# Sell-off or shut-down? Alliance portfolio diversity and two types of high tech firms' exit

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# Sell-off or shut-down? Alliance portfolio diversity and two types of high tech firms' exit

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**Abstract**
Alliance portfolio diversity (APD) – defined as differences between firms' types of alliance partners (i.e. horizontal, upstream, and downstream) – is a strategic determinant of firm survival. This article analyzes APD in the context of high tech firms who rely on various partners to access complementary resources and secure their business survival, and argues that APD has different impacts on two main types of exit – sell-off and shut-down – which have been combined in previous research. Findings from a comprehensive study of French biotech firms from 1994 to 2002 show that the relationship between APD and shut-down is positive and linear whereas that between APD and sell-off is an inverted U-shaped. The article also finds evidence that the association between APD and firm exit mode is contingent on a firm's resources and capabilities. The implications for research and managerial practice are discussed.

**Keywords**
alliance portfolio diversity, biotechnology, exit, high tech firms, sell-off, shut-down

## Introduction

New firms face a number of challenges in their efforts to survive and to develop their businesses, both of which are even more difficult in environments characterized by rapid technological change and high degrees of uncertainty and volatility (Oliver, 2001; Silverman and Baum, 2002). Going it alone may not be an option – so high tech firms engage in alliances with various types of partners at the various stages of the value system (Baum et al., 2000): upstream to benefit from research, horizontal to share experience, and downstream to gain access to customers, with the result that they have different number and types of ties with functionally distinct partners. This article argues that a firm's alliance portfolio diversity (APD) has an impact on the probability of its exit, independent of the size of the alliance portfolio.

Research on firms' alliance activities has mainly focused on the effects of different types of partners in isolation, and has provided convincing evidence that each type of collaboration

(upstream, downstream, horizontal) has the potential to increase firms' innovativeness (Powell et al., 1996; Rothaermel et al., 2006), financial performance (Durand et al., 2008), and chances of survival (Silverman and Baum, 2002). Each type of alliance provides a firm with different kinds of knowledge and resources that can be transferred between partners, that generate different levels of competitive intensity (Khanna et al., 1998; Silverman and Baum, 2002), and that require different levels of alliance management capability (Rothaermel and Deeds, 2006). Both size and variety of the portfolio matter: where two firms have the same number of alliances, the firm with the more varied array of contacts has access to more non-redundant and diverse information (Koka and Prescott, 2002), while, of two firms with the same variety of contacts, that with the greater number has access to higher quantities of information. Although increasing the number of upstream, downstream, and horizontal alliances yields informational and resource benefits to a firm, several studies have cautioned that diminishing returns may accompany alliance-making on too extensive a scale generally on the grounds of the amount of management time and effort involved in their maintenance (Deeds and Hill, 1996; Rothaermel and Deeds, 2006; Rothaermel et al., 2006).

These findings have led scholars to suggest that a firm should aim for an alliance portfolio of balanced diversity, and that such an arrangement will contribute best to its performance (Rothaermel et al., 2006). High levels of APD (i.e. a balanced alliance portfolio) have been found beneficial for firms in terms of their revenue growth and survival (Baum et al., 2000; Powell et al., 1996; Silverman and Baum, 2002; Watson, 2007). Other studies, however, have shown that too high a level has negative effects and may result in diminishing innovativeness (Sampson, 2007) and performance (Goerzen and Beamish, 2005; Jiang et al., 2010) due mainly to increased complexity and costs, and loss of focus. Many scholars seem to agree that the best way to disentangle these mixed results is by looking at a specific type of diversity in connection with a specific firm outcome – such as innovation output, performance, or survival – because different APD dimensions offer different types of benefits and pose different sets of challenges for a firm.

Against this backdrop, we argue that APD may increase or decrease the probability of high tech firms' exiting their industry depending on the type of exit. As far as we are aware, previous studies have not clarified the influence of APD on the probability of firms' exit via shut-down or sell-off, as they have tended to bracket the two under the same general 'exit' umbrella. But conflating these two very different outcomes risks grouping together one (a sell-off) that owners and investors might consider positively with another (shut-down) that lacks any upbeat dimensions. When a business is sold, its capabilities are transferred to a new owner and continue to be part of its commercial practice, so its competencies do not completely 'vanish'. By contrast, when a firm is shut down, all the organization-specific elements of its business routines are lost including its capital (Mitchell, 1994). In the present study we aim to establish the nature of relationship between APD and these two different types of firm exit, and to assess how much this relationship is moderated by the presence of internal capabilities.

Whereas market and accounting measures of performance and innovation output have received a disproportionate amount of interest compared to survival/exit as firm out-turns (which are, clearly, a crucial variable for small businesses) this article considers the impact of APD on the two main types of high tech firm exit – shut-down and sell-off. APD involves three factors that influence the probability that a firm exits according to one or other of these modes: first, a firm's legitimacy due to its network centrality that shapes perceptions of other organizations about the firm; second, the degree of competition within its alliance portfolio due to redundancies and partners' tendencies to be self-regarding; and third, the costs incurred by a firm in managing its alliances of different types. We relate these mechanisms according to various degrees of APD – controlling for the sheer number of each type of alliances in the portfolio – to our two dependent

variables: shut-down and sell-off. Overall, our study advances our understanding of APD's effects by focusing on a specific dimension of diversity (partners' functional diversity) on specific firm outcomes (the probability of exit by sell-off and by shut-down), and a specific context – firms in the emerging stage of a high tech industry, in our case, the French biotech sector, 1994–2002.

