13.963***
			(4.63)	(10.99)
Constant			-33.116***	-33.866***
			(-14.24)	(-13.81)
Observations	1228	1006	1228	1006
Weibull shape parameter			1.738 (0.575)	1.726 (0.210)

Robust z-statistics in parentheses, except for the Weibull shape parameter (standard error). Legend: *** p<0.01, ** p<0.05, * p<0.1

Table 4. Logit estimates of the graduation probability: AIM-listed companies.

Graduations, logit	**(1)**	**(2)**	**(3)**	**(4)**
Total assets	0.503*		0.985***	
	(1.66)		(2.81)	
Total assets, 1995-2000	0.338***		1.195***	
	(4.52)		(3.89)	
Total assets, 2001-2004	1.523**		1.144***	
	(4.36)		(5.09)	
Sales		-0.014		0.445
		(-0.03)		(1.26)
Sales, 1995-2000		0.103		0.466***
		(1.51)		(2.45)
Sales, 2001-2004		0.948***		0.626***
		(8.15)		(7.90)
Age	0.209	0.236	0.199	0.069
	(0.69)	(0.47)	(0.43)	(0.14)
Age, 1995-2000	-0.180	-0.203	0.084	0.149
	(-1.13)	(-1.47)	(0.37)	(0.90)
Age, 2001-2004	0.119	0.045	0.215	-0.014
	(0.82)	(-0.28)	(1.62)	(-0.12)
Science-based	3.310***	2.906*	3.109*	1.731
	(2.64)	(1.84)	(1.91)	(1.29)
Specialized supplier	1.986**	1.828	2.031	0.780
	(1.98)	(1.25)	(1.36)	(0.59)
Supplier-dominated	1.707*	1.390	1.500	0.256
	(1.71)	(0.90)	(0.87)	(0.18)
UK incorporated	-0.241	-0.543		
	(-0.39)	(-1.20)		
1997	-0.633***	-0.525***		
	(-6.56)	(-4.03)		
1998	-2.318***	-2.339***		

	(-13.08)	(-12.31)		
1999	-2.471***	-2.225***		
	(-7.63)	(-8.61)		
2000	-4.616***	-4.224***		
	(-16.10)	(-17.89)		
2001	-16.757***	-11.935***		
	(-3.91)	(-5.25)		
2002	-16.954***	-12.366***		
	(-3.97)	(-5.46)		
2003	-15.657***	-10.682***		
	(-3.64)	(-4.55)		
2004	-16.611***	-12.698***		
	(-3.87)	(-5.28)		
2005	-7.266***	-4.799***		
	(-5.54)	(-3.16)		
2006	-7.393***	-4.702***		
	(-4.93)	(-2.86)		
FTSE 3-years return			1.220	1.005
			(0.58)	(0.42)
NomadBro			2.268*	1.911
			(1.65)	(1.56)
Constant	-4.723***	-1.760	-19.792***	-11.208***
	(-2.84)	(-1.01)	(-4.84)	(-5.65)
Observations	689	570	503	418
Hosmer-Lemeshow test	9.05 (0.338)	6.21 (0.624)	3.22 (0.920)	13.98 (0.082)
% correct prediction	95.1	94.7	97.0	96.4
Predicted prob(grad.)	0.040 (0.091)	0.051 (0.092)	0.027 (0.060)	0.034 (0.052)

Robust z-statistics in parentheses, except: Hosmer-Lemeshow test (p-value), predicted probability (standard error). Legend: *** p<0.01, ** p<0.05, * p<0.1

Table 5. Duration models of the graduation hazard: AIM-listed companies.

Graduations, duration models	**Cox**	**Cox**	**Weibull**	**Weibull**
Total assets	0.639*		0.639*	
	(1.91)		(1.91)	
Total assets, 1995-2000	0.338***		0.328***	
	(5.41)		(4.95)	
Total assets, 2001-2004	1.470***		1.333***	
	(5.66)		(8.34)	
Sales		0.041		0.041
		(0.09)		(0.09)
Sales, 1995-2000		0.112***		0.110***
		(2.65)		(2.85)
Sales, 2001-2004		0.984***		0.981***
		(6.36)		(6.27)
Age	0.125	0.050	0.120	0.034
	(0.64)	(0.14)	(0.63)	(0.10)
Age, 1995-2000	-0.136	-0.161	-0.136	-0.159
	(-0.97)	(-1.31)	(-0.95)	(-1.26)
Age, 2001-2004	0.113	-0.031	0.160	-0.016
	(1.04)	(-0.27)	(1.26)	(-0.15)
Science-based	2.735**	2.984*	2.747**	3.085*
	(2.17)	(1.91)	(2.19)	(1.95)
Specialized supplier	1.526	1.885	1.520	1.960
	(1.30)	(1.20)	(1.28)	(1.23)
Supplier-dominated	1.299	1.539	1.288	1.566
	(1.18)	(0.99)	(1.20)	(1.02)
UK incorporated	-0.092	-0.440	-0.161	-0.588
	(-0.15)	(-0.96)	(-0.24)	(-1.18)
Introduction from LSE	-46.984	-36.654***	-17.543***	-17.428***
	(.)	(-39.52)	(-23.42)	(-17.34)
1997	-0.485***	-0.470***	-0.531***	-0.518***
	(-8.60)	(-7.19)	(-6.91)	(-8.27)
1998	-1.816***	-1.885***	-1.912***	-1.991***
	(-16.52)	(-18.18)	(-14.52)	(-17.66)

1999	-1.851***	-1.554***	-1.912***	-1.640***
	(-11.07)	(-16.15)	(-10.04)	(-14.95)
2000	-4.042***	-3.698***	-4.110***	-3.779***
	(-30.09)	(-41.88)	(-26.77)	(-38.54)
2001	-15.297***	-11.050***	-14.292***	-11.166***
	(-4.97)	(-5.64)	(-5.90)	(-5.56)
2002	-15.829***	-11.626***	-14.611***	-11.657***
	(-4.90)	(-5.64)	(-6.13)	(-5.66)
2003	-14.258***	-9.378***	-13.408***	-9.371***
	(-4.41)	(-4.58)	(-5.21)	(-4.63)
2004	-15.377***	-11.740***	-14.223***	-11.805***
	(-4.72)	(-5.64)	(-5.70)	(-5.57)
2005	-8.070***	-4.063***	-8.193***	-4.053***
	(-4.24)	(-2.74)	(-4.16)	(-2.74)
2006	-8.739***	-4.547***	-8.929***	-4.616***
	(-4.01)	(-3.13)	(-3.99)	(-3.17)
2007	-52.670***	-39.324***	-24.426***	-19.417***
		(-20.88)	(-9.86)	(-10.22)
2008	-51.500***	-38.573***	-24.373***	-18.811***
		(-16.53)	(-9.80)	(-7.94)
Constant			-17.705***	-14.137***
			(-6.25)	(-5.19)
Observations	1228	1006	1228	1006
Weibull shape parameter			1.725 (0.579)	1.555 (0.201)

Robust z-statistics in parentheses, except for the Weibull shape parameter (standard error). Legend: *** p<0.01, ** p<0.05, * p<0.1

Table 6. Multinomial logit estimates for acquisition, graduation, reverse takeover, and failure probabilities: AIM-listed companies.

Multinomial logit	Acquisitions	Graduations	Reverse takeovers	Failures
Total assets	0.686***	0.658**	-0.267***	-0.078
	(5.92)	(2.03)	(-3.58)	(-1.11)
Total assets, 1995-2000	0.159***	0.303**	-0.179	-0.278
	(2.20)	(2.36)	(-1.65)	(-1.64)
Total assets, 2001-2004	0.446**	1.537***	-0.293**	-0.050
	(7.06)	(5.73)	(-2.36)	(-0.48)
Age	-0.042	0.096	-0.457***	-0.215***
	(-0.53)	(0.49)	(-4.19)	(-4.91)
Age, 1995-2000	0.075	-0.240	-0.102	0.024
	(0.53)	(-1.32)	(-1.53)	(0.30)
Age, 2001-2004	-0.033	0.053	-0.098*	-0.100***
	(-0.35)	(0.57)	(-1.80)	(-3.71)
Science-based	1.113**	3.351***	-0.260	-0.091
	(2.52)	(3.15)	(-1.00)	(-0.26)
Specialized supplier	0.776*	2.408**	-0.077	-0.179
	(1.82)	(2.22)	(-0.26)	(-0.57)
Supplier-dominated	0.817**	2.004**	-0.483*	0.269
	(2.19)	(2.08)	(-1.91)	(1.13)
Introduction from LSE	-0.165	-0.077	1.131*	0.022
	(-0.53)	(-0.10)	(1.81)	(0.07)
UK incorporated	0.147	-16.418***	0.283	0.211
	(0.28)	(-20.02)	(0.55)	(1.11)
1997	0.643***	-0.389***	1.335***	0.378***
	(15.27)	(-4.94)	(21.63)	(9.22)
1998	0.741***	-1.566***	1.482***	0.417***
	(14.19)	(-13.14)	(15.48)	(4.97)
1999	0.408**	-1.727***	1.378***	0.689***
	(2.06)	(-5.58)	(14.33)	(5.12)

2000	0.590***	-4.243***	1.495***	0.840***
	(5.69)	(-18.75)	(12.09)	(8.93)
2001	-2.016	-17.296***	1.750	-1.241
	(-1.32)	(-4.39)	(1.36)	(-0.59)
2002	-1.824	-16.607***	1.592	-1.172
	(-1.19)	(-4.26)	(1.26)	(-0.56)
2003	-1.730	-16.092***	1.723	-0.946
	(-1.13)	(-4.06)	(1.37)	(-0.45)
2004	-2.248	-17.212***	1.303	-1.323
	(-1.46)	(-4.36)	(1.01)	(-0.63)
2005	-4.954**	-10.004***	2.611**	-0.919
	(-2.50)	(-4.05)	(2.16)	(-0.47)
2006	-6.417***	-10.919***	1.968	-1.122
	(-3.17)	(-4.07)	(1.58)	(-0.57)
2007	-8.471***	-25.807***	1.916	-2.024
	(-4.10)	(-8.77)	(1.54)	(-1.02)
2008	-7.241***	-26.033***	1.775	-17.653***
	(-3.45)	(-9.06)	(1.38)	(-7.98)
Constant	-3.686*	-3.490	-0.256	1.269
	(-1.92)	(-1.42)	(-0.23)	(0.61)
Observations	1228	1228	1228	1228
Predicted probabilities	0.126 (0.100)	0.031 (0.086)	0.143 (0.105)	0.157 (0.075)

Robust z-statistics in parentheses, except for predicted probabilities (standard deviation). Legend: *** p<0.01, ** p<0.05, * p<0.1

Table 7. Estimates of competing risk models of acquisition and graduation hazards: AIM-listed companies.

Competing risks models	Acquisitions	Acquisitions	Graduations	Graduations
Total assets	0.654***		0.595**	
	(5.98)		(1.98)	
Total assets, 1995-2000	0.187***		0.335***	
	(8.03)		(5.66)	
Total assets, 2001-2004	0.392***		1.495***	
	(8.01)		(5.40)	
Sales		0.418***		0.030
		(9.19)		(0.07)
Sales, 1995-2000		0.032		0.103**
		(1.08)		(2.21)
Sales, 2001-2004		0.385***		0.974**
		(11.94)		(6.24)
Age	0.015	-0.104	0.146	0.088
	(0.20)	(-1.57)	(0.68)	(0.25)
Age, 1995-2000	0.206***	0.226***	-0.125	-0.143
	(3.28)	(3.20)	(-0.97)	(-1.30)
Age, 2001-2004	0.050	-0.050	0.121	-0.038
	(0.50)	(-0.51)	(1.06)	(-0.31)
Science-based	1.380**	1.377*	2.775**	2.895*
	(2.41)	(1.92)	(2.31)	(1.87)
Specialized supplier	0.941*	0.983	1.588	1.841
	(1.91)	(1.63)	(1.47)	(1.21)
Supplier-dominated	1.152**	1.255*	1.316	1.421
	(2.41)	(1.91)	(1.28)	(0.92)
UK incorporated	0.035	-0.382*	-0.134	-0.427
	(0.12)	(-1.68)	(-0.24)	(-1.03)
Introduction from LSE	0.149	0.212	-18.802***	-23.373***
	(0.29)	(0.37)	(-25.85)	(-23.79)
1997	-0.055	-0.120	-0.484***	-0.443***

	(-0.04)	(-0.08)	(-8.10)	(-6.51)
1998	12.603***	14.026***	-1.938***	-1.962***
	(12.09)	(13.44)	(-21.26)	(-20.57)
1999	13.843***	15.292***	-2.026***	-1.775***
	(13.20)	(14.59)	(-12.04)	(-17.12)
2000	13.785***	15.270***	-4.178***	-3.801***
	(13.20)	(14.58)	(-29.45)	(-42.60)
2001	13.138***	14.309***	-15.716***	-10.944***
	(10.29)	(11.73)	(-4.70)	(-5.35)
2002	13.479***	14.374***	-16.179***	-11.614***
	(10.34)	(11.71)	(-4.68)	(-5.39)
2003	13.503***	14.545***	-14.780***	-9.460***
	(10.10)	(11.79)	(-4.22)	(-4.38)
2004	13.547***	14.570***	-15.862***	-11.822***
	(10.70)	(11.96)	(-4.57)	(-5.31)
2005	11.039***	14.473***	-7.962***	-4.366***
	(7.04)	(11.61)	(-5.32)	(-2.91)
2006	9.841***	13.458***	-8.603***	-4.827***
	(6.21)	(10.82)	(-4.94)	(-3.29)
2007	7.973***	-1.490	-26.285***	-26.426***
	(5.01)	(-0.91)	(-12.96)	(-14.08)
2008	9.082***	12.922***	-26.097***	-25.665***
	(5.37)	(10.22)	(-13.06)	(-10.97)
Observations	1228	1006	1228	1006

Robust z-statistics in parentheses. Legend: *** p<0.01, ** p<0.05, * p<0.1

Table 8. Firth logit estimates of the graduation probability: AIM-listed companies.

Graduations, Firth logit	**(1)**	**(2)**	**(3)**	**(4)**
Total assets	0.443		0.873***	
	(1.12)		(2.81)	
Total assets, 1995-2000	0.313*		1.041***	
	(1.89)		(3.44)	
Total assets, 2001-2004	1.339***		1.009***	
	(4.21)		(4.22)	
Sales		-0.021		0.401
		(-0.09)		(1.60)
Sales, 1995-2000		0.094		0.427*
		(0.72)		(1.67)
Sales, 2001-2004		0.823***		0.567***
		(3.72)		(3.51)
Age	0.178	0.185	0.185	0.093
	(0.58)	(0.55)	(0.51)	(0.28)
Age, 1995-2000	-0.164	-0.184	0.090	0.131
	(-1.10)	(-1.23)	(0.37)	(0.57)
Age, 2001-2004	0.110	0.048	0.186	-0.020
	(0.56)	(0.25)	(1.02)	(-0.12)
Science-based	2.604***	2.239**	2.486**	1.265
	(2.77)	(2.34)	(2.08)	(1.26)
Specialized supplier	1.461	1.307	1.601	0.481
	(1.49)	(1.30)	(1.31)	(0.44)
Supplier-dominated	1.165	0.900	1.110	-0.019
	(1.21)	(0.92)	(0.90)	(-0.02)
UK incorporated	-0.314	-0.542	1.293	0.733
	(-0.39)	(-0.65)	(0.83)	(0.48)
Introduction from LSE	-3.370**	-3.872**	-3.310**	-2.832*
	(-2.12)	(-2.37)	(-2.08)	(-1.84)
1996	4.223	1.365		
	(0.85)	(0.43)		
1997	3.660	0.911		
	(0.74)	(0.29)		
1998	2.182	-0.689		

	(0.44)	(-0.21)		
1999	2.076	-0.537		
	(0.42)	(-0.17)		
2000	0.169	-2.331		
	(0.03)	(-0.72)		
2001	-10.438*	-9.091**		
	(-1.75)	(-2.28)		
2002	-10.412*	-9.274**		
	(-1.74)	(-2.32)		
2003	-9.422	-7.979**		
	(-1.58)	(-2.02)		
2004	-10.371*	-9.800**		
	(-1.75)	(-2.44)		
2005	-1.954	-2.522		
	(-0.97)	(-1.30)		
2006	-1.836	-2.288		
	(-0.95)	(-1.18)		
2007	-1.681	-2.038		
	(-0.76)	(-0.91)		
FTSE 3-years return			1.229	1.013
			(0.57)	(0.48)
NomadBro			1.696*	1.434
			(1.72)	(1.56)
Constant	-8.109	-2.569	-18.271***	-10.322***
	(-1.64)	(-0.82)	(-4.40)	(-3.69)
Observations	839	710	661	561

z-statistics in parentheses. Legend: *** p<0.01, ** p<0.05, * p<0.1

Table 9. Rare events logit estimates of the graduation probability: AIM-listed companies.

Graduations, rare events logit	**(1)**	**(2)**	**(3)**	**(4)**
Total assets	0.250		0.664**	
	(1.07)		(2.48)	
Total assets, 1995-2000	0.377***		0.815**	
	(2.92)		(2.50)	
Total assets, 2001-2004	0.582***		0.884***	
	(4.16)		(4.78)	
Sales		-0.033		0.352
		(-0.08)		(1.28)
Sales, 1995-2000		0.194*		0.327**
		(1.71)		(2.21)
Sales, 2001-2004		0.395***		0.557***
		(3.67)		(4.82)
Age	0.085	0.178	0.050	-0.078
	(0.30)	(0.37)	(0.15)	(-0.19)
Age, 1995-2000	0.018	-0.013	-0.029	0.049
	(0.17)	(-0.13)	(-0.13)	(0.35)
Age, 2001-2004	-0.341***	-0.387***	-0.120	-0.253**
	(-2.65)	(-3.34)	(-1.11)	(-2.42)
Science-based	1.702*	1.373	1.707*	1.014
	(1.86)	(1.40)	(1.84)	(0.98)
Specialized supplier	0.802	0.555	0.945	0.392
	(0.79)	(0.52)	(0.88)	(0.34)
Supplier-dominated	0.631	0.259	0.291	-0.306
	(0.65)	(0.25)	(0.26)	(-0.27)

FTSE 3-years return	1.032	0.677	1.436	1.352
	(0.83)	(0.55)	(0.58)	(0.60)
NomadBro			1.595	1.215
			(0.97)	(1.02)
Constant	-7.650***	-5.024***	-13.360***	-7.950***
	(-5.45)	(-4.10)	(-4.44)	(-4.31)
Observations	839	710	661	561

Robust z-statistics in parentheses. Legend: *** p<0.01, ** p<0.05, * p<0.1

Table 10. Heckman probit estimates of the acquisition probability: AIM-listed companies.

Acquisitions, Heckman probit (outcome equation)	**(1)**	**(2)**	**(3)**	**(4)**
Total assets	0.288***		0.303***	
	(7.17)		(4.96)	
Total assets, 1995-2000	0.095***		0.145*	
	(2.87)		(1.74)	
Total assets, 2001-2004	0.142***		0.169*	
	(4.01)		(1.87)	
Sales		0.273***		0.277***
		(6.30)		(6.69)
Sales, 1995-2000		0.050*		0.124**
		(1.76)		(2.07)
Sales, 2001-2004		0.188***		0.202***
		(3.19)		(3.18)
Age	0.025	0.027	0.059	0.048
	(0.59)	(0.80)	(0.94)	(1.16)
Age, 1995-2000	0.043**	0.075	0.047	0.036
	(1.98)	(1.21)	(0.97)	(0.59)
Age, 2001-2004	-0.038	-0.090	-0.010	-0.067
	(-0.67)	(-1.44)	(-0.14)	(-1.01)
Science-based	0.393**	0.702	0.565	0.767
	(2.11)	(1.53)	(1.16)	(1.44)
Specialized supplier	0.339*	0.630**	0.480	0.668**
	(1.84)	(2.08)	(1.52)	(1.98)
Supplier-dominated	0.501***	0.787**	0.554*	0.824**
	(4.36)	(2.43)	(1.71)	(2.21)
UK incorporated	-0.100	-0.247**	-0.120	-0.287**

	(-0.98)	(-2.23)	(-0.94)	(-1.98)
Introduction from LSE	0.29	0.343	0.259	0.264
	(1.37)	(1.18)	(0.77)	(0.66)
NomadBro			0.001	0.030
			(0.01)	(0.28)
Constant	-2.405***	-2.498**	-2.961**	-2.851**
	(-4.50)	(-2.37)	(-2.05)	(-2.51)
Observations	1235	1012	1079	883
Wald test indep. equations	0.23 (0.628)	3.06 (0.080)	2.43 (0.119)	2.79 (0.095)

Robust z-statistics in parentheses, except: Wald test for independence of equations (p-value). Legend: *** p<0.01, ** p<0.05, * p<0.1

Table 11. Heckman probit estimates of the graduation probability: AIM-listed companies.

Graduations, Heckman probit (outcome equation)	**(1)**	**(2)**	**(3)**	**(4)**
Total assets	0.123		0.425***	
	(1.04)		(2.63)	
Total assets, 1995-2000	0.254***		0.531***	
	(3.59)		(3.75)	
Total assets, 2001-2004	0.314***		0.527***	
	(5.67)		(4.37)	
Sales		-0.008		0.178
		(-0.06)		(1.31)
Sales, 1995-2000		0.136***		0.214***
		(3.31)		(2.75)
Sales, 2001-2004		0.206***		0.295***
		(4.76)		(4.09)
Age	0.130	0.126	0.139	0.082
	(0.96)	(0.71)	(0.75)	(0.42)
Age, 1995-2000	0.047	0.030	0.064	0.073
	(0.73)	(0.58)	(0.50)	(0.87)
Age, 2001-2004	-0.111**	-0.133***	0.078	-0.016
	(-2.16)	(-2.62)	(1.31)	(-0.28)
Science-based	1.173***	0.923*	1.540**	0.835
	(2.85)	(1.82)	(2.11)	(1.43)
Specialized supplier	0.681**	0.512	1.001	0.352
	(2.03)	(1.15)	(1.61)	(0.67)
Supplier-dominated	0.594*	0.359	0.743	0.195
	(1.71)	(0.74)	(1.01)	(0.34)
UK incorporated	-0.252	-0.335	5.299***	4.811

	(-0.90)	(-1.34)	(3.76)	(.)
Introduction from LSE	-8.802***	-4.912***	-6.431***	-6.661***
		(-23.26)	(-8.67)	(-5.23)
NomadBro			1.023**	0.853*
			(1.97)	(1.76)
Constant	-4.660***	-3.009***	-14.728***	-10.375***
	(-5.51)	(-4.68)	(-5.09)	(-13.11)
Observations	1234	1011	1058	864
Wald test indep. equations				

Robust z-statistics in parentheses. Legend: *** p<0.01, ** p<0.05, * p<0.1

Appendix B: Models.

Binomial logit. Let $p_{i,\tau}$ be the probability that company *i* transfers from AIM to the LSE Main Market (or, alternatively, is acquired) within a given time window τ, conditional on a matrix of explanatory variables observed at time *t0* (introduction time). Let $1\text{-}p_{i,\tau}$ be the conditional joint probability of all other events. The binomial logit model assumes that the log-odds ratio of observing the event of interest is a linear function of the covariates (Cameron and Trivedi 2005):

$$\log (p_{i,\tau} / 1\text{-}p_{i,\tau}) = X' \beta \quad (1)$$

In Eq. 1, β is a vector of unknown coefficients, to be estimated. All non-binary explanatory variables are taken in natural logarithms; therefore, coefficients can be interpreted as elasticities. The coefficients are estimated via Maximum Likelihood, using a covariance matrix clustered by years.

Weibull. In the Weibull model, the hazard function *h(t, X)*, conditional on covariates *X*, reads

$$h(t \mid X) = \alpha\, t^{\alpha-1}\, \lambda^{\alpha} \quad (2)$$

where $\alpha > 0$ is the shape parameter of the Weibull distribution; $\lambda = X' \beta$; β is the vector of regression coefficients.[xvii] In Eq. 2, is the baseline hazard, measuring duration dependence, whereas observed individual-specific heterogeneity is measured by the systematic component $\lambda = X' \beta$.[xviii] α determines the shape of the baseline hazard: increasing in *t* when $\alpha > 1$, decreasing if α is between 0 and 1. When $\alpha = 1$, the Weibull model reduces to an exponential model, which is characterized by a constant hazard rate. α and β are estimated via Maximum Likelihood using the Stata command streg, with variance-covariance matrix clustered by years.

Cox. The Cox model reads

$$h(t \mid X) = h_0(t) e^{X'\beta} \quad (3)$$

where h_0 is the baseline hazard. Unlike the Weibull and other parametric proportional hazard models, the Cox model makes no assumption on the functional form of the baseline hazard. In the Cox model, the marginal effect of a covariate is measured by the so-called hazard ratio (calculated as the exponentiated coefficient from the Cox model). A positive coefficient implies a hazard ratio

above one, suggesting that an increase of the covariate increases the graduation/acquisition rate. Similarly, a negative coefficient implies a hazard ratio below one, indicating that an increase in the explanatory variable reduces the failure rate. Estimates of the Cox model coefficients are obtained via Partial Maximum Likelihood, using the Stata command stcox, with variance-covariance matrix clustered by years. In the Weibull and Cox models, companies that stayed listed are considered as censored, since those companies may have been delisted after the end of our observation period.

Multinomial logit. Let $p_{i,j,\tau}$ be the probability that firm *i* is involved in a delisting event j within a given time window τ, conditional on the matrix of explanatory variables X. The multinomial logit reads

$$\log (p_{i,j,\tau} / 1\text{-}p_{i,j,\tau}) = X' \beta_j \qquad (4)$$

where the default event j = 0 refers to companies that stay listed; the other events are transfers, takeovers, reverse takeovers, and failures. The coefficients in the vector are set equal to zero for normalization purposes. The MLE estimates are obtained through the Stata command mlogit, with variance-covariance matrix clustered according to the years.

Competing risks. Let us assume that company *i* is at risk of *k* different delisting events. Delisting events have durations associated with them. What we actually observe for each company is only the shortest duration. Durations for different risks are assumed to be independent, conditional on covariates. We estimate the competing risks model by Fine and Gray (1999) using the Stata command stcrreg, with variance-covariance matrix clustered according to the years.

Notes

[i] Collewaert (2012) addresses the issue of entrepreneurial exit by studying the relationship between entrepreneurs and angel investors.

[ii] The example of the acquisition of Paypal by E-Bay is a good case in point, as mentioned by Reuer et al. (2008).

[iii] The alternative hypotheses are economies of scale, regulatory overreach and market conditions.

[iv] In order to keep classification mistakes to a minimum, we have keyword-scanned the announcements published on the website http://investegate.co.uk.

[v] We are unable to distinguish between friendly and hostile takeovers. In a reverse takeover, shareholders of a private

company acquire a public company ("shell company") and merge it with the private company (Sjostrom 2008). According to AIM rules, shell companies listed on AIM are delisted after a reverse takeover, and the company resulting from the merger has to newly file for admission on AIM. What we classify as "failures" include bankruptcies as well as voluntary decisions to go private or dark.

[vi] Carpentier et al. (2010) also use assets as a size variable. Due to lack of data, we could not use market capitalization, that is frequently used as a measure of company size in much of the financial literature on corporate failure.

[vii] Fama and French (2004) noted that listing requirements ultimately boil down to some measure of size.

[viii] Stricter adherence to Pavitt's original idea would require classifying firms, not sectors, among the four categories. However, the literature has long been oriented towards operationalizing the Pavitt taxonomy on a sector basis, due to data availability issues.

[ix] Such as agriculture, mining, fishing, quarrying, public/social/personal services, motion pictures, radio & tv broadcasting, news agencies, libraries, sports, gambling/betting. See Appendix.

[x] All tables are in the Appendix.

[xi] Instead of reporting the coefficients of the interaction terms of size and age with years, these tables – as well as the following ones – report the sums of the size and age coefficients with the respective interaction term coefficients. For instance, on the line "Total assets, 1995-2000" it is reported the sum coefficient of total assets + coefficient of total assets*years. The t-stat behind that estimate is the t-stat of the test that such sum of coefficients is null. This gives a flavor of the time profile of size and age effects on the acquisition and graduation probabilities.

[xii] We prefer the logit to the alternative probit model, since predicted event probabilities for logit and probit models are very similar (see Cameron and Trivedi 2005); it is based on a latent variable model with non-Normal (i.e., logistic) disturbances, that seems more suitable in light of the evidence of heavy tails in firm growth rate distributions (e.g. see Bottazzi and Secchi 2006); and it allows an easier interpretation of coefficients as elasticities of the odd ratio of the events of interest with respect to the explanatory variables (Cameron and Trivedi 2005).

[xiii] We focus on single-spell duration models with time-constant covariates.

[xiv] Estimates of the NomadBro dummy coefficients are only performed in the specifications with FTSE returns. The NomadBro dummy had to be erased from the specifications with yearly dummies for computational reasons.

[xv] Previous studies show that companies which enter the market through a reverse takeover (RTO) are low quality and poor performers (Arellano-Ostoa and Brusco, 2002, Gleason et al., 2005, Adjei, Cyree and Walker, 2008, see also Roosenboom and Vasconcelos, 2009 about agency conflicts on the AIM).

[xvi] Recall that the probit coefficients differ in interpretation and systematically differ in magnitude from logit coefficients, according to an approximate formula reported e.g. by Cameron and Trivedi (2005). Hence, comments will only focus on the direction of the effects.

[xvii] beta is a vector of elasticities of the hazard function with respect to the explanatory variables if these are expressed in logarithmic form.

[xviii] Subscripts are omitted in order to avoid cumbersome notation.

Women in Parliaments and Aid effectiveness in Sub-Saharan African countries*

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Abstract

This study fits into the research field of Aid and Growth, seeking to evaluate whether the gender composition of Parliaments in recipient countries may have any impact on aid effectiveness. By using data from the World Bank and OECD (CRS) databases, the analysis refers to 46 Sub-Saharan African countries over the period 1995-2012. The analysis reveals that the presence of women in parliament reduces this negative effect of aid on growth. The results are robust when controlling for endogeneity problems that may affect the linkages between Aid and Growth and for the inclusion of some crucial control for political factors.

JEL Classification: F35, J16, O1, O43
Keywords: Economic growth, Foreign Aid, Gender, Developing Countries, Institutions.

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1. Introduction

Starting from the seventies the debate on the relationship between foreign aid and economic growth has been enriched by numerous theoretical and empirical contributions. Various aspects of aid effectiveness have been widely analyzed with the attempt to shed light on the often conflicting results reached in different empirical analyses. The great interest on this issue also stems from the fact that, despite the massive delivery of aid by the richest countries, poor countries are still embroiled in slow growth paths.

Most of the recent literature shows that aid effectiveness may depend on specific features of the receiving country, as for example the quality of institutions and the goodness of polity, as well as on the type of aid itself (Burnside and Dollar, 2000, 2004; Clemens et al., 2004, 2012; Masud and Yontcheva, 2005; Michaelowa and Weber, 2008; Mishra and Newhouse, 2009; Nunnenkamp et al., 2007).

Given these general acknowledgements, the aim of this study is to evaluate aid effectiveness on the base of a particular characteristic of institutions in recipient countries, namely the Parliament gender composition.

The study focuses on the specific linkage between the share of women in parliaments and the effectiveness of aid in receiving countries because the recent contributes of the literature showed that female policymakers behave differently than their male counterparts. Indeed, several analyses highlight that women seem to be more altruistic, fairer and less corrupted (Chattopadhyay and Duflo, 2004; Dollar et al., 2001; Croson and Gneezy, 2009; Eckel and Grossman, 1998; Goetz et al., 2003; Knack et al., 2001; Swamy et al., 2001;). These specific character traits may of course affect the goodness of the decisions of a policymaker, becoming crucial for the quality of institutions and, hence, also for aid effectiveness (Shukralla and Allan, 2011). Moreover, the literature proofs that women are more sensitive to well-being needs, like education, health, household and gender policies, which in least developed countries are key for the economic growth process. Women attitudes, therefore, may favour a more efficient use of aid, given that it is largely allocated to sectors such as health, education, household facilities and more generally to social infrastructures.

As far as we know, in the literature there are no studies focusing on the relationship between the parliaments' gender composition and the impact of aid on recipient countries economic growth. The only attempt to investigate the role of women in aid management are the studies of Hicks et al. (2016) that find that the more women are present in Parliaments of donor countries, the greater is the attention focused on social infrastructure issues, and the one of Shukralla and Allan (2011) that fail to find a significant relationship between government gender composition and the impact of aid on corruption.

The analysis refers to a sample of 46 Sub-Saharan African countries because, although collecting the highest amount of aid, they performed worse than other countries. Our intent is to verify whether women in Parliament of recipient countries may contribute to increase development aid effectiveness. To this extent, we adopt an appropriate econometric methodology to overcome problems of endogeneity of explanatory variables, as there could be a reverse causality of aid which is usually sent to poorer countries and there are also problems of omitted variables. In particular, following Rajan and Subramanian (2008) we use an index that captures exogenous political and historical linkages to instrument the variable representing the amount of foreign aid.

The empirical analysis reveals that development aid has a negative effect on growth. This may occur because, even if aid is mainly aimed at improving absolute poverty conditions, health, education and at promoting policies for gender equality, they are too often linked to programs "imposed" by different donors. Hence, if the institutional context is not adequately prepared to receive substantial amount of money, these flows may not favor the growth process or even damage it (*The Curse of Aid,* Djankov et al. 2006, 2008). However the presence of women in parliament reduces this negative effect, as the interaction term turns to be positive and significant, the results are robust when controlling for endogeneity with IV estimations and for the inclusion of some crucial control variables. The policy implication is that the larger the presence of women in institutions more effective may be the aid in promoting economic growth. A possible explanation may be the existence of a virtuous process given by a positive correlation between the presence of women in parliament in recipient countries and the use of aid to improve health and education conditions.

The paper is structured as follows: section two includes the literature review; section three describes the African context; section 4 presents the empirical analysis (strategy, dataset and results); section five concludes.

2. Literature review

2.1 Foreign Aid effectiveness

The recent contributions of the literature on the effectiveness of foreign aid may be divided into three different strands. Some authors argues that foreign aid has positive effects on growth only in certain circumstances, some find only small positive effects of aid on growth and finally, others claims that foreign aid not only have no effects but they may even undermine the growth process of receiving countries.

The first strand of the literature, which includes most studies about the effectiveness of foreign aid, state that they have positive effects on growth only under certain conditions, depending on the

quality of institutions of recipient countries, government policies effectiveness and the type of aid sent. In this line, the most influential study is the one of Burnside and Dollar (2000). These authors argued that donors should be more selective in sending aid and favor countries with good policies, because only in these countries aid may have a greater impact on growth. Weak policies prevent aid to have a positive impact. Several studies, focused on institutions and policy, confirmed these findings (Brutigam and Knack, 2004; Burnside and Dollar, 2004; Collier and Dollar, 2001 and 2002; Economides et al., 2004; Guillaumont and Chauvet, 2004; Ovaska, 2003).

Some authors, as part of this line of research, have stressed that aid effectiveness may depend also on the type of aid sent. For an example, Clemens, Radelet and Bhavnani (2004) divided aid into three categories: humanitarian; long impact aid, including support to democracy, environment, health and education; short impact aid, like budget and balance of payments support, aid to productive sectors and investments in infrastructure. In particular, they focus on the third category, which accounts for about 45% of the overall aid flows, and find a positive relationship between short-impact aid and economic growth within a period of four years. Michaelowa and Weber (2008) evaluate the effectiveness of aid sent to education and provide evidence of a positive correlation between development aid and primary school enrollment. Nunnenkamp, Dreher and Thiele (2007) investigate if aid to specific sectors (emergency, physical infrastructures, etc..) affects educational outcomes and find that foreign aid significantly increases primary school enrollment. Masud and Yontcheva (2005), focusing on health aid, reveal that aid is effective and significant only if designed to the reduction of child mortality and when the assistance is provided by non-governmental organizations (NGOs). Finally, Mishra and Newhouse (2009) examine the relationship between health aid and infant mortality. Their specific model hypothesizes that infant mortality is a function of foreign aid received in the previous period but it may depend also on different human development outcomes as the per capita GDP. According to this view, therefore, infant mortality could be considered as a proxy also of economic growth. They show that foreign aid successes in reducing infant mortality when they used to support specific public health programs.

The second strand of the literature on aid effectiveness proves that aid has some positive effects on growth and that negative results, detected in certain cases, depend on problems of identification strategy, on not proper indicators of aid effectiveness and on the presence of non-linearity in individual variables. Dalgaard and Hansen (2000), for an example, criticized the growth model estimated by Burnside and Dollar (2000) and showed that as a rule foreign aid does affect productivity in the long-run and that government policies may only cause differences in the size of this effect. Hansen and Tarp (2001), tackling the endogeneity of aid, by properly instrumenting

them, demonstrate the existence of a strong non-linear and unconditional impact of aid on growth. Dalgaard et al. (2004), emphasizing countries geographical characteristics, found a significant relationship between aid and the fraction of land in the tropics and show some positive and non-linear effects of aid on growth. Sachs (2004), explained the non-linear effects of foreign aid through the theory of the "Big Push" and the existence of a poverty trap. According to his view, positive effects on economic growth need a long period of substantial investment and development aid may start stimulating growth only after reaching a certain threshold. Dalgaard and Erickson (2008) focused on the Sub-Saharan African context over the period 1970-2000 and found that increasing aid promoted growth. They also quantified the amount of aid necessary to achieve the Millennium Development Goals (MDGs) and to halve the poverty level. Clemens et al. (2012), focused on the typologies of aid that is expected to have an "early impact" on growth, as infrastructure development aid, and found that aid inflows are systematically associated with modest but positive growth. More recently, Frot et al. (2012), using the starting date and length of bilateral aid relationships as an instrument for aid, conclude that foreign aid is associated with a little positive impact of it on growth. Juselius, Møller and Tarp (2013) investigate long-run effect of foreign aid on key macroeconomic variables in 36 sub-Saharan African countries from the mid-sixties to 2007 using a well-specified cointegrated VAR model. They find broad support for a positive long-run impact of aid and little evidence of harmful effects. Moreover, they assert that several analyses in the literature are econometrically inadequate. Finally, Arntd, Jones and Tarp (2015) confirm recent evidence of a positive impact of aid on growth, observing that aid has always enhanced growth, promoted structural change, improved social indicators, and reduced poverty.

The third strand states that aid programs do not improve economic growth and may even undermine it, Several studies (Bauer, 1982; Easterly, 2003, 2006 and 2008; Friedman, 1995; Moyo, 2009; Rajan and Subramanian, 2008) observe that in poor countries development aid is responsible for the increase of bureaucracy, the endurance of poor governments, the enrichment of the ruling or simply represent a waste of resources. Citing the widespread poverty in Africa and South Asia, they argue that these countries, despite decades of aid, show a very low growth rate. According to these evidences, aid programs should be radically reformed, consistently reduced or totally abolished. The strongest attacks on the robustness of Burnside and Dollar growth pattern, were presented by Easterly et al. (2004). This study, using the same dataset, model specifications and econometric approach as Burnside and Dollar (2000), extend slightly the sample period and reaches completely different results. Other authors (Meier and Stiglitz, 2001; Moyo, 2009; Rajan and Subramanian, 2008 and 2011), agree that development aid may even undermine incentives for the production in the private sector and may weaken growth, while maintaining weak governments, helping to

perpetuate poor economic policies and postpone reform. According to Meier and Stiglitz (2001), large increases in resources from rich countries to poor countries can lead to unwanted effects, especially those associated with *Dutch Disease*[1] (Rajan and Subramanian, 2011; Williams, 2011), because higher aid flows may contribute to a slowdown in the growth of export sectors. Among the most influential studies of this strand, Rajan and Subramanian (2008) examine the effectiveness of aid and find little positive or negative relationships between aid flows and economic growth. They find no evidence that aid works better in better policy or geographical environment nor that its effectiveness depends on its. In a further analysis (Rajan and Subramanian, 2011), they show that aid has systematically negative effects on country's competitiveness because of the real exchange appreciation caused by the inflows of aid. A remarkable conclusion is the one of Moyo (2009), who argued that foreign aid was and continues to be harmful in the political, economic and humanitarian fields for the majority of developing countries. She demonstrated that in African countries loans and grants (different from emergency resources) have the same effect as valuable natural resources: aid flows encourage corruption and conflicts and at the same time discourage free enterprise damaging the growth process.

2.2 Women in institutions

The role of women in institutions has long been debated in the literature. Some studies (Chattopanday and Duflo, 2004; Childs et al., 2005; Paxton et al., 2003) suggest that the involvement of women in politics brings considerable changes within societies. Some empirical analyses on this issue (Powley, 2006; Shevchenko, 2002; Caiazza, 2002; Shwindt and Bayer, 2006) show that the presence of women in Parliament foster policies and laws aimed to reduce gender discrimination and to promote health and family care.

The literature (Chattopadhyay and Duflo, 2004; Croson and Gneezy, 2009; Eckel and Grossman, 1998; Goetz et al., 2003) identifies some reasons why women in politics govern differently than their male colleagues. Women have different life experiences than men and bring their experience to support their political decisions. In particular, it was observed that in politics, women empowered to decide invest more in infrastructure directly relevant to their own needs (Chattopadhyay and Duflo, 2004) as for an example drinking water, childcare, education and gender policy. Women are also more likely to see themselves as represented by other women and as highlighted by Reingold (1992) in a study on US legislators, feel a special responsibility to represent other women and are more able to represent their own interests (Galligan, 2004). Eckel and Grossman (1998) found that

[1] The term was coined in 1977 to describe the decline of the manufacturing sector in the Netherlands after the discovery of a large natural gas basin in Slochteren in 1959. In the literature it is used to explain the relationship between the exploitation of natural resources and the decline of the manufacturing sector.

women are more "socially orientated" (altruistic)while men are more "individually orientated" (selfish), they also found that women on average donate two times more than men even when the donor cannot be traced back.

Hicks et al. (2016) reveal that an increase of women in donor countries' governments will increase the total amount of aid sent to poorer countries and the portion allocated to social infrastructure. An Inter Parliamentary Union (IPU) survey conducted in 1999 on female parliamentarians from 65 countries, revealed that 40% of respondents entered into politics because of her social interests and 34% of them through non-governmental organizations, differently from the more traditional path of the political party often followed by men. This result closely reflects a well-established tendency among women to engage in civil society as a way to promote projects that support the survival of families.

It is not clear, as empirical studies display conflicting results, whether women have a different approach to corruption. It was repeatedly said that countries with a higher number of women in politics have lower levels of corruption. According some authors (Dollar et al., 1999; Knack et al., 2001; Swamy et al., 2001) the hypothesis of a higher incorruptibility of women is based on their propensity to adopt a more ethical behavior in political life, meaning that they are considered more trustworthy and oriented to the social well-being. This belief is confirmed by Dollar et al. (1999) and Swamy et al (2001) that find evidences of women in Parliament effectiveness in promoting honest government and in reducing the level of corruption. Knack et al. (2001) show that women are less likely to tolerate bribes and that corruption is less severe in countries where they have a greater share of parliamentary seats. However, more recent research indicates that women are not necessarily more honest or adverse to corruption than men (Frank et al. 2011). In fact, they show that women's attitudes and behavior regarding corruption depend on the institutional and cultural context of each specific country (Alhassan-Alolo, 2007; Alatas, Cameron, and Chaudhuri, 2009; Armantier and Boly, 2008; Schulze and Frank, 2003). Treisman (2007), for an example, states that they are more likely to be corrupted in autocratic states where corruption and favoritism are often a way to go to do business. Similarly, Esarey and Chirillo (2013) claim that the inclination of women towards corruption is contextual: they are less susceptible to corruption in democracies while they are equally sensitive in autocratic systems.