## Theory and hypotheses

In this article we study APD as the functional diversity of a firm's partners, i.e. their different value chain positions. High levels of diversity (i.e. a balanced alliance portfolio) describe a firm that has an equal number of alliance partners in all three categories – upstream, downstream, and horizontal; moderate levels reflect the situation when a firm has different numbers of alliance partners in all these categories; and a firm can be said to have low diversity when it only has partners in two of the three possible categories and the number of its alliances in each category vary significantly.

The major insight developed in this article explains how having a balanced vs. unbalanced APD influences the type of a firm's exit, independent of the number of ties it has with its partners. Three main arguments concur in explaining this effect – that the variety of ties adds something in explaining a firm's likelihood of exit beyond the count of each type of alliances taken independently.

First, alliances influence not only the capabilities firms can access (in effect, their raison d'etre) they also influence perceptions others have about those capabilities. APD provides advantages in terms of endorsement and legitimacy (Gargiulo and Benassi, 2000; Koka and Prescott, 2002), due to firms' higher centrality and visibility in their industry networks (Kogut, 2000; Powell et al., 1996, 2005). Firms' APD serves to signal information about their resources, capabilities, and status to other industry actors (Stuart, 2000). Beyond visibility and endorsement, a balanced portfolio of alliances indicates to stakeholders that a focal firm has a composed development mode. As a consequence, the addition of another alliance of the same type contributes less to a focal firm's legitimacy and positive evaluations than adding one of a different kind, which helps balance the firm's APD.

Second, keeping comparable numbers of different types of allies leads to the costs of intra-portfolio competition being lower than if all a firm's alliances are of a same type (Khanna et al., 1998), so that a firm is better off with a portfolio of six alliances across the three types, than having three of two types or six of the same type. In this last case, the tensions generated within the alliance portfolio by too many redundancies and partners' fears of losing 'special' or private benefits are much higher than in the other cases, and lower in the first mode.

Finally, the management of the portfolio entails important costs for the focal firm itself, which are even more consequential for smaller firms, as managing multiple alliances has time, resources, and attention costs, among others. While it may be possible to routinize these tasks where partners are of a single kind, as APD increases, the specific needs and requirements of different types and of individual partners prevent most firms from accessing such benefits: so complexity of management costs is more detrimental for balanced that for unbalanced portfolios.

We examine how these factors influence the probability of shut-down and sell-off at different values of APD.

### *APD and shut-down*

Firms with low levels of APD will have contracted alliances with the same type(s) of partners, thus increasing the risks of redundancies in the resources, information, and knowledge they can access

through their multiple partnerships, so that each additional similar alliance produces negative marginal returns for the firm. Suspicions about poor engagement from like-minded partners and of limited private benefits for everyone will affect each member of such unbalanced portfolios, and will prove detrimental for the focal firm as well, negatively impacting its chances of survival. As the level of APD increases, intra-alliance portfolio competition costs diminish whereas the benefits of spanning across a variety of resources and competences tend to increase, so the focal firm benefits from having broader search options, access to enriched resource pools, and increased value creation and capability development opportunities (Jiang et al., 2010). External signals – in the form of positive perception and enhanced legitimacy – will also benefit the firm while, at moderate APD values, the complexity of the portfolio remains reasonably manageable, especially in view of the value of these survival benefits. At the highest APD levels, the managerial costs of attending to a plurality of partners' distant needs are likely to increase significantly, to the point where they may overcome the benefits of positive evaluations and reduced intra-portfolio competition. As diversity increases, the degree of alliance portfolio complexity escalates, and with them the coordination and managerial costs (Sarkar et al., 2009) which increase the probability to shut down. As Rothaermel and Deeds (2006) note, upstream, horizontal, and downstream alliances require different management capabilities from the focal firm, so that managing a widely dissimilar group of alliance partners that have 'different vocabularies, paradigms, and even objectives' (Goerzen and Beamish, 2005: 334) becomes very challenging.

In sum, we suggest that low APD values will be associated with a higher probability of firms' shutting down; that increased APD will better chances of survival (hence, reduce those of shutting-down), but also that very high APD levels involve firms facing other costs that increase again the probability of a firm to shut down – so we hypothesize a U-shaped relationship between APD and the probability of firm shut-down:

**Hypothesis 1:** The association between alliance portfolio diversity and the probability of firm exit by shut-down follows a U-shaped curve – the probability first decreasing as APD grows, but then, beyond a certain point, increasing again.