Finally, Shukralla and Allan (2011) state that if women's involvement in politics helps to reduce corruption (as argued by Dollar et al. 2001) and if one of the main reasons for foreign aid ineffectiveness is corruption (as in Rajan and Subramanian, 2007), then, it is possible that foreign aid is more effective in those countries with larger participation of women in politics.

3. The African context

This section describes the African context which is the object of our analysis. The reason why we have chosen this geographical context is the fact that, despite the considerable development aid flows of the past decades, the laggard countries of this continent remained on a weak growth path. In what follows we present some evidence on the role and the main interests of women in African Parliaments and then a brief descriptive analysis of development aid sent to these countries.

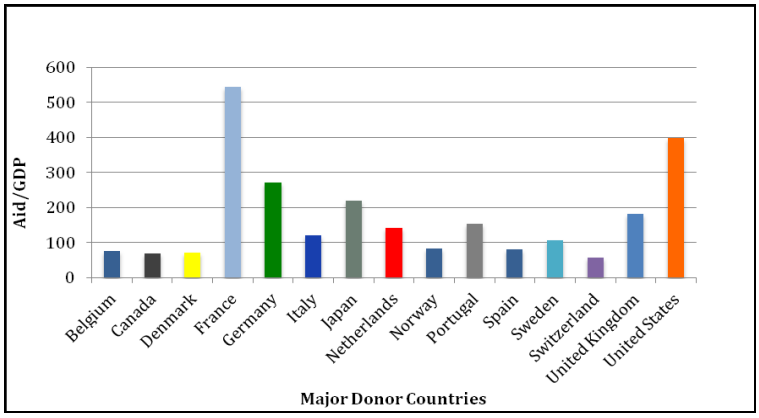
The participation of women in African government helped to promote and implement projects closely related to their main interests. They are mostly projects aimed to improve social well-being and that imply an increase of spending on health, nutrition and education programs.

Goetz (1998) noted that, despite the adversities, women in African governments, particularly in Uganda and South Africa, managed to insert the interests of women in the political agenda. Similarly Bauer and Britton (2006), show that African women working together, despite the presence of religious, ethnic and class divisions, succeeded in formulating or pushing for the adoption of laws concerning social welfare. Focusing on Rwanda, Burnet (2008) found that the increasing representation of women in government paved the way to democracy and greater social participation, while Powley (2007) highlighted their contribute in pushing a law strengthening the rights of women, as for example the right to inherit land. In the wake of the Rwandan genocide, indeed, the exclusion of women from land ownership became a critical issue. A part from being a violation of women's rights, the impossibility of owing land had a negative impact on food production, safety, the environment, settlement patterns and family life. More women in Parliament have also actively supported the increase in spending on health and education.

Shukralla and Allan (2011), using a sample worldwide countries (not only African) try to show whether the more women are involved in politics the less the corruption and aid effectiveness in reducing corruption itself. Under this hypothesis, women in parliaments modify institutional context making it more conducive to aid management because they agree on the objectives chosen independently by indigenous politicians of the country.

Moving now to the context of development aid received by African countries, we refer to the OECD Creditor Reporting System (CRS), which contains data on Official Development Aid (ODA) sent to poor countries from worldwide donors. In particular, we refer to aid sent to 46 countries in sub-Saharan Africa. Foreign Aid data include flows from individual countries members of the Development Assistance Committee (DAC) as well as from multilateral organizations. The time horizon considered in our analysis is 1995-2012.

Figure 1. *Major donor Countries in the period 1995-2012*

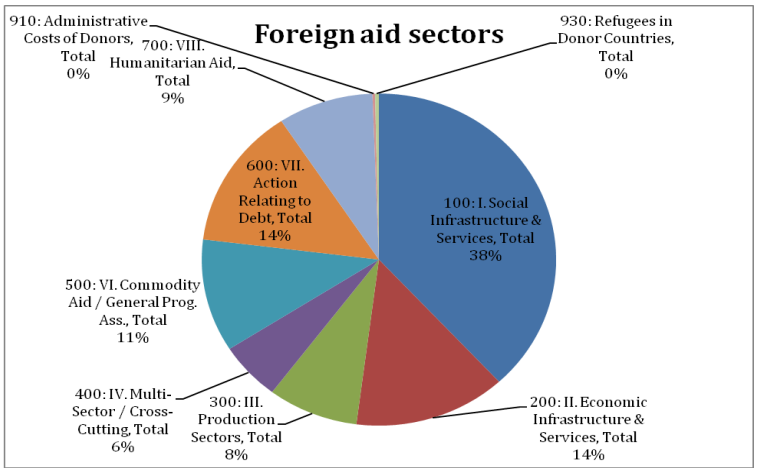


Source: our elaboration on OECD (CRS) dataset

Figure 1 shows the aggregate quantity of aid[2] (measured as a share of recipient countries' GDP) sent from the major donors to all the Sub-Saharan African countries. Data show that France, followed by the United States, Germany, Japan and United Kingdom are in this order the major donors. A common characteristic of all donors is the existence of a particular relationship with the recipient countries based either on former colonization linkages or on political and economic strategies.

Most of foreign aid sent to Sub-Saharan African countries in the period 1995-2012 (fig.2) was devolved to Social Infrastructure and Services sector (38%). Less consistent are flows addressed to other sectors like Economic Infrastructure and Services (14%), Action Relating to Sovereign debt (14%), Commodity, Humanitarian, Production and Environment.

Figure 2. *Foreign Aid divided by sectors (1995-2012)*

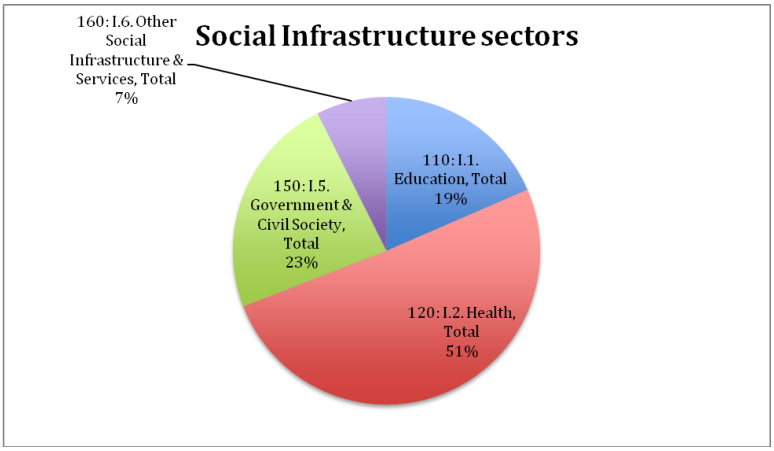


Source: our elaboration on OECD (CRS) dataset

[2] Data are measured in terms of 2012 US dollar exchange rate.

Within the Social Infrastructure and Services sector (fig.3), Health receives the greatest amount of aid resources (51%) followed by Government and Civil Society (23%) and Education (19%).

Figure 3. *Foreign aid for Social infrastructure sectors*



Source: our elaboration on OECD (CRS) dataset

4. Empirical Analysis

4.1 The econometric model and data

The analysis aims to evaluate the relationship between the parliaments' gender composition and the impact of Aid on economic growth in recipient countries. To this extent, we build a baseline model where our explanatory variables of interest are foreign development aid and the share of women in Parliaments interacted with aid. The interaction term aims to capture the influence of female parliamentarians on aid management outcome, measured in terms of growth. We include controls for different social and economic factors and, in order to account for common factors to all countries and for time-invariant characteristics, we include also time and country fixed effects. The sample is given by 46 Sub-Saharan African countries observed over the period 1995-2012. In order to encompass short-term business cycle noises and serial correlation effects, we followed an approach, standard in the empirical literature (Di Liberto et al., 2008; Islam, 1995, 2003), and choose a three year time span.

The empirical model, tested by means of panel data approaches, is structured as follows:

$$g_{it} = \alpha + \delta Aid_{it} + \mu Aid_{it} W_{it} + \beta_{it} X_{it} + \eta_i + \upsilon_t + \varepsilon_{it} \qquad (1)$$

where g_{it} indicates the average three years per capita GDP growth rate[3] in country *i* (with *i= 1,…,45)* at time *t* (with *t=1, …,6*), Aid_{it} is the total amount of Official Development Assistance in terms of recipient country's GDP, W_{it} represents the share of women in Parliament (available from the Inter Parliamentary Union-IPU database), $\boldsymbol{X}_{it}$ is a vector of socio-economic variables suggested in the empirical growth literature, η_i are country fixed effects accounting for countries exogenous heterogeneity, υ_t are time fixed effects which measure common events and factors affecting all countries and ε_{it} is the error term (*iid~ (0, σ^2)*).

The empirical literature identifies different political, economic, and social drivers for economic growth as listed below. We include the initial level per capita GDP[4] (*lnGDP_{t0}*) in each time span, expressed in logarithm. A measure of demographic structure is given by the logarithm of population (*lnPOP*). As a measure of capital endowment we include for each country the amount of Public Expenditure (*Pub_Exp*), for public investment, and the Foreign Direct Investment (*FDI*) that indicates the net amount of foreign investments. As a proxy of human capital endowment, we use the primary education completion within the country (*Primary_Edu*). Trade openness (*Trad_Open*) is given by the sum of total exports and total imports divided by GDP. Institutions (*Institutions*) accounts for the quality of governments within surveyed countries. This variable is obtained as the First Major Component of the six measures taken from the Worldwide Governance Indicators[5] (WGI) of the World Bank, namely Voice and Accountability, Political Stability, Absence of Violence, Government Effectiveness, Regulatory Quality, Rule of Law and Control of Corruption (Kaufmann et al., 2010). Higher values of this indicator mean a better functioning of the institutions. *Polity* represents the occurrence of significant national polity changes, like autocratic backslidings, revolutions, state failures and successful military coups. Values for this variable are taken from the polity IV dataset (Marshall and Jaggers, 2013). Institutions and Polity will be used alternatively in our model. Corruption is usually considered as a factor that may affect both growth performance of a country and the effectiveness of the aid itself. In this analysis we rescale the aggregate indicator Control of corruption of WGI so that higher values will be associated to higher levels of corruption (*Corruption*). A dummy variable is included to account for the recipient country involvement in armed conflicts (*War*), equals to one in case of conflict and zero otherwise, based on UCDP/PRIO Armed Conflict dataset (Gleditsch et al. 2002; Melander et al. 2016). Moreover, we interact *War* with an index of Ethnolinguistic

[3] Per capita GDP growth rate are based on constant local currencies.
[4] Expressed in constant 2010 US$.
[5] The WGI indicators are based on surveys summarizing the opinions on the quality of governance provided by entrepreneurs, citizens and experts from industrialized and developing countries (Kaufmann et al., 2010).

Fractionalization[6] (*War*Fractionalization*) taken from Easterly and Levine (1997) and Roeder (2001) datasets. Finally, the variable *Oil* is included to account for Oil rents (difference between crude and total cost of production, at world prices) in percentage of GDP made available by the World Bank dataset.

The baseline model is first estimated by means of an OLS approach, which results will be taken as benchmark. Then, since this simple estimation does not account for possible endogeneity due to omitted variables correlated with foreign aid and to the problem of reverse causality that typically arises in this case, we estimate again the model by means of the Instrumental Variable approach. To this extent, following Rajan and Subramanian (2008), we build an instrument for foreign aid and for the interaction term by estimating, with OLS, an equation with Aid as dependent variable and several different historical and political factors, that determine aid and satisfy the exclusion restrictions, taken as explanatory variables. After running this estimation we use the predicted values of aid to instrument *Aid* itself and *Aid*W* in the growth regression (eq. 1).

In this line, foreign aid sent to a recipient country *i* is derived from the estimation of the following model:

$$Aid_{it} = Inf_{it} + IMF_{it} + Inf_{it} * \left(\frac{Pop_R}{Pop_D}\right) + Inf_{it} * IMF_{it} + AS_{it} + T + \omega_{it} \qquad (2)$$

where Inf_{it} is the colonial influence, that is a dummy variable which is one if the former colonizer country is also the major donor and zero otherwise; IMF_{it} is the value of International Monetary Fund quota of donors; $\left(Pop_R/Pop_D\right)_{it}$ is the ratio between the population of recipient and donor countries; AS_{it} is the share of asylum seekers from the recipient country *i* at time *t* towards donor countries and *T* is a time trend. The choice of these factors

4.2 Results of the econometric analysis

This section shows the results of our econometric analysis. The empirical relationship among growth, aid and gender parliament composition is first estimated through the OLS methodology and then, accounting for the presence of endogeneity, due to reverse causality between growth and aid and omitted variable, we follow an IV methodology.

[6]This index represents the probability that two individuals, taken randomly from the population in each country, belong to different ethnic groups.

Table 1 presents the results the estimation of equation 2 which shows the goodness of variables chosen to instrument Aid as all the coefficients are highly statistically significant.

Table 1. *Estimation results for determinants of foreign Aid*

VARIABLES	Aid
Inf	7.438**
	(3.229)
IMF	2.080***
	(0.385)
Inf*$\left(\frac{POP_R}{POP_D}\right)$	-3.302**
	(1.348)
Inf*IMF	-1.634**
	(0.702)
AS	-6,807*
	(3,533)
T	-2.292*
	(1.383)
Constant	34.50**
	(17.60)

OLS Estimations.Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In particular, donors give more aid, and are also the major ones, if they were the former colonizers. Their generosity is greater towards recipient countries which are smaller in terms of relative population size and increases with their representativeness in International organizations. Besides, as many requests of asylum donors receive from poor countries the less they send them development aid, probably because they are forced to increase the domestic expenditure to support migrants arriving in the country. Finally, results show a decrease of aid sent over time that could be explained by different dynamics like a general discouragement due to lack of aid effectiveness or the worldwide financial crises of the last decades.

Table 2 presents the results of the OLS and IV estimations of the empirical model formalized in the equation 1. The OLS approach, which results are displayed in columns 1, 2 and 3, evaluates the correlation between aid and growth, to see whether and to what extent foreign aid, considering the interaction with women in Parliament, is associated with recipient countries growth performances.

Table 1. *Growth, Foreign Aid and Parliament Gender composition, econometric results.*

VARIABLES	Dependent variable: *per capita GDP Growth rate*					
	OLS (1)	OLS (2)	OLS (3)	IV (4)	IV (5)	IV (6)
Aid	-0.197***	-0.172***	-0.186***	-0.675***	-0.578***	-0.643***
	(0.0515)	(0.0505)	(0.0504)	(0.167)	(0.148)	(0.165)
AidxW	0.00796***	0.00650**	0.00583**	0.0208***	0.0155***	0.0144***
	(0.00295)	(0.00293)	(0.00292)	(0.00499)	(0.00478)	(0.00487)
$lnGDP_{t0}$	-15.55***	-17.45***	-18.08***	-16.84***	-18.41***	-19.94***
	(1.167)	(1.272)	(1.289)	(1.434)	(1.519)	(1.698)
lnPOP	0.183	0.0235	-0.0559	0.521	0.371	0.222
	(0.299)	(0.297)	(0.296)	(0.387)	(0.373)	(0.377)
Oil	0.000936	-0.00403	0.0113	-0.0288	-0.0512	-0.0200
	(0.0576)	(0.0568)	(0.0566)	(0.0695)	(0.0687)	(0.0701)
FDI	0.0560	0.0367	0.0210	0.0188	0.00633	-0.0329
	(0.0407)	(0.0403)	(0.0405)	(0.0505)	(0.0485)	(0.0534)
War	1.576	2.424	2.415	2.754	3.487	3.513
	(2.524)	(2.479)	(2.455)	(3.020)	(2.924)	(3.023)
War*Fractionalization	-0.0306	-0.0458	-0.0465	-0.0494	-0.0685*	-0.0716*
	(0.0347)	(0.0339)	(0.0335)	(0.0415)	(0.0403)	(0.0418)
Pub_Exp	-0.121**	-0.0455	-0.0554	-0.113*	-0.000140	-0.0181
	(0.0563)	(0.0559)	(0.0556)	(0.0669)	(0.0682)	(0.0697)
Trad_Open	0.0395***	0.0305**	0.0310**	0.0588***	0.0500***	0.0531***
	(0.0140)	(0.0142)	(0.0141)	(0.0191)	(0.0183)	(0.0192)
Primary_Edu	0.0569**	-0.00748	-0.0112	0.0125	-0.0598	-0.0734*
	(0.0238)	(0.0281)	(0.0279)	(0.0317)	(0.0380)	(0.0409)
Institution	0.0104**			0.0210***		
	(0.00428)			(0.00704)		
Polity		0.646***	0.718***		0.796***	0.979***
		(0.154)	(0.156)		(0.195)	(0.222)
Corruption			-0.0253**			-0.0584***
			(0.0109)			(0.0184)
Constant	104.8***	121.3***	128.0***			
	(7.826)	(9.016)	(9.381)			
Observations	276	270	270	275	269	269
R-squared	0.595	0.616	0.626	0.400	0.448	0.410
Number of Country	46	45	45	46	45	45

All regressions include time and country Fixed Effects; Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Results reveal that total aid is always negatively correlated with the per capita GDP growth rate, confirming the presence of a process that the literature defines "*The curse of Aid*" (Djankov et al. 2006, 2008). However, when aid is interacted with the share of women in parliaments the coefficient turns out to be positive, suggesting that higher presence of women drives a more virtuous management of foreign aid. This finding is robust to different controls for political factors like Institutions, Polity and Corruption. These latter, when included, are always significant and with the expected sign and, among them, polity shows the higher impact. Countries with lower levels of per capita GDP appear to grow faster. A slight positive impact on growth derives also

from the trade openness. Education has a positive and significant effect only when the model controls for the quality of institutions.

We are well aware that these results can be biased because of omitted variables that may induce endogeneity problems. To this extent, we estimate the model also by means of an Instrumental Variable approach. Overall IV results (table 2, columns 4,5 and 6) are consistent with the OLS findings. The main difference is that aid, in absolute terms, performs worse in enhancing the growth process. However, women involvement in politics appear to be even more important for aid effectiveness when the empirical analysis accounts for endogeneity problems affecting aid itself.

5. Conclusions

The literature on development aid effectiveness is considerably vast. Even though, as far as we know, up to now the linkages between government gender composition and aid effectiveness have not been properly explored. The aim of this study is to investigate whether a greater involvement of women in Parliaments may have an impact on aid effectiveness measured in terms of receiving countries growth performances. The empirical analysis focuses on a sample of 46 Sub-Saharan African countries observed over the period 1995-2012. African countries, indeed, although collecting the highest amount of aid from Western rich countries, performed worse than other countries. As regards the empirical strategy, we followed an appropriate econometric methodology able to deal with endogeneity problems arising from the aid-growth reverse causality and omitted explanatory variables. To this end, we built an instrument for development aid based on different political and historical determinants.

The empirical analysis reveals that, even if development aid has a negative effect on growth, a larger participation of women in parliament increases its effectiveness. A possible explanation may be the existence of gender different interests in the political agenda. They are particularly interested in promoting interventions aimed to improve social well-being at country level. These results may be reached through greater efforts in terms of public spending on health, nutrition and education programs. Further analyses will be dedicated to investigate the existence of this virtuous process and its possible channels.

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Order of resource extraction and factor intensity

Giuseppe Freni

Abstract

This paper characterizes the optimal time paths of extraction of several nonrenewable resource deposits with different costs of extraction when the extracted resource can be converted into productive capital and the extraction process, as well as the production of the substitute, requires two primary factors of production. Under a technological assumption granting that the time paths of primary factor prices are monotonic, we show that, for each pair (lower cost/higher cost) of deposits, an intensity condition is necessary in order to have discontinuous extraction of the lower cost deposit. We also show that the same condition is sufficient for discontinuous extraction of the lower cost deposit, provided the stock of the lower cost deposit is sufficiently large and the stocks of all other deposits are sufficiently small.

1. Introduction

If an “energy” sector can exploit several deposits of an exhaustible resource, then a problem of order of extraction arises. Partial equilibrium analysis suggests that efficient extraction should occur sequentially from the lowest-cost deposit to the highest-cost one (Herfindahl, 1967) and that, if a high-cost substitute exists, then its production by means of the 'backstop technology' should begin after exhaustion of all deposits. In an attempt to evaluate the generality of the above principles, Kemp and Long (1980) showed that both the above 'folk theorems' are invalid in a “Ricardian” general equilibrium context. Within that framework, the ‘theorems’ fail because the desire to smooth consumption and the fact that the product is non-storable provide an incentive to delaying extraction from low cost deposit. In turn, procrastination of extraction implies the generic existence of time intervals during which (at least) two processes are operated. Building on this argument, Lewis (1982) developed an extended model in which storage is allowed, and proved that the least-cost-first principle is restored, provided the extracted resource can be converted into productive capital, where productive capital means that stored capital grows at a positive rate.

More recently, Amigues, Favard, Gaudet and Moreaux (1998) have modified the Kemp and Long model by introducing a constraint for the capacity of the backstop that is active in the long run equilibrium. Amigues et al. (1998) found that the capacity constraint generates an additional incentive to delay extraction, which may lead to start the backstop well before a lower cost resource is ever put into use. Favard (2002) extended these results to the Lewis (1982) framework. Capacity constraints have been further investigated by Freni (2004) and Holland (2003) in partial equilibrium settings. Both studies reported a series of negative counter-examples showing, in particular, that deposits may be temporarily abandoned after a period of initial extraction and that high-cost deposits may be either opened or exhausted before low-cost ones. To our knowledge, Freni’s (2004) and Holland’s (2003) articles are the only studies that reported the possibility of discontinuous extraction of a nonrenewable resource reserve in a single demand setting (for discontinuous extraction with multiple demands see Gaudet, Moreaux and Salant, 2001 and Im, Chackavorty and Roumasset, 2006).

Capacity constraints reflect the existence of specific primary factors of production in fixed supply. In general, therefore, adding a capacity constraint increases by one the number of primary factors of the system and opens the door to 'substitution' effects

associated with the transitional dynamics of factor prices. These effects are indeed at the root of the results of Amigues et al. (1998), Favard (2002), Freni (2004) and Holland (2003). For example, in Favard's (2002) model, which involves two factors of production (transferable 'labor' and a backstop-specific factor of production), the specific factor price increases and the price of the transferable factor decreases during the transition to the long run equilibrium. Hence, in Favard's (2002) model, delaying extraction is optimal because a factor that will be *cheaper* in the future is intensively used in exploiting the resource. Analogous mechanisms are at work in the Amigues et al. (1998), Freni (2004), and Holland (2003) models, although in these models consumption smoothing operates as in the Kemp and Long (1980) model, and labor supply is elastic.

The purpose of this paper is to characterize the optimal time paths of extraction and production of an "energy" sector in which two non-specific primary factors of production are required to exploit the reserves and to produce the substitute. The main result is that the incentive to procrastinate extraction in response to monotonic factor price dynamics can lead to discontinuous extraction of lower cost deposits along the optimal path, even if the resource can be converted into productive capital (Solow and Wan, 1976, Lewis, 1982). Given a higher cost and a lower cost deposit, a factor intensity condition turns out to be necessary for a complete cost reversal. The condition is also sufficient, provided the stocks in the higher cost deposit and in all other deposits are sufficiently small. In this case, if the stock in the lower cost deposit is small, then the higher cost deposit is exploited before the lower cost one. On the other hand, if the stock in the lower cost deposit is sufficiently large, it will be optimal to have an initial phase during which the lower cost deposit is exploited.

For the sake of simplicity, we embed the results in a simple endogenous growth model in which, as it is typically assumed in the endogenous growth literature, the instantaneous utility function exhibits a constant inter-temporal elasticity of substitution and the discount rate is smaller than the given maximum rate of growth. Such a set of assumptions ensures an equilibrium in which a constant consumption growth rate is sustained by a constant rate of interest, while only level effects are associated with the existence of non-reproducible factors either in fixed or, as for the exhaustible resources, in decreasing supply.

In Section 2, I present the model and give the optimality conditions for the general case of n, n ≥ 2, deposits. The structure of the optimal paths for the case of two deposits is discussed in details in Section 3. Section 4 characterizes the optimal extraction path for the case of n deposits. Section 5 presents some concluding remarks.

2. The model

Consider an "energy" sector whose output derives either from the exploitation of n, n ≥ 2, deposits of an exhaustible resource or from the activation of a backstop technology, or from both. The backstop system is the one sector AK model with a drift, in which the drift is due to the possibility of operating a backstop production process without the use of capital. This process can be run at any scale of operation, but requires the services of two primary resources, called 'labor' and 'land', which are in fixed supply. We normalize the existing amounts of labor and land to 1.

The initial stocks in the n deposits are given by the vector $\bar{\mathbf{y}}$, $\bar{\mathbf{y}} \in R^n_{++}$. As for the backstop, the extraction technology from each deposit exhibits constant returns and requires (the services of) labor and/or land in a given proportion. Storage of the good is possible. The rate of growth of stored capital is a constant $\Gamma, \Gamma \in R$. The capital stock at time zero is denoted by $\bar{s}$, $\bar{s} \in R_+$.

Formally, we have n + 1 production processes for "energy": the backstop and the n extraction processes. At the unitary level, the backstop requires l_0, $l_0 > 0$, units of labor and d_0, $d_0 > 0$, units of land:

$$(l_0, d_0) \rightarrow 1,$$

while the extraction process i, $i \in \{1.2,\ldots,n\}$, requires l_i, $l_i \geq 0$, units of labor, d_i, $d_i \geq 0$, units of land, and depletes deposit i of one unit of the resource:

$$(l_i, d_i, 1) \rightarrow 1.$$

At time t, s(t) denotes the stock of capital, and $\mathbf{y}(t)$ denotes the resource stocks. Moreover, I use $x_0(t)$ to indicate the intensity of the backstop production process and $\mathbf{x}(t)$ to indicate the intensities of the extraction processes. To simplify the notation, whenever the context makes clear which time is referred to, I omit the time argument.

The preference side of the model is standard. There is a representative consumer with an infinite horizon, who derives utility only from consumption of "energy", c(t), c(t) ≥ 0. His utility function is time additive separable, with the instantaneous utility function u(c) taking the form:

$$u(c) = \begin{cases} \dfrac{c^{1-\sigma}}{1-\sigma} & \sigma \neq 1 \\ log(c) & \sigma = 1 \end{cases} \qquad \text{(CES)}$$

Future utilities are discounted at the constant rate ρ.[1]

The Pareto-optimal allocations of our system are therefore the solutions of the following optimal control problem:

$$V(\bar{s}, \bar{\mathbf{y}}) = \sup \int_0^{\infty} e^{-\rho t} u(c(t))dt \qquad \text{(PO1)}$$

$$\text{s. to} \quad x_0(t)l_0 + \mathbf{x}(t)\mathbf{l} \leq 1 \qquad (1)$$

$$x_0(t)d_0 + \mathbf{x}(t)\mathbf{d} \leq 1 \qquad (2)$$

$$\dot{s}(t) = x_0(t) + \mathbf{x}(t)\mathbf{e} + \Gamma s(t) - c(t) \qquad (3)$$

$$\dot{\mathbf{y}}(t) = -\mathbf{x}(t) \qquad (4)$$

$$x_0(t) \geq 0 \quad \mathbf{x}(t) \geq \mathbf{0} \qquad (5)$$

$$c(t) \geq 0 \qquad (6)$$

$$s(t) \geq 0 \quad \mathbf{y}(t) \geq \mathbf{0} \qquad (7)$$

$$s(0) = \bar{s} \quad \mathbf{y}(0) = \bar{\mathbf{y}} \qquad (8),$$

where $\mathbf{l} = [l_1, \ l_2, \ \ldots, \ l_n]$, $\mathbf{d} = [d_1, \ d_2, \ \ldots, \ d_n]$, $\mathbf{e} = [1, \ 1, \ \ldots, \ 1]$, and $u(c(t))$ takes the CES form given above.

In this section, we study problem (PO1) under the following set of assumptions:

[A1] $(l_i, d_i) \geq \mathbf{0}$, $(l_i, d_i) \neq \mathbf{0}$, $(l_i, d_i) \neq (l_j, d_j)$, $(l_0, d_0) >> (l_i, d_i)$, j, $i \in \{1, 2, \ldots, n\}$,

[1] As in Rebelo (1991), I do not assume ρ > 0.

[A2] $\Gamma > 0$,

[A3] $\rho - \Gamma(1 - \sigma) > 0$,

[A4] $\Gamma - \rho > 0$.

Assumption [A1] means that there is not free lunch and that, although deposits differ from one another, each extraction process dominates the backstop production method. The meaning of [A2] is that capital is productive. The inequality under [A3] is a condition ensuring the existence of an optimal solution of problem (PO1) with $-\infty < V(\bar{s}, \bar{\mathbf{y}}) < \infty$ (see Freni, Gozzi and Salvadori, 2006). The condition in [A4] gives the incentive to accumulate. Assumptions [A1] - [A4] imply that the optimal production path is nonincreasing. This conclusion, that is the main result of this section, is presented in Proposition 1 below.

In the two following sections, we specialize problem (PO1) by adding two further assumptions.

[A5] $d_0 < l_0$, $d_i > l_i$ $i \in \{1, 2, \ldots, n\}$,

[A6] $(l_1, d_1) >> (l_2, d_2) >> \ldots >> (l_n, d_n)$.

Assumption [A5] means that the total endowments of the two factor inputs belong to each diversification cone generated by the backstop process and any extraction process. This assumption grants monotonic dynamics of the factor prices and, almost ever, prevents simultaneous extraction from multiple deposits. Finally, Assumption [A6] contains the conditions that allow us to order deposits with costs in a natural way. Whenever this assumption holds, I label the deposits in reverse order of costs.

Define the current value Lagrangian function:

$$L(s, \mathbf{y}, v, \mathbf{p}, x_0, \mathbf{x}, c, \mathbf{q}, \mu) = u(c) + (x_0 + \mathbf{xe} + \Gamma s - c)v - \mathbf{xp} + \mathbf{yq} + s\mu$$

where v and **p** are the costate variables corresponding to s and **y**, respectively, and **q** and μ are the multipliers for the non-negativity constraints in (7), and let w(t) and r(t)

be the multipliers for the constraints (1) and (2), respectively.[2] Then the following conditions are sufficient for optimality:[3]

$$\dot{s}(t) = x_0(t) + \mathbf{x}(t)\mathbf{e} + \Gamma s(t) - c(t) \tag{3}$$

$$\dot{\mathbf{y}}(t) = -\mathbf{x}(t) \tag{4}$$

$$\dot{v}(t) \leq (\rho - \Gamma)v(t) \tag{9}$$

$$s(t) \geq 0 \tag{10}$$

$$\dot{v}(t)s(t) = (\rho - \Gamma)v(t)s(t) \tag{11}$$

$$\dot{\mathbf{p}}(t) \leq \rho\mathbf{p}(t) \tag{12}$$

$$\mathbf{y}(t) \geq \mathbf{0} \tag{13}$$

$$\dot{\mathbf{p}}(t)\mathbf{y}(t) = \rho\mathbf{p}(t)\mathbf{y}(t) \tag{14}$$

$$\mathbf{p}(t) \geq 0 \tag{15}$$

$$c(t)^{-\sigma} = v(t) > 0 \tag{16}$$

[2] The usual interpretation in terms of spot competitive prices applies both to the costates, v(t) and **p**(t), and to the multipliers, w(t) and r(t). Thus, in what follows, I will often refer to v(t) as to the competitive price of energy, to **p**(t) as to the vector of the *in situ* competitive prices for the different grades of the resource, to w(t) as to the wage rate, and to r(t) as to the land rent rate.

[3] See Freni, Gozzi and Pignotti (2008).

$$\begin{gathered}\min\left[w(t)+r(t)\right]\\ v(t)\le w(t)l_0+r(t)d_0\\ \mathbf{e}v(t)-\mathbf{p}(t)\le w(t)\mathbf{l}+r(t)\mathbf{d}\\ w(t)\ge 0,\ r(t)\ge 0\end{gathered}\tag{17}$$

$$\begin{gathered}\max\left\{x_0(t)v(t)+\mathbf{x}(t)\left[\mathbf{e}v(t)-\mathbf{p}(t)\right]\right\}\\ x_0(t)l_0+\mathbf{x}(t)\mathbf{l}\le 1\\ x_0(t)d_0+\mathbf{x}(t)\mathbf{d}\le 1\\ x_0(t)\ge 0,\ \mathbf{x}(t)\ge\mathbf{0}\end{gathered}\tag{18}$$

$$\lim_{t\to\infty} e^{-\rho t}\left[s(t)v(t)+\mathbf{y}(t)\mathbf{p}(t)\right]=0\,.\tag{19}$$

Given that exhaustion of a deposit is irreversible, condition (12) can be satisfied as an equality. Moreover, since Assumption [A4] implies that for each optimal path we must have s(t) > 0 for t > 0, we can use Theorem 5.3 in Freni, Gozzi and Pignotti (2008) to claim that the above conditions are also necessary for optimality. This allow us to state condition (9) as an equality without missing any of the optimal solutions. We can therefore immediately derive from condition (16) that the rate of growth of consumption is the constant $g^o=\dfrac{\Gamma-\rho}{\sigma}$ along the whole optimal path.

From the above set of conditions and Assumption [A1], we must have that the scarcity rent vector **p**(t) is positive. Otherwise the demand for a grade of the resource would become infinite. Henceforth, given that conditions (9), (12) and (14) imply that the left side of inequality $\mathbf{e}v(t)-\mathbf{p}(t)\le w(t)\mathbf{l}+r(t)\mathbf{d}$ becomes negative in finite time, the date of exhaustion of the resources is finite. We denote this date by $T_{\mathbf{y}}$, $T_{\mathbf{y}}>0$.

Once all deposits are exhausted, the system behavior is given by the solution of the following problem:

$$\sup\int_0^{\infty} e^{-\rho t}u(c(t))dt \qquad \text{(POB)}$$

$$\dot{s}(t)=\frac{1}{l_0}+\Gamma s(t)-c(t)$$

$$c(t)\ge 0,\ s(t)\ge 0,\ s(0)=\hat{s}\ge 0\,.$$

Given that the utility function takes the CES form, a straightforward verification procedure (see for example Jones and Manuelli, 1990, or Rebelo, 1991) provides the solutions of (POB):

$$c^B(t) = (\Gamma - g^o)\left(\hat{s} + \frac{1}{\Gamma l_0}\right)e^{gt} \tag{20}$$

$$s^B(t) = -\frac{1}{\Gamma l_0} + \frac{c^B(t)}{\Gamma - g^o},\ s^B(t) \geq 0\,. \tag{21}$$

Figure 1 illustrates the optimal trajectory (21) in the (s(t), c(t)) space. We note that along the optimal path condition (21) must hold from the time T_y on, because, once we have $\mathbf{y}(t) = 0$, the transversality condition (19) forces the optimal solution of (PO1) on the half-line AB.

Let us define $\hat{\mathbf{p}}(t) = \frac{1}{v(t)}\mathbf{p}(t)$, $\hat{w}(t) = \frac{w(t)}{v(t)}$ and $\hat{r}(t) = \frac{r(t)}{v(t)}$. Substituting these in the above optimality conditions, we first rearrange the linear problems (17) and (18) as follows:

$$\begin{gathered} \min\left[\hat{w}(t) + \hat{r}(t)\right] \\ 1 \leq \hat{w}(t)l_0 + \hat{r}(t)d_0 \\ \mathbf{e} - \hat{\mathbf{p}}(t) \leq \hat{w}(t)\mathbf{l} + \hat{r}(t)\mathbf{d} \\ \hat{w}(t) \geq 0,\ \hat{r}(t) \geq 0 \end{gathered} \tag{22}$$

$$\begin{gathered} \max\left\{x_0(t) + \mathbf{x}(t)\left[\mathbf{e} - \hat{\mathbf{p}}(t)\right]\right\} \\ x_0(t)l_0 + \mathbf{x}(t)\mathbf{l} \leq 1 \\ x_0(t)d_0 + \mathbf{x}(t)\mathbf{d} \leq 1 \\ x_0(t) \geq 0,\ \mathbf{x}(t) \geq \mathbf{0} \end{gathered}\ , \tag{23}$$

and then, taking conditions (9) and (12) as equalities, we get:

$$\dot{\hat{\mathbf{p}}}(t) = \Gamma\hat{\mathbf{p}}(t), \tag{24}$$

which can be interpreted as the Hotelling rule,[4]

[4] Since $\dot{v}(t) = (\rho - \Gamma)v(t)$, the maximum rate of uniform growth and the rate of interest in the dual price system are equal as in von Neumann (1945) (see also Rebelo, 1991).

Using equation (24) in conjunction with the dual linear problems (22) and (23), we can now derive the following proposition:

Proposition 1: Let Assumptions [A1]-[A4] hold. Then the optimal production paths, $\bar{x}_0(t)+\bar{\mathbf{x}}(t)\mathbf{e}$, is a decreasing step function with $\bar{\mathbf{x}}(t)\neq\mathbf{0}$ and $\bar{x}_0(t)+\bar{\mathbf{x}}(t)\mathbf{e} > \max\left(\frac{1}{l_0}, \frac{1}{d_0}\right)$ for $t<T_{\mathrm{y}}$, and $\bar{\mathbf{x}}(t)=\mathbf{0}$ and $\bar{x}_0(t)=\max\left(\frac{1}{l_0}, \frac{1}{d_0}\right)$ for $t>T_{\mathrm{y}}$.

Proof. Note that equation (24) implies constancy in the scarcity rents ratios. Thus, fixing $\hat{\mathbf{p}}(0)$, the family of vectors $\left[\frac{\hat{p}_1(0)}{\hat{p}_n(0)}, \frac{\hat{p}_2(0)}{\hat{p}_n(0)}, \ldots, \frac{\hat{p}_{n-1}(0)}{\hat{p}_n(0)}, 1\right]\hat{p}_n(t)$ can be used in (22) to generate a family of linear programs. Linear parametric programming theory then implies that the minimum value, $m(\hat{p}_n(t))=\min\left(\hat{w}(t)+\hat{r}(t)\right)$, is a continuous, convex and piecewise linear function of $\hat{p}_n(t)$. Furthermore, given that the admissible region of problem (22) is non-decreasing with $\hat{p}_n(t)$, the function is non-increasing and becomes the constant $\max\left(\frac{1}{l_0}, \frac{1}{d_0}\right)$ for $\hat{p}_n(t)\geq \hat{p}_n(T_y)$. An example of the minimum function is depicted in Figure 2. Then, from the Duality Theorem of Linear Programming we get:

$$m(\hat{p}_n(t))=\bar{x}_0(t)+\bar{\mathbf{x}}(t)\mathbf{e}-\bar{\mathbf{x}}(t)\left[\frac{\hat{p}_1(0)}{\hat{p}_n(0)}, \frac{\hat{p}_2(0)}{\hat{p}_n(0)}, \ldots, \frac{\hat{p}_{n-1}(0)}{\hat{p}_n(0)}, 1\right]^T\hat{p}_n(t),$$

where $\bar{x}_0(t)+\bar{\mathbf{x}}(t)\mathbf{e}$ is the output associated with an optimal basic solution.

We therefore conclude that the optimal production paths $\bar{x}_0(t)+\bar{\mathbf{x}}(t)\mathbf{e}$, is a decreasing step function with the stated properties.

An implication of Proposition 1 is that the optimal stock trajectory solves the following piecewise linear differential equation:

$$\dot{s}(t)=\bar{x}_0(t)+\bar{\mathbf{x}}(t)\mathbf{e}+\Gamma s(t)-c(0)e^{g^o t}, \qquad (25)$$

in which consumption at time zero is jointly determined by the initial condition $s(0)=\bar{s}$, and by the "final" condition

$$s(T_{\mathrm{y}})=-\frac{1}{\Gamma l_0}+\frac{c(T_{\mathrm{y}})}{\Gamma-g^o},\ s(T_{\mathrm{y}})\geq 0. \qquad (26)$$

What is left out is the analysis of the production path and, hence, the determination of date T_y given in equations (25) and (26). For the case where Assumptions [A5] and [A6] hold, this is the task we accomplish in the following two sections. To fix ideas, in the next section we take n = 2 and give a complete characterization of both the extraction and the substitute production optimal paths.

3. Order of extraction with two deposits

Let us now consider the case where n = 2 and Assumptions [A5] and [A6] hold. The factor intensity conditions in Assumption [A5] have two main implications. First, given that each extraction process is relatively more land-intensive and the backstop is relatively more labor-intensive than is the overall system, then we have $\begin{vmatrix} l_0 & d_0 \\ l_i & d_i \end{vmatrix} > 0$ and $[1, \quad 1]\begin{bmatrix} l_0 & d_0 \\ l_i & d_i \end{bmatrix}^{-1} >> [0 \quad 0], i \in \{1,2\}$. On the other hand, either

$$\begin{vmatrix} l_1 & d_1 \\ l_2 & d_2 \end{vmatrix} = 0,$$

and $[x_1, \quad x_2]\begin{bmatrix} l_1 & d_1 \\ l_2 & d_2 \end{bmatrix} = [1, \quad 1]$ does not have a solution by Assumption [A1], or

$$[1, \quad 1]\begin{bmatrix} l_1 & d_1 \\ l_2 & d_2 \end{bmatrix}^{-1} \ngeq [0, \quad 0].$$

Therefore six basic feasible solutions of the linear problem (23) exist and we can compute them to be:

$$\left[x_0^1, \mathbf{x}^1\right] = \left[0, \quad \left(0, \quad \frac{1}{d_2}\right)\right], \left[x_0^2, \mathbf{x}^2\right] = \left[0, \quad \left(\frac{1}{d_1}, \quad 0\right)\right],$$

$$\left[x_0^3, \mathbf{x}^3\right]=\left[\frac{d_1-l_1}{l_0d_1-l_1d_0}, \quad \left(\frac{l_0-d_0}{l_0d_1-l_1d_0}, \quad 0\right)\right], \left[x_0^4, \mathbf{x}^4\right]=\left[\frac{d_2-l_2}{l_0d_2-l_2d_0}, \quad \left(0, \quad \frac{l_0-d_0}{l_0d_2-l_2d_0}\right)\right]$$

$$\left[x_0^5, \mathbf{x}^5\right]=\left[\frac{1}{l_0}, \quad (0, \quad 0)\right], \left[x_0^6, \mathbf{x}^6\right]=\left[0, \quad (0, \quad 0)\right].$$

We note that the first five of these solutions can be optimal and that the fifth is indeed the long-run optimal solution.

Now we can use Proposition 1 to get

$$m(\hat{p}_2(t))=\max\left\{\frac{1}{l_0}, \quad G_1(\hat{p}_2(t)), \quad G_2(\hat{p}_2(t))\right\}, \tag{27}$$

where

$$G_1(\hat{p}_2(t))=\max\left\{\mathbf{x}^2\mathbf{e}(1-\frac{\hat{p}_1(0)}{\hat{p}_2(0)}\hat{p}_2(t)), \quad \mathbf{x}^3\mathbf{e}+x_0^3-\mathbf{x}^3\mathbf{e}\frac{\hat{p}_1(0)}{\hat{p}_2(0)}\hat{p}_2(t)\right\} \tag{28}$$

and

$$G_2(\hat{p}_2(t))=\max\left\{\mathbf{x}^1\mathbf{e}(1-\hat{p}_2(t)), \quad \mathbf{x}^4\mathbf{e}+x_0^4-\mathbf{x}^4\mathbf{e}\hat{p}_2(t)\right\}. \tag{29}$$

Both function $G_1(\hat{p}_2(t))$ and $G_2(\hat{p}_2(t))$ are continuous, piecewise linear, convex, and decreasing, and both the graphs have a kink, the first at $(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}(1-\frac{d_1}{d_0}), \frac{1}{d_0})$ and the second one at $((1-\frac{d_2}{d_0}), \frac{1}{d_0})$. The graph of $m(\hat{p}_2(t))$ for a given value of $\frac{\hat{p}_2(0)}{\hat{p}_1(0)}$ is depicted in Figure 3.

Thus, we can conclude that deposits extraction will always end with a phase during which the substitute is produced and that an initial phase during which the backstop is inactive will exist only if the stocks are sufficiently large.

A second implication of Assumption [A5] is that, along the optimal path, the price of the factor that is used intensively in the extraction processes cannot increase and the price of factor that is used intensively in the production of the substitute cannot decrease. To prove this, consider the family of linear problems (22). We note that when the backstop is inactive the solution is $\hat{w}=0, \hat{r}=\max\left(G_1, \quad G_2\right)$, while in the long run

we have $\hat{w} = \frac{1}{l_0}, \hat{r} = 0$. Furthermore, when the substitute is produced in the phase preceding exhaustion of the resource, the equilibrium factor prices solve the system of equations

$$\begin{bmatrix} \hat{w} \\ \hat{r} \end{bmatrix} \begin{bmatrix} l_0 & d_0 \\ l_{i*} & d_{i*} \end{bmatrix} = \begin{bmatrix} 1 \\ 1 - p_{i*} \end{bmatrix},$$

where i* is the cost-minimizing extraction process. The desired result follows from the fact that the entries of $\begin{bmatrix} l_0 & d_0 \\ l_{i*} & d_{i*} \end{bmatrix}^{-1}$ are positive at the diagonal and negative off the diagonal.[5]

We are now ready to determine the structure of the optimal extraction path. In constructing Figure 3, we showed that the extraction path ends with a phase during which $\bar{x}_0(t) > 0$. The maximum length of this phase, L, is the solution of the following equation:

$$\hat{p}_2(T_y) = \max\left\{1 - \frac{d_2}{d_0}, (1 - \frac{d_1}{d_0})\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right\} e^{\Gamma t},$$

where $\hat{p}_2(T_y) = \max\left\{1 - \frac{l_2}{l_0}, (1 - \frac{l_1}{l_0})\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right\}$. Thus,

$$L = \frac{1}{\Gamma} \log \frac{\max\left\{1 - \frac{l_2}{l_0}, (1 - \frac{l_1}{l_0})\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right\}}{\max\left\{1 - \frac{d_2}{d_0}, (1 - \frac{d_1}{d_0})\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right\}}. \qquad (30)$$

Since $\frac{\hat{p}_2(0)}{\hat{p}_1(0)} < \min\left\{\frac{1 - \frac{l_2}{l_0}}{1 - \frac{l_1}{l_0}}, \frac{1 - \frac{d_2}{d_0}}{1 - \frac{d_1}{d_0}}\right\}$ implies $m(\hat{p}_2(t)) > G_1(\hat{p}_2(t))$ for each $\hat{p}_2(t)$, the resource price ratio that supports an optimal path must satisfy the inequality

[5] Note that this result is a version of the Samuelson-Stolper Theorem.

$\frac{\hat{p}_2(0)}{\hat{p}_1(0)} \geq \min\left\{\frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}, \frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}}\right\}$. If $\frac{\hat{p}_2(0)}{\hat{p}_1(0)} \geq \max\left\{\frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}, \frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}}\right\} > \min\left\{\frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}, \frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}}\right\}$, then, as shown in Figure 3, only the higher cost deposit is exploited during the phase in which the substitute is produced. On the other hand, if $\min\left\{\frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}, \frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}}\right\} < \frac{\hat{p}_2(0)}{\hat{p}_1(0)} < \max\left\{\frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}, \frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}}\right\}$, then a part of the time L is spent in exploiting the higher cost deposit and the rest in exploiting the lower cost deposit. In this case, the precise sequence of extraction will depend on the value of $\max\left\{\frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}, \frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}}\right\}$. If $\frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}} > \frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}$, then the lower cost deposit is extracted before the higher cost deposit. On the contrary, if $\frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}} < \frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}$, then a cost reversal occurs and the higher cost deposit is used first. Finally, if $\frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}} = \frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}} = \frac{\hat{p}_2(0)}{\hat{p}_1(0)}$, then there is a continuum of optimal extraction paths and the sequence of extraction is therefore indeterminate. Figures 4(a), 4(b) and 4(c) depict the graphs of $m(\hat{p}_2(t))$ for the three case discussed above. Figure 4(a) portrays a "normal" case where $\frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}} > \frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}$ and Figure 4(c) depicts the pathological situation where $\frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}} = \frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}} = \frac{\hat{p}_2(0)}{\hat{p}_1(0)}$. On the other hand, Figure 4(b) illustrates that, when a cost reversal occurs in the phase just preceding the transition to the backstop, then it can be optimal to exploit the lower cost

deposit over two disjoint intervals and, from the above analysis, we expect that for any given initial stock $\bar{y}_1$ below a critical value, there is a threshold level on $\bar{y}_2$ which will determine whether or not discontinuous extraction will occur.

In order to pursue all these cases more deeply, we now study the minimum value of the family of linear programs (22) as a function of the two *in situ* prices, $(\hat{p}_1, \hat{p}_2)$. The graph of this function consists of flat faces, each of which is associated with a specific production of the substitute/extraction profile, so changes in the production of the substitute/extraction strategy occur when a $(\hat{p}_1(t), \hat{p}_2(t))$ ray from the origin crosses the projection of the edges of the graph in the $(\hat{p}_1, \hat{p}_2)$ plane (i. e., where the minimum function is not differentiable). Substituting $\hat{p}_1(t) = \dfrac{\hat{p}_1(0)}{\hat{p}_2(0)}\hat{p}_2(t)$ in (27) and (28) and rearranging the terms in (27), we first calculate:

$$m(\hat{p}_1(t), \hat{p}_2(t)) = \max\left\{\mathbf{x}^2\mathbf{e}(1-\hat{p}_1(t)), \quad \mathbf{x}^1\mathbf{e}(1-\hat{p}_2(t))\right\}$$

$$\text{for } \min\left\{\frac{1-\hat{p}_1(t)}{d_1}, \quad \frac{1-\hat{p}_2(t)}{d_2}\right\} \le \frac{1}{d_0}, \tag{31}$$

$$m(\hat{p}_1(t), \hat{p}_2(t)) = \max\left\{\mathbf{x}^3\mathbf{e} + x_0^3 - \mathbf{x}^3\mathbf{e}\hat{p}_1(t), \quad \mathbf{x}^4\mathbf{e} + x_0^4 - \mathbf{x}^4\mathbf{e}\hat{p}_2(t)\right\} \text{ for}$$

$$\min\left\{\frac{1-\hat{p}_1(t)}{d_1}, \quad \frac{1-\hat{p}_2(t)}{d_2}\right\} \ge \frac{1}{d_0}, \min\left\{\frac{1-\hat{p}_1(t)}{l_1}, \quad \frac{1-\hat{p}_2(t)}{l_2}\right\} \le \frac{1}{l_0}, \tag{32}$$

and

$$m(\hat{p}_1(t), \hat{p}_2(t)) = \frac{1}{l_0} \quad \text{for } \min\left\{\frac{1-\hat{p}_1(t)}{l_1}, \quad \frac{1-\hat{p}_2(t)}{l_2}\right\} \ge \frac{1}{l_0}, \tag{33}$$

and then, using expression (31), (32) and (33), we identify the five regions in the $(\hat{p}_1, \hat{p}_2)$ plane where the basic solutions $\left[x_0^1, \mathbf{x}^1\right], \left[x_0^2, \mathbf{x}^2\right], \left[x_0^3, \mathbf{x}^3\right], \left[x_0^4, \mathbf{x}^4\right]$, and $\left[x_0^5, \mathbf{x}^5\right]$ are optimal.

In Figure 5(a), we depict these regions for the case $\frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}} > \frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}$. Extraction occurs from the lower (higher) cost deposit when $(\hat{p}_1(t), \hat{p}_2(t))$ belongs to the union of sets 1 and 4 (2 and 3). The long run is reached when a ray from the origin crosses set 5. Making time runs backwards, we note that the interior of the union of set 1 and 4 absorbs the trajectories generated by equation (24). We therefore conclude that extraction occurs in order of costs. We also note that $\frac{l_2}{d_2} \geq \frac{l_1}{d_1} \Rightarrow \frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}} > \frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}$.

Using Figure 5(a) we can construct the optimal policy of extraction as follows. Assume $\frac{\hat{p}_2(0)}{\hat{p}_1(0)} \geq \frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}$, let $\hat{p}_2(t) = \frac{\hat{p}_2(0)}{\hat{p}_1(0)}\hat{p}_1(t)$ be a ray from the origin generated by solving equation (24) on the time interval $(-\infty, \infty)$, and let $L_1^3\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)$ be the interval of time that the trajectory spends in set 3. Once $L_1^3\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)$ is known, the time spent in set 4, $L_2^4\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)$, can be found using equation (30) as follows:

$$L_2^4\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right) = \frac{1}{\Gamma}\log\frac{(1-\frac{l_1}{l_0})\frac{\hat{p}_2(0)}{\hat{p}_1(0)}}{\max\left\{1-\frac{d_2}{d_0}, (1-\frac{d_1}{d_0})\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right\}} - L_1^3\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right), \qquad (34)$$

If $\frac{\hat{p}_2(0)}{\hat{p}_1(0)} \geq \frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}}$, then $L_1^3\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right) = \frac{1}{\Gamma}\log\frac{1-\frac{l_1}{l_0}}{1-\frac{d_1}{d_0}}$ and $L_2^4\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right) = 0$. On the other side, if $\frac{\hat{p}_2(0)}{\hat{p}_1(0)} = \frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}$, then $L_1^3\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right) = 0$ and $L_2^4\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right) = \frac{1}{\Gamma}\log\frac{1-\frac{l_2}{l_0}}{1-\frac{d_2}{d_0}}$. For

intermediate values of the resources price ratio, using (32) to find the coordinates of the point where a trajectory enters region 3 and using equation (24) to evaluate $L_1^3\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)$, we get

$$e^{\Gamma L_1^3\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)} = \frac{(1-\frac{l_1}{l_0})(\mathbf{x}^3\mathbf{e}-\mathbf{x}^4\mathbf{e}\frac{\hat{p}_2(0)}{\hat{p}_1(0)})}{\mathbf{x}^3\mathbf{e}+x_0^3-\mathbf{x}^4\mathbf{e}-x_0^4}, \qquad (35).$$

Then, substituting from (35) for $\frac{\hat{p}_2(0)}{\hat{p}_1(0)}$ in (34), we obtain

$$L_2^4 = \frac{1}{\Gamma}\log\frac{(1-\frac{l_1}{l_0})\frac{\mathbf{x}^3\mathbf{e}}{\mathbf{x}^4\mathbf{e}}-\frac{\mathbf{x}^3\mathbf{e}+x_0^3-\mathbf{x}^4\mathbf{e}-x_0^4}{\mathbf{x}^4\mathbf{e}}e^{\Gamma L_1^3}}{1-\frac{d_2}{d_0}} - L_1^3 \qquad (36).$$

Finally, since the amounts extracted in regions 3 and 4, y_1^* and y_2^*, are given by $\mathbf{x}^3\mathbf{e}L_1^3$ and $\mathbf{x}^4\mathbf{e}L_2^4$, respectively, substituting these values in (36) we get

$$y_2^* = \mathbf{x}^4\mathbf{e}\frac{1}{\Gamma}\log\frac{(1-\frac{l_1}{l_0})\frac{\mathbf{x}^3\mathbf{e}}{\mathbf{x}^4\mathbf{e}}-\frac{\mathbf{x}^3\mathbf{e}+x_0^3-\mathbf{x}^4\mathbf{e}-x_0^4}{\mathbf{x}^4\mathbf{e}}e^{\Gamma\frac{y_1^*}{\mathbf{x}^3\mathbf{e}}}}{1-\frac{d_2}{d_0}} - \frac{\mathbf{x}^4\mathbf{e}}{\mathbf{x}^3\mathbf{e}}y_1^* \qquad (37)$$

Figure 5(b) portraits the projection of the optimal paths in the $(y_1(t), y_2(t))$-space. In the figure, the graph of function (37) is the decreasing dashed curve that identifies the boundary of the region where $\bar{x}_0(t) > 0$

In a similar way, we can use Figure 6(a) to fully characterize the optimal extraction paths when $\frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}} < \frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}$ and Figure 7(a) for the singular case $\frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}} = \frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}$. In the first case, $\frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}} < \frac{\hat{p}_2(0)}{\hat{p}_1(0)} < \frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}$ implies that a ray will re-enter the union of set 1 and 4 after leaving it. Therefore, instead of the single function in (37), we need two different functions to define the threshold levels where the lower cost deposit is

temporary abandoned and where $\bar{x}_0(t) > 0$, respectively. We graph the two curves in Figure 6(b), where we also portrait the projection of the optimal paths in the $(y_1(t), y_2(t))$-space. The algebra is relegated in the Appendix.

In the second case, the extraction policy is determined, and no cost reversal occurs, only if the stock in the higher cost deposit is sufficiently large. Otherwise, the optimal path is indeterminate. Figure 7(b) depicts the region of indeterminacy. In the Appendix we provide a formal derivation of the results.

The above findings are summarized in Proposition 2.

Proposition 2: Let Assumptions [A1]-[A6] hold and let n = 2. Then:

(i) for each ray $(\lambda y_1(t), \lambda y_2(t)) \in R^2_+$, $\lambda \geq 0$ there is a number M > 0 such that $\lambda < M \Rightarrow \bar{x}_0(t) > 0$ and $\lambda > M \Rightarrow \bar{x}_0(t) = 0$.

(ii) the real rental rate of factor used intensively in the extraction processes is not increasing and the real rental rate of factor that is used intensively in the production of the substitute is not decreasing along any dual optimal path,

(iii) if $\dfrac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}} > \dfrac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}$, then the optimal order of extraction is the order of costs. If $\dfrac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}} \leq \dfrac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}$, then there is a number N > 0 such that: (a) deposits are optimally extracted in order of costs if $\bar{y}_1 \geq N$, (b) a cost reversal occurs along the optimal path if $\bar{y}_1 < N$ and $\dfrac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}} < \dfrac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}$. In this case, for each $\bar{y}_1 < N$ there is a threshold value on $\bar{y}_2$, $P(\bar{y}_1)$, such that the lower cost resource is optimally extracted on two disjoint intervals if and only if $\bar{y}_2 > P(\bar{y}_1)$, (c) If $\bar{y}_1 < N$ and $\dfrac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}} = \dfrac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}$, then a portion of the optimal extraction path is indeterminate.

4. Order of extraction with any number of deposits

Consider the general case of an arbitrary number of deposits n and let Assumptions [A5] and [A6] hold. By extending the argument used in section 3, we see that $[1, \quad 1]\begin{bmatrix} l_0 & d_0 \\ l_i & d_i \end{bmatrix}^{-1} >> [0 \quad 0], i \in \{1,2,\cdots,n\}$ and no system $[x_i, \quad x_j]\begin{bmatrix} l_i & d_i \\ l_j & d_j \end{bmatrix} = [1, \quad 1]$ has a non-negative solution for $i, j \in \{1,2,\cdots,n\}, i \neq j$. Therefore, only 2n – 1 semi-positive basic feasible solutions of the linear problem (23) exist and, hence, by using Proposition 1, we can get

$$m(\hat{p}_n(t)) = \max\left\{\frac{1}{l_0}, G_1(\hat{p}_n(t)), G_2(\hat{p}_n(t)), \ldots, G_n(\hat{p}_n(t))\right\}, \tag{38}$$

where

$$G_i(\hat{p}_n(t)) = \max\left\{\frac{1-\frac{\hat{p}_i(0)}{\hat{p}_n(0)}\hat{p}_n(t)}{d_i}, \quad \frac{d_i - l_i + l_0 - d_0}{l_0 d_i - l_i d_0} - \frac{l_0 - d_0}{l_0 d_i - l_i d_0}\frac{\hat{p}_i(0)}{\hat{p}_n(0)}\hat{p}_n(t)\right\}$$

$$i \in \{1,2,\cdots,n\}. \tag{39}$$

Since the graph of each $G_i(\hat{p}_n(t))$ is kinked at $(\frac{\hat{p}_n(0)}{\hat{p}_i(0)}(1-\frac{d_i}{d_0}), \frac{1}{d_0})$, as for the two-deposits case, extraction will always ends with a phase during which $\bar{x}_0(t) > 0$, and an extraction phase during which the backstop is inactive will exists only if the stocks are sufficiently large. Thus, along the optimal dual path the "wage rate" is still not decreasing, while the "land rent rate" is still not increasing and, furthermore, the maximum number of disjoint intervals during which a single deposit can be used is two. We have, therefore, constrained the optimal extraction path, and established that point (ii) and the general analog of point (i) of Proposition 2 hold with an arbitrary number of deposits.

We can further characterize the optimal extraction path as in Proposition 3.

Proposition 3: Let Assumptions [A1]-[A6] hold. Then:

(i) if $\dfrac{1-\dfrac{d_j}{d_0}}{1-\dfrac{d_i}{d_0}} > \dfrac{1-\dfrac{l_j}{l_0}}{1-\dfrac{l_i}{l_0}}$ $\forall\, i,j \in \{1,2,\cdots,n\}, i<j$, then the optimal order of extraction is the order of costs,

(ii) if $\exists\, i,j \in \{1,2,\cdots,n\}, i<j$ such that $\dfrac{1-\dfrac{d_j}{d_0}}{1-\dfrac{d_i}{d_0}} < \dfrac{1-\dfrac{l_j}{l_0}}{1-\dfrac{l_i}{l_0}}$, then there exist a non zero measure subset of R^n_{++}, U, such that $\bar{\mathbf{y}} \in U$ implies that deposit j is extracted on two disjoint intervals.

Proof. First, note that if $\dfrac{1-\dfrac{d_j}{d_0}}{1-\dfrac{d_i}{d_0}} > \dfrac{1-\dfrac{l_j}{l_0}}{1-\dfrac{l_i}{l_0}}$, $i,j \in \{1,2,\cdots,n\}, i<j$, then $G_i(\hat{p}_n^*) = G_j(\hat{p}_n^*) \Rightarrow\ G_i(\hat{p}_n) > G_j(\hat{p}_n)$ for each $\hat{p}_n > \hat{p}_n^*$. This proves point (i). Assume now that $\exists\, i,j \in \{1,2,\cdots,n\}, i<j$ such that $\dfrac{1-\dfrac{d_j}{d_0}}{1-\dfrac{d_i}{d_0}} < \dfrac{1-\dfrac{l_j}{l_0}}{1-\dfrac{l_i}{l_0}}$. By choosing sufficiently high resource price ratios $\dfrac{\hat{p}_z(0)}{\hat{p}_i(0)}$ and $\dfrac{\hat{p}_z(0)}{\hat{p}_j(0)}, z \neq i,j$, we know from point (iii) of Proposition 2 that we can choose $\dfrac{\hat{p}_j(0)}{\hat{p}_i(0)}$ in such a way that deposit j is cost-minimizing on two disjoint intervals of the range of $\hat{p}_n$. Now, we can progressively diminish prices $\hat{p}_z(0)$ until each deposit will appear on the $m(\hat{p}_n(t))$ frontier on (at least) an interval of the range of $\hat{p}_n$, leaving at the same time deposit j on the frontier on two disjoint intervals. This proves point (ii).

5. Concluding remarks

We have examined the optimal order of extraction of several nonrenewable resource deposits with different costs of extraction when the extracted resource can be

converted into productive capital and the extraction process, as well as the production of the substitute, requires two primary factors of production. As we have shown, even if the time paths of primary factor prices are monotonic, when high cost resources are not abundant, then complete cost reversals can occur depending on whether or not an intensity condition is satisfied for each pair of deposits. In turn, these cost reversals will determine discontinuous extraction from low cost reserves if the initial endowment of these low cost deposits is sufficiently large.

Our analysis extends to a single demand setting in which resources are differentiated by cost and the extracted resource can be converted into productive capital a phenomenon that is known can arise with multiple demands (Gaudet, Moreaux and Salant, 2001, Im, Chackavorty and Roumasset, 2006), with resources that are differentiated by their polluting characteristics (Chackavorty, Moreaux and Tidball, 2008), and with capacity constraints on the extraction rate of a non storable resource (Freni, 2004, Holland, 2003).

Two important assumptions in the model are that there is in incentive to accumulate (Assumption [A4]), and that the factor intensity of the overall system is intermediate between the factor intensity of the backstop and that of each extraction process (Assumption [A5]), implying that transitional dynamics of factor price is monotonic. It may be of some interest to know what kind of new phenomena can arise without these assumptions.

Appendix

Consider in Figure 6(a) a ray from the origin whose slope $\frac{\hat{p}_2(0)}{\hat{p}_1(0)}$ lies in the interval $\left(\frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}}, \frac{1-\frac{l_2}{l_0}}{1-\frac{l_1}{l_0}}\right)$. Let $\left(p_1^*\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right), \frac{\hat{p}_2(0)}{\hat{p}_1(0)} p_1^*\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)\right)$ be the coordinates of the point where the ray intersects the set $(3 \cap 4)$ and let $\left(p_1^{**}\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right), \frac{\hat{p}_2(0)}{\hat{p}_1(0)} p_1^{**}\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)\right)$ be the coordinates of the point where the ray intersect the set $(1 \cap 2)$. Using first equation (24) to calculate the time the trajectory stays in the different regions, and then (31) and (32) to evaluate $p_1^*\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)$ and $p_1^{**}\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)$ we get

$$e^{\Gamma L_1^3\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)} = \frac{p_1^*\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)}{1-\frac{d_1}{d_0}} \tag{A1}$$

$$e^{\Gamma L_2^4\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)} = \frac{1-\frac{l_2}{l_0}}{\frac{\hat{p}_2(0)}{\hat{p}_1(0)} p_1^*\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)} \tag{A2}$$

$$e^{\Gamma L_1^2\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)} = \frac{1-\frac{d_1}{d_0}}{p_1^{**}\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)} \tag{A3}$$

$$p_1^*\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right) = \frac{\mathbf{x}^3\mathbf{e} + x_0^3 - \mathbf{x}^4\mathbf{e} - x_0^4}{\mathbf{x}^3\mathbf{e} - \mathbf{x}^4\mathbf{e}\frac{\hat{p}_2(0)}{\hat{p}_1(0)}} \tag{A4}$$

and

$$p_1^{**}\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)=\frac{\mathbf{x}^2\mathbf{e}-\mathbf{x}^1\mathbf{e}}{\mathbf{x}^2\mathbf{e}-\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\mathbf{x}^1\mathbf{e}} \quad , \qquad \text{(A5)}$$

where $L_1^2\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)$ is the time spent in set 2. Then, substituting from (A4) for $p_1^*\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)$ in (A1) and (A2) and from (A4) for $p_1^{**}\left(\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\right)$ in (A3), we have

$$L_1^3=\frac{1}{\Gamma}\log\frac{\mathbf{x}^3\mathbf{e}+x_0^3-\mathbf{x}^4\mathbf{e}-x_0^4}{(1-\frac{d_1}{d_0})(\mathbf{x}^3\mathbf{e}-\mathbf{x}^4\mathbf{e}\frac{\hat{p}_2(0)}{\hat{p}_1(0)})} \qquad \text{(A6)}$$

$$e^{\Gamma L_2^4}=\frac{(1-\frac{l_2}{l_0})(\mathbf{x}^3\mathbf{e}-\mathbf{x}^4\mathbf{e}\frac{\hat{p}_2(0)}{\hat{p}_1(0)})}{(\mathbf{x}^3\mathbf{e}+x_0^3-\mathbf{x}^4\mathbf{e}-x_0^4)\frac{\hat{p}_2(0)}{\hat{p}_1(0)}} \qquad \text{(A7)}$$

$$L_1^2=\frac{1}{\Gamma}\log\frac{(1-\frac{d_1}{d_0})(\mathbf{x}^2\mathbf{e}-\frac{\hat{p}_2(0)}{\hat{p}_1(0)}\mathbf{x}^1\mathbf{e})}{\mathbf{x}^2\mathbf{e}-\mathbf{x}^1\mathbf{e}} \qquad \text{(A8).}$$

Finally, since the amount of the resource extracted in set 2, y_1^{**}, is given by $\mathbf{x}^2\mathbf{e}L_1^2$, substituting from (A7) for $\frac{\hat{p}_2(0)}{\hat{p}_1(0)}$ into (A6) and (A8) and remembering that $y_1^*=\mathbf{x}^3\mathbf{e}L_1^3$ and $y_2^*=\mathbf{x}^4\mathbf{e}L_2^4$, we get

$$y_1^*=\frac{\mathbf{x}^3\mathbf{e}}{\Gamma}\log\frac{\mathbf{x}^3\mathbf{e}+x_0^3-\mathbf{x}^4\mathbf{e}-x_0^4}{(1-\frac{d_1}{d_0})(\mathbf{x}^3\mathbf{e}-\mathbf{x}^4\mathbf{e}\frac{(1-\frac{l_2}{l_0})\mathbf{x}^3\mathbf{e}}{(\mathbf{x}^3\mathbf{e}+x_0^3-\mathbf{x}^4\mathbf{e}-x_0^4)e^{\frac{\Gamma y_2^*}{\mathbf{x}^4\mathbf{e}}}+(1-\frac{l_2}{l_0})\mathbf{x}^4\mathbf{e}})} \qquad \text{(A9)}$$

$$y_1^{**} = \frac{\mathbf{x}^2\mathbf{e}}{\Gamma}\log\frac{(1-\frac{d_1}{d_0})(\mathbf{x}^2\mathbf{e} - \frac{(1-\frac{l_2}{l_0})\mathbf{x}^3\mathbf{e}}{(\mathbf{x}^3\mathbf{e} + x_0^3 - \mathbf{x}^4\mathbf{e} - x_0^4)e^{\frac{\Gamma y_2^*}{\mathbf{x}^4\mathbf{e}}} + (1-\frac{l_2}{l_0})\mathbf{x}^4\mathbf{e}}\mathbf{x}^1\mathbf{e})}{\mathbf{x}^2\mathbf{e} - \mathbf{x}^1\mathbf{e}} \qquad \text{(A10)}.$$

The graph of function (A9) and that of the sum of the functions (A9) and (A10) give the two threshold curves in Figure 6(b).

Consider now the case depicted in Figure 7(a). Note that $\mathbf{x}^3\mathbf{e}\frac{1}{\Gamma}\left[\log(1-\frac{l_1}{l_0}) - \log(1-\frac{d_1}{d_0})\right]$ is the maximum amount of the resource that can be extracted from the higher cost deposit when $\frac{\hat{p}_2(0)}{\hat{p}_1(0)} = \frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}}$ and that $\frac{\hat{p}_2(0)}{\hat{p}_1(0)} > \frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}}$ implies that the minimum amount extracted from the higher cost deposit exceeds $\mathbf{x}^3\mathbf{e}\frac{1}{\Gamma}\left[\log(1-\frac{l_1}{l_0}) - \log(1-\frac{d_1}{d_0})\right]$. We have, therefore

$$\bar{y}_1 > \mathbf{x}^3\mathbf{e}\frac{1}{\Gamma}\left[\log(1-\frac{l_1}{l_0}) - \log(1-\frac{d_1}{d_0})\right] \Rightarrow \frac{\hat{p}_2(0)}{\hat{p}_1(0)} > \frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}}$$

$$\bar{y}_1 \le \mathbf{x}^3\mathbf{e}\frac{1}{\Gamma}\left[\log(1-\frac{l_1}{l_0}) - \log(1-\frac{d_1}{d_0})\right] \Rightarrow \frac{\hat{p}_2(0)}{\hat{p}_1(0)} = \frac{1-\frac{d_2}{d_0}}{1-\frac{d_1}{d_0}}.$$

Hence, by inspecting Figure 7(a) we can conclude that the optimal extraction path is determined if $\bar{y}_1 > \mathbf{x}^3\mathbf{e}\frac{1}{\Gamma}\left[\log(1-\frac{l_1}{l_0}) - \log(1-\frac{d_1}{d_0})\right]$.

Assume now $\frac{\bar{y}_1}{\mathbf{x}^3\mathbf{e}} \le \frac{1}{\Gamma}\left[\log(1-\frac{l_1}{l_0}) - \log(1-\frac{d_1}{d_0})\right]$. Note that the maximum amount that can be extracted from the low cost deposit in set $(3 \cap 4)$ is given by $\mathbf{x}^4\mathbf{e}\left\{\frac{1}{\Gamma}\left[\log(1-\frac{l_1}{l_0}) - \log(1-\frac{d_1}{d_0})\right] - \frac{\bar{y}_1}{\mathbf{x}^3\mathbf{e}}\right\}$. Thus, the optimal extraction strategy will have

a support in $(3 \cap 4)$ if and only if $\frac{\bar{y}_2}{\mathbf{x}^4\mathbf{e}} \leq \left\{\frac{1}{\Gamma}\left[\log(1-\frac{l_1}{l_0})-\log(1-\frac{d_1}{d_0})\right]-\frac{\bar{y}_1}{\mathbf{x}^3\mathbf{e}}\right\}$. In this case, any (measurable and locally integrable) function $\theta(t)$, such that $\theta(t) \geq 0$, $\int_0^{\frac{\bar{y}_2}{\mathbf{x}^4\mathbf{e}}+\frac{\bar{y}_1}{\mathbf{x}^3\mathbf{e}}} \theta(t)dt = \frac{\bar{y}_1}{\mathbf{x}^3\mathbf{e}}$ and $\int_0^{\frac{\bar{y}_2}{\mathbf{x}^4\mathbf{e}}+\frac{\bar{y}_1}{\mathbf{x}^3\mathbf{e}}} (1-\theta(t))dt = \frac{\bar{y}_2}{\mathbf{x}^4\mathbf{e}}$ will generate the optimal extraction strategy $\left[\bar{x}_1(t) \quad \bar{x}_2(t)\right]=\left[\theta(t)\mathbf{x}^3\mathbf{e}, \quad (1-\theta(t))\mathbf{x}^4\mathbf{e}\right]$. If the stock in the low cost deposit exceeds the given threshold, $\frac{\bar{y}_2}{\mathbf{x}^4\mathbf{e}} > \left\{\frac{1}{\Gamma}\left[\log(1-\frac{l_1}{l_0})-\log(1-\frac{d_1}{d_0})\right]-\frac{\bar{y}_1}{\mathbf{x}^3\mathbf{e}}\right\}$, then the initial price support lies in region 1, so the optimal extraction path has an initial segment during which $\left[\bar{x}_1(t) \quad \bar{x}_2(t)\right]=\left[0, \quad \mathbf{x}^1\mathbf{e}\right]$. This phase will end when $\frac{\bar{y}_2-\mathbf{x}^1\mathbf{e}t}{\mathbf{x}^4\mathbf{e}} = \left\{\frac{1}{\Gamma}\left[\log(1-\frac{l_1}{l_0})-\log(1-\frac{d_1}{d_0})\right]-\frac{\bar{y}_1}{\mathbf{x}^3\mathbf{e}}\right\}$. Then the system will enter the indeterminacy region if $\left\{\frac{1}{\Gamma}\left[\log(1-\frac{l_1}{l_0})-\log(1-\frac{d_1}{d_0})\right]-\frac{\bar{y}_1}{\mathbf{x}^3\mathbf{e}}\right\} > 0$. We have, therefore, the result stated in point (iii)-(c) of Proposition 2.

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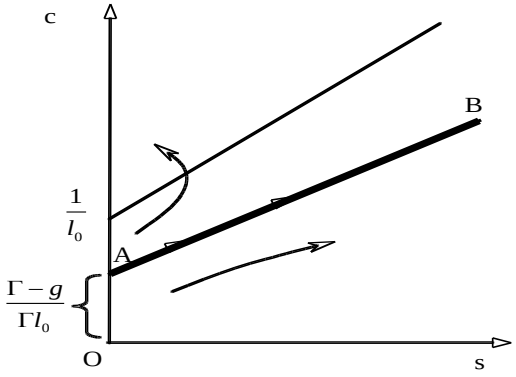


Figure 1

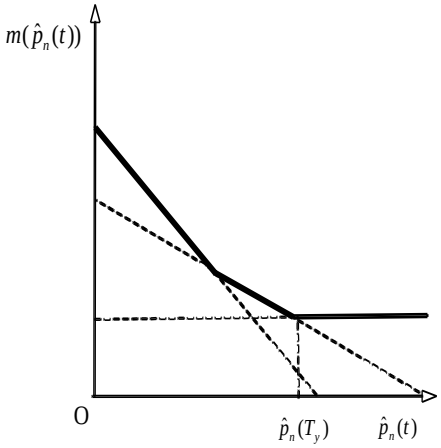


Figure 2

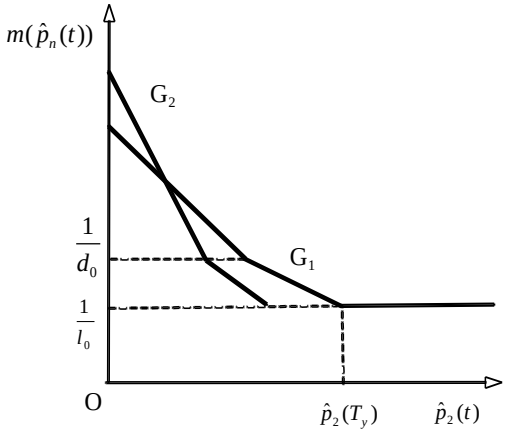
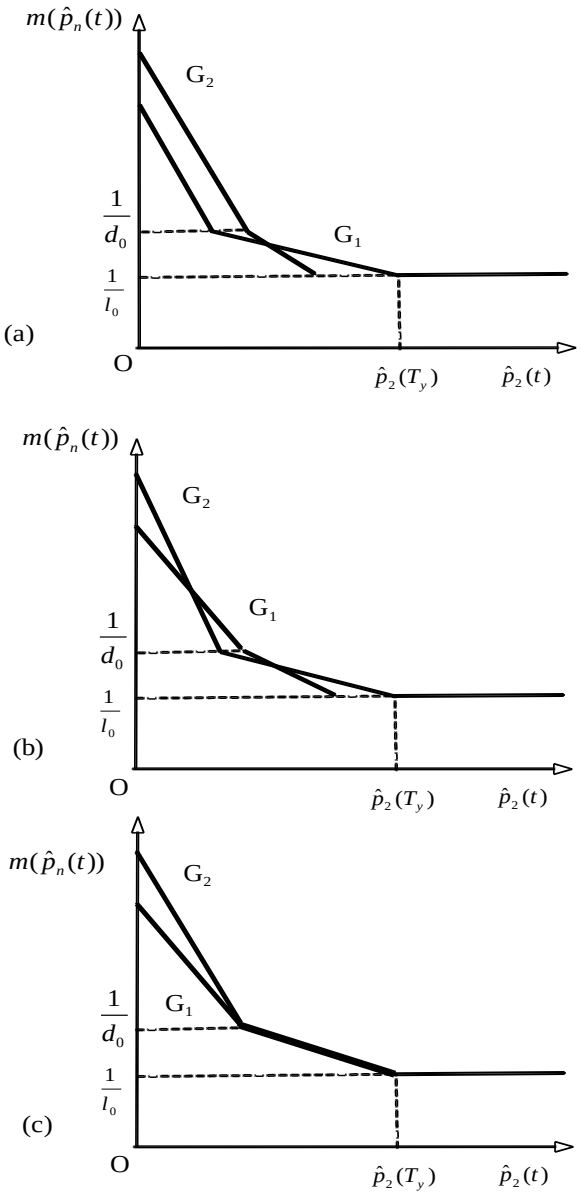


Figure 3


$m(\hat{p}_n(t))$
G_2
G_1
$\frac{1}{d_0}$
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O
$\hat{p}_2(T_y)$
$\hat{p}_2(t)$
(a)
$m(\hat{p}_n(t))$
G_2
G_1
$\frac{1}{d_0}$
$\frac{1}{l_0}$
O
$\hat{p}_2(T_y)$
$\hat{p}_2(t)$
(b)
$m(\hat{p}_n(t))$
G_2
G_1
$\frac{1}{d_0}$
$\frac{1}{l_0}$
O
$\hat{p}_2(T_y)$
$\hat{p}_2(t)$
(c)

Figure 4

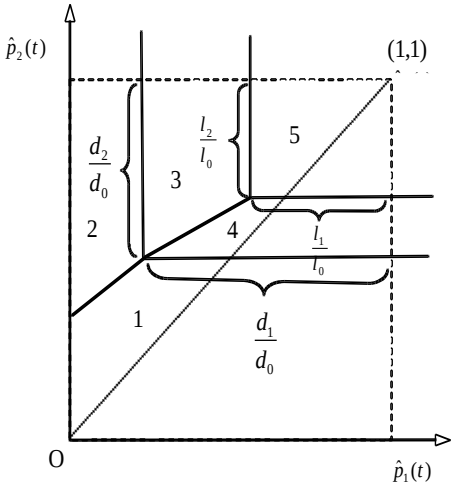

Figure 5(a)

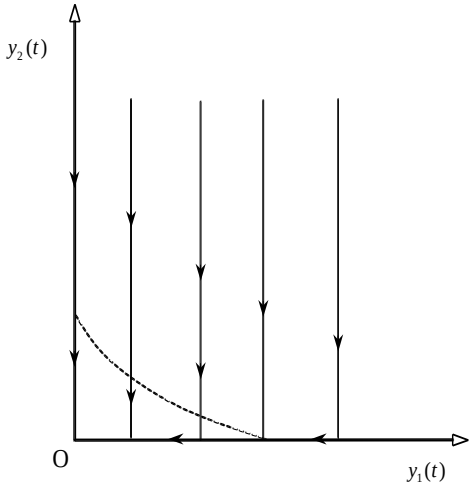

Figure 5(b)

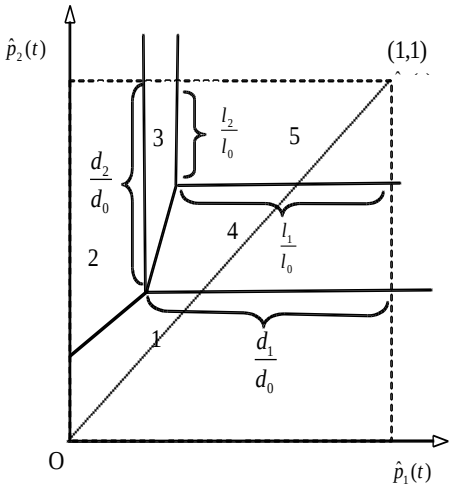

Figure 6(a)

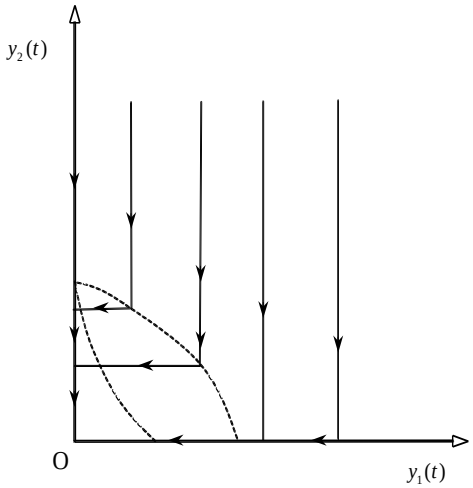

Figure 6(b)

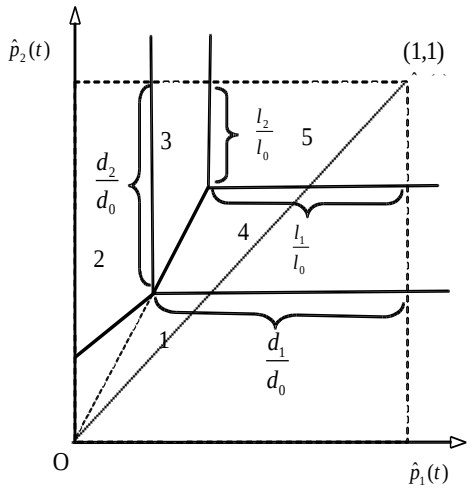

Figure 7(a)

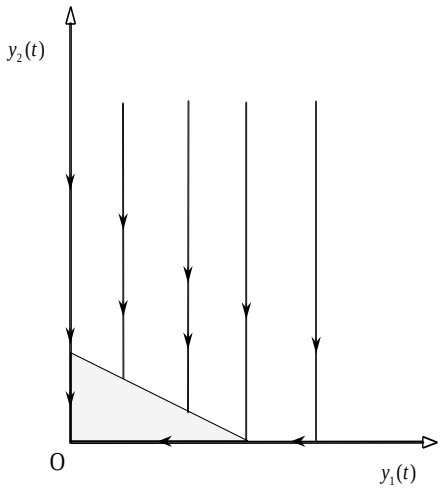

Figure 7(b)

Water Conservation Behavior and Environmental Concerns

Maria Carmela Aprile and Fiorillo Damiano

Abstract

Water conservation represents one important pro-environmental behavior for a sustainable environment. This paper investigates the link between water conservation behavior and general environmental concerns using a large dataset as the1998 wave of Multipurpose Household Survey conducted annually by the Italian Central Statistical Office. Univariate probit models show that *pollution* and *resource exhaustion* are positively related to individual water conservation behavior while *alteration of environmental heritage* exhibits a negative relationship with water saving behavior. These findings are robust to the inclusion of environment knowledge and social capital variables. The robustness analysis also indicates that television and radio, participation to environmental initiatives, money for environmental protection and churchgoing are significant determinants of water conservation behavior.

*JEL classification***:** Q25, Q50, C21, C25, Z00
*Keywords***:** Water conservation, environmental concerns, socio and economic characteristics, environmental knowledge, social capital, Italy

1. Introduction

Water has been identified as one of the most important natural resources and somewhat different from the rest, because it is viewed as a key to prosperity and wealth (Arbués et al. 2003). Water depletion and contamination are among the main environmental problems faced worldwide in the 21st century and water conservation represents important pro-environmental behavior for a sustainable way of life on the planet (Corral-Verdugo et al. 2003). Water is generally abundant within the European region, but it is also unevenly distributed both in time and space, with large areas experiencing levels of water scarcity and drought (EEA 2012). Moreover, the current state of Europe's water resources is perceived to be under increasing pressure from a range of external drivers, which contribute to reduce water availability and increase pollution, thereby affecting water quality. Socio-economic factors such as population growth, increased consumption, and land use enhance the imbalance between water demand and water availability. As a result of this increasing imbalance, water resources are expected to diminish in Europe (Metzger et al. 2006). Climate change also has a huge impact on water scarcity (Weiβ and Alcamo 2011). Many regions in southern and eastern Europe, as well as some in western Europe, are already experiencing severe drought during the summer. However, projections indicate a deterioration and also a northward extension of the problem in future. Because the most significant causes of the water problem arise from human behavior, the search for determinants of water conservation behavior is one of the main objectives of environmental sciences (Corral-Verdugo et al. 2008) which has attracted research attention across numerous disciplines, including psychology, sociology, political science and economics. A number of studies have suggested that water consumption behavior is mainly predicted by price, socio-demographic features, psychological factors and environmental knowledge. One key result of this research is that environmental concerns are correlated with water conservation behavior when concerns and behaviors are assessed at a corresponding level of specificity.

In this paper we consider environmental concerns as non-monetary incentives in order to investigate the relationship between water conservation behavior and general environmental concerns using a large survey that provides information about environmental concerns and behaviors in a Mediterranean country: Italy. To the best of our knowledge, the empirical assessment of the relationship between general environmental concerns and water conservation behavior has never been performed in Italy.

Our study contributes to the literature in several ways. First, we perform an econometric analysis of the relationship between general environmental concerns and water conservation behavior, when concerns and behavior are not assessed at the same corresponding level of specificity controlling for

socio-economic characteristics. Secondly, in line with the psychological environmental literature we consider two types of general environmental concerns, egoistic and altruistic, and set up economic empirical hypotheses linking general environmental concerns with water saving behavior. Finally, we also take into account the source of information about environment problems and social capital to perform robustness analysis. Indeed, environmental knowledge and social capital may have simultaneous effects on general environmental concerns and water conservation behavior (Vicente-Molina et al. 2013; Owen and Videras 2007).

In the empirical analysis we use a dataset of approximately 41,000 individuals from the Multipurpose Household Survey (MHS) conducted annually by the Italian Central Statistics Office (ISTAT). We consider the year 1998 for an important reason: in this year there was no promotional campaign to inform the population about the importance of environmental issues. Thus people's sensibility to environmental problems was exclusively influenced by their own way of being.

In the ISTAT dataset respondents are asked about the frequency with which they save water at home. Our dependent variable *water conservation behavior* is a dummy variable equal to 1 for individuals who always save water, 0 otherwise. The key independent variables are general environmental concerns. We identify four variables that measure general environmental concerns: (EC1) *pollution* (noise, air, soil, water, electromagnetic); (EC2) *climate change* (greenhouse effect, climate change); (EC3) *resource exhaustion* (destruction of forests, depletion of natural resources); (EC4) *alteration of environmental heritage* (species extinction, destruction of the landscape).

Using univariate probit models we show that *pollution* and *resource exhaustion* are positively related to individual water conservation behavior while *alteration of environmental heritage* exhibits a negative relationship with water saving behavior. The former result may indicate that when an individual perceives general environmental issues as a threat to his/her own welfare as well as the welfare of the group which he/she is part of, the individual will save water at home. The latter finding may point out that when an individual perceives that general environmental issues are a threat to his/her group's welfare but thinks that for the others this is not so, then the individual will not save water. These findings are robust to the inclusion of the source of information about environment problems and social capital variables. Robustness investigation shows that specific sources such as television and radio, participation in environmental initiatives, supporting environmental protection with money and churchgoing are also significant determinants of water conservation behavior.

The paper is organized as follows. Section 2 contains a review of the related literature while Section 3 presents the empirical hypothesis. Section 4 describes the data and presents the empirical strategy. Sections 5 and 6 illustrate and discuss the econometric results.

2. Literature review

A large body of economic and social research has investigated the factors influencing water use behavior. Previous research has focused on specific areas of interest in attempting to define the determinants of water saving behavior. These areas are: i) water price; ii) socio-demographic features; iii) belief, attitude and concern; iv) environmental knowledge.

Water price

Price and economic incentives relate to the extent to which individuals believe price is a significant variable in reducing water conservation (Syme et al. 2000; Gilg and Barr 2006). Although price influences water demand, most research has found water demand rather price inelastic (Barrett 2004; Hoffman 2006; Clark and Finley 2007; Worthington and Hoffman 2008; Schleich and Hillenbrand 2009). This is because water has no substitutes for basic uses and water bills represent a small proportion of income (Arbuès et al. 2003).

Socio-demographic features

Socio-demographic characteristics examined include both individual characteristics, such as age, education, income, household composition and tenancy (Hamilton 1983; Berk et al. 1993; De Oliver 1999; Loh and Coghlan 2003; Campbell et al. 2004; Gilg et al. 2005; Willis et al. 2013); and property characteristics, such as house size and house age (Cavanagh et al. 2002; Olmstead et al. 2003; Syme et al. 2004).

With specific reference to individual characteristics, most studies that have examined age as a determinant of water conservation have found that older people are more likely to be water conservers (Gregory and Di Leo 2003; Gilg and Barr 2006; Clark and Finley 2007). Gregory and Di Leo (2003), who investigated water conservation behavior as a function associated with different experiences of generations, suggest that age may be positively related to water conservation while Gilg and Barr (2006) who analyzed the individual characteristics of different types of water savers pointed out that the most committed to water saving in the home were people with the highest age. Similar results are reported by Clark and Finley (2007). Inconsistencies emerge from the research investigating the impact of education on water conservation behavior. Some researchers report a positive relationship between education and water conservation (De Oliver 1999; Gilg and Barr 2006; Lam 2006). Thus, people who are more committed to water conservation are also more highly educated. Conversely, other researchers show an inverse relationship. In particular, they found that it is less educated individuals that show both more water conservation behavior and higher water conservation intentions (Gregory and Di Leo 2003; Clark and Finley 2007). Results from studies that examine income as a determinant of water conservation behavior are more

consistent. Research generally shows that individuals with higher income levels consume more water (Arbuès and Villanua 2006; Russell and Fielding 2010; Willis et al. 2013). Past research has also identified household size as a relevant variable influencing water consumption behavior. Makki et al. (2013) who explore the predominant determinants of water consumption show that the number of children and teenagers in a household is the most important characteristic influencing the increased water consumption. These findings are consistent with those of Randolph and Troy (2008) who found that households with children are the biggest users of water. Gregory and Di Leo (2003) have demonstrated a positive relationship between the number of residents and water use. More residents in a household explained a higher proportion of water consumption. Moreover, Gilg and Barr (2006) found that committed environmentalists who tended to have smaller households were more likely to engage water conservation behavior. However, Willis et al. (2013) demonstrated the opposite results. Their study indicates that there is a general decrease in water consumption per capita as family size increases. It was found that the kind of houses people live in and whether they are homeowners are additional factors that may influence water conservation behavior. Studies have found that individuals who live in detached houses report higher saving behavior (Gilg and Barr 2006; Clark and Finley 2007). Randolph and Troy (2008) showed that home owners are likely to have a direct control over their homes and are in a better position to undertake refitting through the installation of new appliances that can assist in lowering overall water use. In contrast, residential tenants have less control over practical conservation methods and do not know how much water they use as their water consumption is usually paid as part of the service charge payment. These findings suggest that homeowners are more likely to engage in more efficient behaviors, compared to tenants.

Belief, attitude and concern

Belief, attitude and concern have been perceived as predictors of water conservation behaviors. Within the (environmental) psychological literature, belief is conceptualized as a person's worldview which reflects beliefs about the relationship of people with the natural world (Scott and Willits 1994; Schultz et al. 2004; Russell and Fielding 2010). Attitude is determined by strengths of beliefs about consequences of behaviors and evaluations of such consequences (Ajzen 1989, 1991; Ajzen and Fishbein 2000). Environmental concern is treated as an attitude toward facts, one's own behavior, or others' behavior with consequences for the environment (Weigel 1983; Takala 1991; Bamberg 2003). Environmental concern may refer to either a specific attitude directly determining behaviors, or more broadly to a general attitude or value orientation (Stern 1992; Stern et al. 1993, 1995; Fransson and Garling 1999; Schultz 2000, 2001; Russell and Fielding 2010). These studies identify three different general attitudes:

(i) in the first case, environmental concern represents a new way of thinking called the New Environmental Paradigm (NEP). The NEP seeks to measure people's general environmental beliefs and their ecological worldview on a survey scale. The scale measures beliefs about the limits of nature and resources, human impacts on the balance of nature, humans' right to dominate over nature and the potential for ecological catastrophe. The works of Corral-Verdugo et al. (2003) and Corral-Verdugo et al. (2008) used the NEP survey scale to investigate the relationship between general environmental beliefs and water conservation behavior. In the first study general environmental beliefs were not found to be predictors of water consumption behavior while, in the second study, general environmental beliefs were shown to be drivers of water saving. Also Willis et al. (2011) used a survey scale on environmental issues showing, through cluster analysis, a positive link between general environmental attitudes and water conservation behavior.

(ii) In a second value orientation, environmental concern is tied to altruism: people care about environmental quality because they belief that a degraded environment poses a threat to people's health. Hence, it is the threat to wellbeing of people that is of central concern. In other words, a person judges environmental problems on the basis of the costs or benefits for other people, be they individuals, a neighborhood, a social network, a country or all humanity (Black et al. 1985; Hopper and Nielsen 1991; Schultz 2000). Stern et al. (1993) show that a person with an altruistic environmental concern has a higher pro-environmental behavior.

(iii) According to a third value orientation, environmental concern expresses self-interest: it is the perceived personal threats caused by environmental deterioration which is the important factor in underlying environmentally responsible behavior. Hence, self-interest may predispose a person to protect aspects of the environmental that affect him/her personally or to oppose protection of the environment if the personal costs are perceived as high (Stern and Dietz 1994). However, Stern et al. (1993, 1995) found a positive relationship between self-interested environmental concern and pro-environmental behavior.

Environmental knowledge

Most studies view environmental knowledge as antecedence of environmental concerns (Bamberg 2003). In particular, it has been found that the level of environmental knowledge could be crucial in turning individuals' behavior toward sustainability (Adomssent 2013; Bradley et al. 1999; Szerényi et al. 2009). People who have greater knowledge of environmental problems and their causes will become more motivated to act toward the environment in more responsible ways (Barber et al. 2009). Conversely, lack of knowledge or the holding of contradictory information might limit pro-environmental behavior (Vicente-Molina et al. 2013). However, as reported in Vicente-Molina et al. (2013), although the theoretical literature states that knowledge might play a significant role in pro-

environmental behavior, the empirical evidence is not clear. Some studies find no close relationship between environmental knowledge and pro-environmental behavior (Bartiaux 2008; Laroche et al. 2001; Maloney and Ward 1973). Others show that a deeper knowledge of environmental issues increases the likelihood of people taking action to protect the environment (Kaiser and Fuhrer 2003; Kollmuss and Agyeman 2002; Mobley et al. 2010). Specifically, according to Stern (1992), when individuals who are more actively engaged in environmental issues are compared to less actively engaged individuals, the factor which most clearly differentiates between the groups is knowledge about the specific problem and how to act in order to most effectively deal with it. Grob (1995) finds that the more people know about environmental problems, the more appropriately they will behave. This hypothesis is supported by Kaiser et al. (1999) who suggest that environmental knowledge has predictive power in terms of pro-environmental behavior. In a specific study on water conservation, Clark and Finley (2007) sought to identify the relationship between specific knowledge of environmental problems and water conservation behavior, finding that individuals who reported greater awareness of environmental problems also reported greater conservation actions.

It is worth pointing out that general knowledge about environmental issues is often acquired through the education system (García – Valiñas et al. 2010). The literature agrees in describing such a source of environmental knowledge as formal education. In particular, some studies suggest that formal education aims to raise concern for the environment and provide individuals with the knowledge and skills required to tackle environmental problems and prevent new ones (Oğuz et al. 2010). However, the literature on environmental knowledge also recognizes the importance of informal education channels such as media (watching television or reading magazines), the Internet or social interactions in influencing people's environmental behavior. Through these channels people can learn more about environmental problems and increase their environmental responsibility (Chan 1998; Thamwipat et al. 2012; Adomssent 2013). It was found that the media generate social norms in individuals, which influence pro-environmental behavior through attitudes and behavioral intentions (Bamberg and Moser 2007). The role of both formal and informal education is analyzed by Vicente-Molina et al. (2013) who investigate the influence of environmental knowledge on pro-environmental behavior among university students from countries with different levels of economic development. Research findings suggest that while knowledge from the formal education system influences environmental behavior, attitude and informal education are not relevant variables.

3. The present study

The starting point of the present paper is the approach of Stern and colleagues regarding egoistic and altruistic general environmental concerns. We try to apply this approach in economic terms with the aim of building empirical hypotheses with which to study the relationship between general environmental concerns and water conservation behavior in Italy.

We consider two types of environmental concerns: egoistic and altruistic. Individuals with egoistic environmental concerns take care of their own welfare. In the absence of economic incentives (penalties) they are not prone to adopt water conservation behavior. However, such people may become water conservation individuals if general environmental problems are perceived to affect their own welfare by increasing the personal costs of environmental degradation. In this context, individuals would reduce water consumption with the aim of internalizing future personal costs. In other words, if individuals with egoistic environmental concerns perceive general environmental issues as a threat to their own welfare through an increasing in personal costs, they would internalize such costs by engaging with water conservation behavior. Based on this argument, we pose the first empirical hypothesis:

H1: We would expect a positive correlation between egoistic environmental concerns and water conservation behavior if general environmental issues are perceived as a threat to own welfare.

Individuals with altruistic environmental concerns take care of the welfare of others. In the absence of economic incentives they save water because, for these people, the group's benefits linked to water conservation are higher than personal costs. According to this model, altruistic environmental concerns are positively correlated with water conservation behavior. Hence, we set up the second empirical hypothesis:

H2: We would expect a positive correlation between altruistic environmental concerns and water conservation behavior if general environmental issues are perceived as a threat to the group's welfare.

However, individuals with altruistic environmental concerns may not save water if they perceive that group's members will behave as free riders, i.e. they will not engage water conservation behavior. In this case, there would be a negative correlation between altruistic environmental concerns and water conservation behavior. Therefore, we advance the third empirical hypothesis.

H3: We would expect a negative correlation between altruistic environmental concerns and water conservation behavior if individuals perceive that group's members will behave as free riders.

4. Data and empirical method

The empirical analysis uses the 1998 wave of the Multipurpose Household Survey (MHS) conducted annually by the Italian Central Statistics Office. This large dataset is one of the best available for studying pro-environmental behaviour in a cross-section framework as it investigates a wide range of behaviours by means of face-to-face interviews on a sample of about 20,000 households corresponding to about 60,000 individuals. The 1998 wave is a unique dataset because it includes a section on environmental issues not available in the other waves. The unit of analysis is the individual. The final dataset used in the empirical analysis contains about 41,000 observations. Table 1 shows definitions of the variables used in the econometric analysis with weighted summary statistics.

Water conservation behavior

The 1998 wave of the MHS includes a section devoted to environmental issues. This section is used to identify the measure of pro-environmental behavior, i.e. water conservation behavior. The dependent variable *water conservation behavior* (WCB) is measured by the question "How often are you careful in not wasting water at home?" where possible responses are: yes always, yes sometimes, never. Responses are re-coded into a binary variable which is equal to 1 in cases of "yes always" and 0 otherwise. As we can see in Table 1, more than half of the respondents in our sample adopt water conservation behavior at home.

Table 1. Weighted descriptive statistics

Variable	Description	Mean	Std. Dev.
Dependent variables			
Water conservation	=1 if the respondent always saves water at home	0.54	0.50
Key independent variables: environmental concerns			
EC1. Pollution	0-5 scale: air, soil, water, electromagnetic, noise	1.38	0.98
EC2. Climate change	0-2 scale: greenhouse effect, climate change	0.96	0.71
EC3: Resource exhaustion	0-2 scale: depletion of natural resources, destruction of forests	0.42	0.58
EC4. Alteration of env. heritage	0-2 scale: extinction of species, destruction of the landscape	0.33	0.53
Source of information about the environment problems			
Tv and radio	= 1 if respondent follows programs on environmental issues on TV and the radio	0.35	0.47
Magazines and books	= 1 if respondent reads news on environmental issues in newspapers, magazines and books	0.26	0.44
Conferences	= 1 if respondent attends environmental conferences	0.02	0.15
Member	=1 if respondent is a member of environmental associations	0.01	0.11
Initiatives	=1 if respondent takes part in initiatives of environmental associations	0.01	0.11
Money	=1 if respondent gives money for environmental protection	0.01	0.10
Demographic and socio-economic characteristics			
Judgment on water rates	= 1 if the respondent values water rates high	0.45	0.50
Female	= 1 if female. Reference group: male	0.51	0.50
Married	= 1 if married. Reference group: single	0.59	0.49
Divorced	= 1 if separated/divorced	0.03	0.17
Widowed	= 1 if widowed	0.06	0.23
Age31-40	= 1 if age between 31 and 40. Reference group: age 16-30	0.18	0.38
Age41-50	= 1 if age between 41 and 50	0.17	0.38
Age51-60	= 1 if age between 51 and 60	0.15	0.36
Age61-70	= 1 if age between 61 and 70	0.13	0.34
Age71-80	= 1 if age between 71 and 80	0.08	0.27
Household size	Number of people who live in family	3.36	1.27
Children0_5	1 = if children aged between 0 and 5 years. Reference group: no children	0.13	0.40
Children6_12	1 = if children aged between 6 and 12 years	0.18	0.46
Children13_17	1 = if children aged between 13 and 17 years	0.24	0.51
Low education	= 1 if no education, completed elementary school and completed junior high school**.** Reference group: high school (diploma)	0.61	0.49
Bachelor's degree	= 1 if university degree and/or doctorate	0.07	0.26
Household income (ln)	Natural logarithm of household income	10.71	0.45
Good health	= 1 if self-perceived health is good	0.76	0.43
Homeowner	= 1 if homeowner	0.72	0.45
No. of rooms	Number of rooms between 1 and 15	4.53	1.63
Entrepreneur	= 1 if entrepreneur	0.05	0.22
Employed	= 1 if employed	0.43	0.49
Unemployed	= 1 if unemployed. Reference group: other status	0.07	0.26
Retired	= 1 if retired	0.19	0.39
Size of municipality			
Metropolis	= 1 if metropolitan area. Reference group: <2,000 inhabitants	0.22	0.42
Neighboring metropolis	= 1 if close to metropolitan area	0.08	0.27
>50,000	= 1 if more than 50,000 inhabitants	0.15	0.36
10,000-50,000	= 1 if between 10,000 and 50,000 inhabitants	0.22	0.41
2,000-10,000	= 1 if between 2,000 and 10,000 inhabitants	0.24	0.43
Social capital			
Volunteering membership	= 1 if passive and/or active participation in voluntary associations	0.10	0.30
Church attendance	= 1 if church attendance one or more a week	0.34	0.47

Table 2. Weighted correlation matrix between water conservation behavior and environmental concerns

	EC1	EC2	EC3	EC4
WCB	0.012**	0.004	0.007	-0.028**

Note:

** denotes that the coefficient is statistically different from zero at 5 percent.

General environmental concerns

A series of major environmental issues in the 1998 wave of the MHS captures individual concerns on the quality of the environment. The answers to the multiple choice question "What are the worrying environmental problems?" are used as proxies for general environmental concerns. Respondents could choose five answers among the following: (i) greenhouse effect; (ii) species extinction; (iii) climate change; (iv) noise; (v) air pollution; (vi) soil pollution; (vii) water pollution; (viii) destruction of forests; (ix) electromagnetic pollution; (x) destruction of landscape; (xi) depletion of natural resources.

We consider environmental concerns linked to four specific issues. We add 1 to the environmental concern variable when the respondent states that he/she agrees with the related environmental issue. The four general environmental concerns variables are:

EC1. *Pollution* (noise; air, soil, water, electromagnetic);

EC2. *Climate change* (greenhouse effect, climate change);

EC3. *Resource exhaustion* (destruction of forests, depletion of natural resources);

EC4. *Alteration of environmental heritage* (species extinction, destruction of the landscape).

With reference to concern on pollution, we focus on the types of environmental pollution with the hugest effects on human health and the alteration of biodiversity (Kampa and Castenas, 2008; Passcher-Vermeer and Passcher, 2000; Ising and Kruppa, 2004; Vörösmarty et al., 2010; Oliver, 1997; Balmori, 2009). People's awareness about the direct effects of pollution on their health and the environmental setting in which they live led us to interpret people's concern with pollution as an egoistic environmental concern.

As regards the environmental concern labeled as climate change, we consider both climate change and the greenhouse effect. Past studies have found that the majority of people in industrialized countries are increasingly aware of and concerned about climate change and the greenhouse effect (Leiserowitz, 2007; Tobler et al., 2012), which are expected to bring about major change in freshwater availability, the productive capacity of soils, and patterns of human settlement (Raleigh, Urdal, 2007). Uncertainty around future risk scenarios increases people's concern that future generations will not be able to make use of the stock of natural resources, which ensures well-being for the present. Moreover, it was also demonstrated that people's perception of climate change

influences their level of concern, which affects their motivation to act (Swim et al., 2009). In line with this assumption, some studies indicate that concern about climate change increases consumers' willingness to modify their behaviors (Semenza et al., 2008). Consistent with these assumptions, we assume people's concern on climate change as an altruistic environmental concern.

Among environmental concerns, we view resource exhaustion as a specific concern influenced by the assumption that resource depletion may threaten the welfare of future generations. Indeed, several scholars contend that the earth cannot for long continue to support current and anticipated levels of demand for both exhaustible and renewable resources (Tilton, 1996). In line with people's perception that natural resources depletion represents a dangerous threat to the welfare of future generations, we interpret people's concern on resource exhaustion as an altruistic environmental concern.

Lastly, we consider people's concern on the alteration of environmental heritage. We use the expression 'environmental heritage' to indicate the complexity of elements that form the natural capital. The natural capital performs two kinds of functions. The first is directly relevant to the production process. The other, which is defined as the environmental one, comprises basic life-support functions that are guaranteed by the conservation of biological and genetic diversity, such as wild plants and animals. Moreover, environmental functions contribute to human welfare through amenity services, such as the beauty of wilderness and landscape (Pearce and Turner, 1990). Both life-support functions and amenity services are produced directly by natural capital independently of human activity, but human activity can have an (often negative) effect on these functions (Ekins et al., 2003). Based on these assumptions of the economic theory, we focus on extinction of natural species and destruction of landscape perceived by people as negative effects produced by human activity on the environmental heritage at the expense of both present and future generations. Thus, we read people's concern on the alteration of environmental heritage as an altruistic concern.

The sample average as well as the standard deviation of the variables are reported in Table 1. Means of these scales indicate that the highest levels of concern are for pollution (mean = 1.38) and climate change (mean = 0.98), followed by resource exhaustion (mean = 0.42). The lowest level is for alteration of environmental heritage (mean = 0.33).

It is important to point out that in line with the environmental literature in our study environmental concerns and pro-environmental behavior are not assessed at the same level of specificity, i.e. in our dataset we have general environmental concerns and not specific water environmental concerns. Although WCB and EC are not assessed at the same level of specificity, as pointed out by some descriptive studies (see Corral-Verdugo et al. 2003), our descriptive results show statistically significant correlations among WCB, EC1 and EC4 (Table 2).

Demographic and socio-economic characteristics

In order to consider factors, which might influence both water conservation behavior and environmental concerns we focus on some demographic and socio-economic characteristics. Specifically, we concentrate on the following features: (i) assessment of respondents on water rates as a proxy of water price; (ii) gender (*female* and *male* as the reference category); (iii) marital status including categories for *married*, *divorced* and *widowed* against a base category of being single; (iv) age (*31-40*, *41-50*, *51-60*, *61-70*, *71-80*, with *age16-30* used as reference group); (v) the number of individuals living in the household (*household size*); (vi) age of children (*Children0_5*, *Children6_12*, *Children13_17*); (vii) level of education (*low education*, *bachelor's degree*, with *high school* being the reference category); (viii) household income (h*ousehold income (ln)*); (ix) self-reported good health (*good health*); (x) tenure status (*homeowner*); (xi) number of rooms; (xii) employment status (*unemployed*, *entrepreneur*, *employed*, *retired* with other status utilized as reference category). The average respondent in the sample is married, poorly educated (elementary school and/or junior high school completed), is in good health and a homeowner.

Moreover, we also consider the size of the municipality (*metropolis*, *neighboring metropolis*, *>50,000*, *10,000-50,000*, *2,000-10,000* with *<2,000* inhabitants being the reference category). Regional fixed effects are also included to account for the high regional heterogeneity in economic development and environmental quality existing in Italy.

Source of information about environmental problems

Environmental knowledge is measured by the question "How do you keep informed about environmental issues?". Specifically, we consider the following sources: TV and radio; magazines and books; attending conferences; membership of environmental associations; involvement in environmental initiatives; supporting environmental protection with money. On the basis of respondents' answers, we build binary variables (= 1 if the answer is yes, 0 otherwise).

Table 1 shows that 35% of the respondents are informed on environmental issues by television and radio programs, while 25% of the interviewees usually read information in newspapers, magazines and books. Only a minority of respondents (1%) use, as sources of information on environmental issues, their *membership of environmental associations, involving in environmental initiatives, and supporting environmental protection with money*.

Social capital

Social capital has also been underlined as a significant factor influencing pro-environmental behavior (Torgler and García-Valiňas 2007; Owen and Videras 2007, 2012; Fiorillo 2013). Torgler and García-Valiňas (2007) study the determinants of individuals' attitudes toward preventing

environmental damage in Spain, finding that trust and membership in voluntary environmental organizations have a strong impact on individuals' preferences to avoid environmental damage. Owen and Videras (2007) using OECD data show that individuals who are more willing to behave according to moral norms are also more willing to protect the public good of the natural environment while Videras et al. (2012), with US datasets, extend Owen and Videras' (2007) findings to social ties.

We build a variable according to membership in associations. *Volunteering membership* is a binary variable equal to one if the individual is a passive member (the individual participates in association meetings) and/or an active member (the individual does unpaid work) in volunteering associations. On average, about 10% of the respondents participate in voluntary associations. Moreover, we also take account of a *church attendance* variable measured through a dummy variable which is equal to one it the respondent goes to a church or another place of worship one or more times a week. According to Owen and Videras (2007), religious traditions include world views, ethical precepts and spiritual elements that shape perceptions about the natural environment and can act as guiding principles regarding how our acts and choices affect nature. The sample mean of this variable is 0.34.

Empirical model

The empirical model of water conservation behavior can be represented through the following estimation equation:

$$WCB_i^* = \alpha + EC_i'\beta + \lambda Y_i + Z_i'\delta + \varepsilon_i \quad (1)$$

where WCB^* is the water conservation behavior of the respondent *i*; *EC* are the environmental concerns variables defined at the individual level; *Y* is annual household income; the *Z* matrix consists of the other variables that are known to influence water conservation behavior and ε is a random-error term.

We do not observe the "latent" variable WCB^* in the data. Rather, we observe *WCB* as a binary choice which takes value 1 if the respondent always saves water at home. Thus, the structure of (1) makes it suitable for estimation as a probit model:

$$\Pr(WCB_i = 1) = \Phi(\alpha - EC_i'\beta - \lambda Y_i - Z_i'\delta) \quad (2)$$

where $\Phi(\cdot)$ is the cumulative distribution function of a normal standard.

5. Econometric results

The findings of econometric analysis are divided into three sections. In the first section, the basic relationship between water conservation behavior and environmental concerns are considered. In the second, the socio-economic determinants of water saving behavior are examined. In the last section, a robustness analysis is performed with factors linked to pro-environmental behaviors, such as the source of information about environmental issues and social capital.

5.1. Environmental concerns

In Table 2, Columns (I) – (V) present the probit estimations of Eq. (2), marginal effects and standard errors (in brackets) are corrected for heteroskedasticity, using as a dependent variable water conservation behavior, as key independent variables general environmental concerns and as control variables all socio-economic characteristics variables.

Let us discuss first the basic results on general environmental concerns variables. Through columns (I) – (V) we observe that all such variables, i.e. *pollution*, *climate change*, *resource exhaustion* and *alteration of environmental heritage*, are statistically significant at the 1 percent level but with a different sign. A greater concern for pollution, climate change and resource exhaustion is related to a higher likelihood that the respondent saves water at home. A greater concern for alteration of environmental heritage is linked to a higher probability of the individual's water conservation behavior diminishing.

Table 2. Probit results: marginal effects of the basic determinants of water conservation behavior

	I	II	III	IV	V
EC1. Pollution	0.008(0.002)***				0.009(0.003)***
EC2. Climate change		0.010(0.003)***			0.011(0.003)***
EC3. Resource exhaustion			0.016(0.004)***		0.018(0.004)***
EC4. Alteration of env. heritage				-0.016(0.005)***	-0.015(0.005)***
Judgment on water rates	0.031(0.005)***	0.031(0.005)***	0.031(0.005)***	0.031(0.005)***	0.031(0.005)***
Female	0.011(0.005)**	0.011(0.005)**	0.011(0.005)**	0.011(0.005)**	0.011(0.005)**
Married	-0.033(0.009)***	-0.033(0.009)***	-0.033(0.009)***	-0.032(0.009)***	-0.034(0.009)***
Divorced	-0.071(0.015)***	-0.071(0.015)***	-0.071(0.015)***	-0.071(0.015)***	-0.071(0.015)***
Widowed	-0.070(0.014)***	-0.070(0.014)***	-0.070(0.014)***	-0.070(0.014)***	-0.070(0.014)***
Age31-40	0.037(0.009)***	0.037(0.009)***	0.037(0.009)***	0.037(0.009)***	0.038(0.009)***
Age41-50	0.057(0.010)***	0.057(0.010)***	0.057(0.010)***	0.056(0.010)***	0.058(0.010)***
Age51-60	0.075(0.011)***	0.076(0.011)***	0.076(0.011)***	0.075(0.011)***	0.077(0.011)***
Age61-70	0.126(0.012)***	0.127(0.012)***	0.127(0.012)***	0.125(0.012)***	0.128(0.012)***
Age71-80	0.155(0.014)***	0.156(0.014)***	0.157(0.014)***	0.153(0.014)***	0.159(0.014)***
Household size	-0.027(0.003)***	-0.027(0.003)***	-0.027(0.003)***	-0.027(0.003)***	-0.027(0.003)***
Children0_5	0.042(0.008)***	0.042(0.008)***	0.042(0.008)***	0.041(0.008)***	0.041(0.008)***
Children6_12	0.043(0.006)***	0.043(0.006)***	0.043(0.006)***	0.043(0.006)***	0.043(0.006)***
Children13_17	-0.031(0.006)***	-0.031(0.006)***	-0.031(0.006)***	-0.031(0.006)***	-0.032(0.006)***
Low education	0.015(0.006)**	0.015(0.006)**	0.015(0.006)**	0.014(0.006)**	0.016(0.006)**
Bachelor's degree	0.013(0.010)	0.014(0.010)	0.014(0.010)	0.014(0.010)	0.014(0.010)
Household income (ln)	-0.023(0.010)**	-0.023(0.010)**	-0.024(0.010)**	-0.022(0.010)**	-0.025(0.010)***
Good health	-0.016(0.006)**	-0.016(0.006)**	-0.016(0.006)**	-0.015(0.006)**	-0.016(0.006)***
Homeowner	0.026(0.007)***	0.026(0.007)***	0.026(0.007)***	0.026(0.007)***	0.026(0.007)***
No. of rooms	-0.004(0.002)**	-0.004(0.002)**	-0.004(0.002)**	-0.004(0.002)**	-0.004(0.002)**
Entrepreneur	-0.036(0.012)***	-0.036(0.012)***	-0.037(0.012)***	-0.036(0.012)***	-0.036(0.012)***
Employed	-0.010(0.007)	-0.011(0.007)	-0.010(0.007)	-0.011(0.007)	-0.010(0.007)
Unemployed	0.026(0.010)**	0.026(0.010)**	0.027(0.010)**	0.026(0.010)**	0.026(0.010)**
Retired	0.020(0.009)**	0.020(0.009)**	0.020(0.009)**	0.020(0.009)**	0.019(0.009)**
Metropolis	0.013(0.010)	0.014(0.010)	0.013(0.010)	0.013(0.010)	0.013(0.010)
Neighboring metropolis	-0.000(0.013)	0.000(0.013)	-0.000(0.013)	-0.000(0.013)	-0.000(0.013)
>50,000	0.008(0.011)	0.009(0.011)	0.008(0.011)	0.008(0.011)	0.008(0.011)
10,000-50,000	0.014(0.010)	0.014(0.010)	0.014(0.010)	0.014(0.010)	0.014(0.010)
2,000-10,000	0.015(0.010)	0.015(0.010)	0.014(0.010)	0.014(0.010)	0.015(0.010)
Regional dummies	Yes	Yes	Yes	Yes	Yes
No. of observations	40,321	40,321	40321	40321	40321
Pseudo R-squared	0.022	0.022	0.022	0.022	0.023
Log-likelihood	-27,153.98	-27,154.27	-27,151.89-	-27,152.62	27,136.00

Notes: The dependent variable *water conservation behavior* takes value 1 if the respondent always saves water at home. The models are estimated with standard probit. Regressors' legend: see Table 1. Regional dummies are omitted from the Table for reasons of space. The standard errors are corrected for heteroskedasticity. The symbols ***, **, * denote that the coefficient is statistically different from zero at 1, 5 and 10 %, respectively.

Since we have interpreted *pollution* as an egoistic environmental concern and respectively *climate change*, *resource exhaustion* and *alteration of environmental heritage* as altruistic environmental concerns (Section 4), the findings on EC1-EC4 seem to fit the empirical hypothesis H1, H2, and H3 of Section 3. The results on *pollution* may indicate that when the respondent perceives general environmental issues as a threat to his/her own welfare, the individual will save water at home. Moreover, *climate change* and *resource exhaustion* may point out that if the respondent perceives general environmental issues as a threat to the welfare of the group he/she takes part in, he/she will save water at home, too. Instead, if the individual perceives general environmental issues as a threat to the group's welfare he/she takes part in but thinks that for the others this is not so, then he/she will behave as a free rider and will not save water. This seems the case of the finding about *alteration of environmental heritage,* which fits hypothesis H3 of Section 3.

5.2. Socio-economic characteristics

The marginal effects of all socio-economic features variables are reported in Table 2, Columns (I) – (V). We discuss those variables that have a statistically significant sign.

The respondent's opinion on water cost has a positive relationship with water saving behavior, significant at the 1 percent level. Although the data do not provide information on water fees but only on the individual's assessment about the cost of water consumption at home, this finding seems to point out that the higher the individual judges water rates to be, the greater the likelihood of him/her reducing water consumption.

The results on gender and marital status indicate that females are more water-saving than males, while the married, divorced and widowed save less water than single people. The marginal effect on *female* presents a positive sign and is statistically significant at the conventional level whereas the marginal effects on all marital status variables have a statistically significant negative sign at the 1 percent level. Previous research on gender found similar differences (Arcury and Johnson, 1987; Davidson and Frendenburg, 1995; Vicente-Molina et al., 2013).

A statistically significant linear relationship is observed between age dummies and water conservation (at the 1% level): older people are more likely to be water savers. These results are in line with previous studies (Gregory and Di Leo 2003; Gilg and Barr 2006; Clark and Finley 2007). The evidence in Table 2 shows that the likelihood of being a water saver decreases with family size and the presence of teenagers. The marginal effects on *household_size* and *children13_17* have a statistically significant negative sign (at the 1% level). These findings are consistent with one strand of the literature (Gregory and Di Leo 2003; Randolph and Troy 2008; Makki et al. 2013). On the other hand, having children aged between 0 and 12 raises the probability of being water savers: the

marginal effects on *children0_5* and *children6_12* present a statistically significant positive sign at the 1 percent level.

Regarding education, in line with some previous studies described in Section 2, *low education* shows a positive and significant correlation with water conservation (at the 1% level). Hence, we find that individuals who are more committed to water conservation are not those who are more highly educated. Household income has a significant and negative relationship with water saving. Individuals with higher income consume more water. This result is consistent with previous research reviewed in Section 2.

Water conservation behavior is also influenced by home ownership and number of rooms. Results in Table 2 show that homeowners are more likely to engage in water saving (significant at the 1% level). On the other hand, having a house with a large number of rooms raises the probability of consuming water (significant at a conventional level).

Perceived health and employment status are also significant determinants. An individual who perceives his/her health status as good is less likely to save water at home. With regard to employment status, being an entrepreneur is correlated with a higher probability of consuming water (significant at the 1% level) while being unemployed and retired is linked with a higher likelihood of saving water (significant at a conventional level).

5.3. Robustness analysis

A potential problem with the interpretation of the previous findings may be omitted variables bias, i.e. other factors might cause both a high propensity to save water and to increase their own concerns about environmental quality. Here, we regard this issue by adding further control variables. First of all, we take into account six sources of information about the environmental problems. As reviewed in Section 2, a greater knowledge of environmental problems increases the likelihood that individuals take action to protect the environment. Second, we consider two variables intended to capture additional relational aspects of individual behavior, namely membership of volunteering associations and churchgoing, which previous empirical investigations found to be correlated with pro-environmental behaviors (see Section 2). Table 3 reports the results for environmental knowledge variables (I), social capital variables (II) and all control variables (III).

Table 3. Probit results: marginal effects of robustness analysis with environmental knowledge variables (I), social capital variables (II) , environmental knowledge, social capital and all control variables (III)

	I	II	III
Pollution	0.006(0.003)**	0.009(0.003)***	0.006(0.003)**
Climate change	0.006(0.004)*	0.010(0.004)***	0.006(0.004)
Resources exhaustion	0.012(0.004)***	0.018(0.004)***	0.012(0.004)***
Alteration of env. heritage	-0.021(0.005)***	-0.015(0.005)***	-0.021(0.005)***
Tv and radio	0.054(0.007)***		0.053(0.007)***
Magazines and books	0.004(0.008)		0.005(0.008)
Conferences	0.008(0.017)		0.007(0.018)
Member	-0.018(0.025)		-0.018(0.025)
Initiatives	0.050(0.025)**		0.052(0.025)**
Money	0.065(0.024)***		0.064(0.024)***
Volunteering member.		0.003(0.009)	-0.003(0.009)
Church attendance		0.040(0.006)***	0.040(0.006)***
Judgment on water fees	0.032(0.005)***	0.030(0.005)***	0.031(0.005)***
Female	0.011(0.005)**	0.005(0.006)	0.005(0.006)
Married	-0.035(0.009)***	-0.035(0.009)***	-0.036(0.009)***
Divorced	-0.071(0.015)***	-0.068(0.015)***	-0.068(0.015)***
Widowed	-0.073(0.014)***	-0.073(0.014)***	-0.075(0.014)***
Age31-40	0.037(0.009)***	0.038(0.009)***	0.038(0.009)***
Age41-50	0.056(0.010)***	0.056(0.010)***	0.054(0.010)***
Age51-60	0.076(0.011)***	0.073(0.011)***	0.073(0.011)***
Age61-70	0.130(0.012)***	0.123(0.013)***	0.125(0.013)***
Age71-80	0.165(0.014)***	0.155(0.014)***	0.160(0.014)***
Household size	-0.024(0.003)***	-0.025(0.003)***	-0.023(0.003)***
Children0_5	0.040(0.008)***	0.042(0.008)***	0.041(0.008)***
Children6_12	0.041(0.006)***	0.040(0.006)***	0.038(0.006)***
Children13_17	-0.033(0.006)***	-0.034(0.006)***	-0.035(0.006)***
Low education	0.021(0.006)***	0.016(0.006)**	0.021(0.006)***
Bachelor's degree	0.009(0.010)	0.013(0.010)	0.007(0.010)
Household income (ln)	-0.035(0.010)***	-0.027(0.010)***	-0.037(0.010)***
Good health	-0.018(0.006)***	-0.015(0.006)**	-0.016(0.006)***
Homeowner	0.028(0.007)***	0.025(0.007)***	0.027(0.007)***
Number rooms	-0.004(0.002)**	-0.005(0.002)***	-0.005(0.002)***
Entrepreneur	-0.035(0.012)***	-0.034(0.012)***	-0.033(0.012)***
Employed	-0.007(0.007)	-0.007(0.007)	-0.004(0.007)
Unemployed	0.028(0.010)***	0.029(0.010)***	0.031(0.010)***
Retired	0.019(0.009)**	0.019(0.009)**	0.019(0.009)**
Metropolis	0.013(0.010)	0.011(0.011)	0.010(0.011)
Neighboring metropolis	-0.001(0.013)	-0.002(0.013)	-0.002(0.013)
>50,000	0.007(0.011)	0.006(0.011)	0.005(0.011)
10,000-50,000	0.013(0.010)	0.011(0.011)	0.010(0.011)
2,000-10,000	0.014(0.010)	0.013(0.010)	0.013(0.010)
Regional dummies	Yes	Yes	Yes
No. of observations	40,321	39,859	39,859
Pseudo R-squared	0.025	0.024	0.026
Log-likelihood	-27,073.31	-26,800.66	-26,739.76

Notes: see Table 2.

According to previous studies, environmental knowledge is an antecedent of environmental concerns. Adding environmental knowledge variables to equation (1) changes the size and significance of environmental concerns variables. Column (I) shows that the marginal effects on *pollution* and *climate change* decrease and lose significance, being statistically significant, respectively, at 5 and 10 percent. Moreover, also the marginal effect on *resource exhaustion* decreases while remaining significant at the 1 percent level. Finally, the marginal effect on *alteration of environmental heritage* rises and continues to be significant at the 1 percent level. Regarding the environmental knowledge variables, results in Column (I) show a high statistical correlation among *tv and radio*, *initiatives, money* and water conservation behavior. Indeed, reading magazines and books, attending environmental conferences and being a member of environmental associations are not important for water conservation. The former findings are in line with one strand of the literature which found a relationship between environmental knowledge and pro-environmental behavior (see Section 2).

Putting social capital variables into equation (1) does not modify the size or significance of environmental concerns variables (see Table 2). Moreover, *church attendance* is positively correlated with water conservation behavior as previous studies on churchgoing and pro-environmental behavior have found (see Section 4). Additionally, *church attendance* changes size and significance of the female variable. Indeed, the marginal effect on *female* is no more statistically significant, indicating that the correlation between *female* and water conservation is mediated by churchgoing.

Column (III) shows the findings with all covariates. The results on environmental knowledge and social capital variables are close to those reported in previous columns while the evidence on environmental concerns variables are similar to those of Column (I) with the exception of *climate change* which is no longer statistically significant. These results point out that the media, active participation in environmental events, social ties and religious norms are related both to pro-environmental behavior and environmental concerns. In other words, greater knowledge of environmental problems, social relationships and moral norms impact on beliefs and behavior driving people to take action to protect the environment.

6. Discussion

The present study investigates the relationship between four different kinds of general environmental concerns – *pollution, climate change, resource exhaustion, alteration of environmental heritage* - and water conservation behavior using the 1998 Multipurpose Household Survey (MHS) conducted annually by Italian Centre Statistics Office. The paper is an empirical

contribution to the debate regarding the link between environmental concern and water saving when concerns and behaviors are not assessed at the same level of specificity (Corral-Verdugo et al. 2003). In so doing, the study focuses for the first time on the relationship between general environmental concerns and water conservation behavior in Italy.

In line with previous findings (Stern et al. 1993; 1995; Corral-Verdugo et al. 2008), the study shows that general environmental concerns are found associated with the probability of saving water at home. Thus, individuals with higher concerns regarding pollution and resource exhaustion have, respectively, a 0.6 and 1.2 percent higher probability of saving water. Instead, people with higher concerns on the alteration of environmental heritage present a 2.1 percent higher probability of being water consumers. These results seem to confirm our empirical hypothesis according to which individuals who perceive general environmental issues as a threat to their own welfare as well as the group's welfare to which they belong, will be water savers (H1 and H2). On the other hand, when individuals perceive that other group members will be water consumers, they will be water consumers too (H3).

Interesting findings regard environmental knowledge and social capital variables. When the models are fitted with these further control variables, environmental concerns variables change size and significance with the climate change variable no longer significant. Hence, greater knowledge of environmental problems, social ties and religious norm are found related both to the water conservation behavior and general environmental concerns. Thus, following programs on environmental issues on television and on the radio is associated with a 5.3 % higher probability of adopting water conservation behavior. Moreover, being active in environmental protection, taking part in initiatives and giving money, is related to a higher likelihood of being a water saver (5.2 and 6.4 percent, respectively). Furthermore, churchgoing is linked with a 4.0 percent higher probability of saving water. Evidence about the link between environmental knowledge, social capital and environmental concerns would suggest the need of initiatives by policy makers through environmental campaigns aimed at steering people's general environmental concerns toward pro-environmental behavior.

The paper also finds various significant relationships at the individual level. Evaluating water fees as high, being female, older, poorly educated, a homeowner, unemployed, retired and having children is associated with a higher probability of being a water saver. The features with the greatest marginal effect are age dummy variables. Thus individuals over 70 years have a 12.5 % higher probability of saving water at home. On the contrary, being married, divorced, widowed, an entrepreneur and having a large family with the presence of teenagers, higher (household) income and a big house are related with a higher likelihood of being a water consumer. Here, the

characteristics with the highest marginal effect are marital status variables. Being widowed increases the likelihood of consuming water by 6.8 percent. These results are consistent with previous research, confirming that individual characteristics are able to affect water conservation behavior.

Future research to examine the interaction among water conservation, environmental concerns and environmental knowledge would be desirable, taking account that the environmental context may be endogenously determined.

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