## *APD and sell-off*

At low APD levels, a firm's alliance portfolio is unbalanced, so the benefits of APD (in terms of legitimacy, network centrality, and positive external evaluations) are low, which is detrimental to its chances of being sold off. Moreover, relative to firms with more varied allies, the universe of potential buyers of a firm with a reduced variety of allies is restrained. On the firm's side, at low values of APD, the firm itself lacks access to a range of potential buyers. Although this unbalanced portfolio situation means that the complexity (and thus costs) of managing the portfolio are significantly lower, the costs of intra-portfolio competition are significantly greater than when APD values are higher values. In sum, at low levels of APD, the probability of a sell-off will be low.

An increase in a firm's APD puts it in a better position to capture the opportunity of a sell-off, specifically, by increasing its chances of contacting potential buyers (Stuart, 2000) and signaling to them about its assets and capabilities. For instance, R&D alliances with universities and research institutions inform potential buyers about a firm's technological knowledge and research excellence (George et al., 2001), while manufacturing alliances with downstream partners speak about its understandings of efficient production processes and the commercialization potential of its technology and products (Inkpen, 1998). By increasing its APD, a firm improves its sources of complementary knowledge, non-redundant information, experience and expertise, and secures greater

access to external resource flows (DeCarolis et al., 2009), leading perceptions about the firm to be more positive, increasing its chances of whetting buyers' appetites. As APD represents access to a range of intangible resources that acquirers may seek to exploit, the probability of sell-off increases with greater levels of APD, while – at moderate APD values – the costs of redundancies and self-serving partner behaviors are still controllable, as are the management costs of APD complexity.

Higher levels of diversity, while they may give outside actors the most favorable perceptions of a focal firm, may make it difficult for concretely interested buyers to assess how the combination of their own and the target's resources will play out, given that the latter's upstream, horizontal, and downstream capabilities may be tightly connected to those of its alliance partners. The fact that some portfolio ties will probably have to be dissolved post- acquisition (Spedale et al., 2007) complicates potential buyers' assessments of a target firm's true value. Although the intra-portfolio competition costs are not expected to be the most problematic, the complexity of managing and making sense of the two networks of ties – those of the purchaser and of the target – may tend to discourage the former, lowering the probability of a focal firm's exit by sell-off.

Thus, we expect that the probability of sell-off will first grow and then reduce as the focal firm's APD level increases:

**Hypothesis 2:** The association between alliance portfolio diversity and the probability of firm exit by sell-off follows an inverted U-shaped curve – the probability first increasing as APD grows, but then decreasing again at higher APD values.

## *Moderating effects of valuable resources and capabilities*

The resource-based view (Barney, 1991) holds that a firm's success depends on its ability to leverage resources and capabilities (hereinafter R&C) that are valuable, rare, and difficult-to-imitate or to substitute. This suggests that APD's effect on the probabilities of firms being shut down or sold off may be more or less pronounced depending on the superiority of firms' internal R&C stocks.

Possessing valuable R&C helps firms navigate through difficult times (DeCarolis et al., 2009). For a given level of APD, more resourceful firms – those with more specifically appropriate assets or with greater scale or size – should be able both to cope better with the costs associated with APD (inter-partner competition and complexity management), and to lay claim to a greater share of the associated benefits (being more visible, more likely to gain positive evaluations and a better legitimacy, and to handle the opportunities better). This twofold argument leads us to expect that – for any given level of APD – firms with superior R&C will be less likely to face shut-down than those which lack such valuable assets, so that we can expect that their possession will shift the theorized U-shaped APD–shut-down relationship curve downwards:

**Hypothesis 3a:** Valuable firm R&C will negatively moderate the predicted curvilinear APD–shut-down relationship.

In regard to sell-offs (for the same reasons) the benefits of APD will be amplified and its costs cushioned where firm resourcefulness is stronger, so that resourceful firms will have a higher likelihood of being sold off than less well-endowed firms (again, at any given level of APD). Possessing valuable R&C will increase a firm's APD value in the eyes of potential buyers, and mitigate problematic APD issues of inter-partner competition and complexity management costs. Thus, resourcefulness magnifies the association between a firm's APD and its likelihood of being sold off, and we can expect that the inverted U-shaped curve we suggest represents the relationship between APD and probability of firm sell-off to shift upwards:

**Hypothesis 3b:** Valuable firm R&C will positively moderate the predicted curvilinear APD–sell-off relationship.

## Methods

### *Data and sample*

The data used to test our hypotheses comprise the population of French biotechnology firms over the nine-year period 1994–2002, involving 311 firms and 1750 firm-years:[1] the average firm in our database was five years old and employed 45 employees. The data were obtained from a survey initiated by the MENRT[2] Technology Division (Biotechnology group) and conducted by an INRA/SERD research group (Mangematin et al., 2003), which represents probably the most extensive research ever conducted on the French biotechnological industry, and includes all firms claiming to be engaged in biotech research and classified in the MENRT biotech enterprises census. (Basic information about this classification can be accessed via the ministry web site at biotech.education.fr.) We collected further data on the surveyed firms from their websites and other available sources (including the France Biotech, Infogreffe, and Diane databases) to help ensure the data's accuracy, as well as collecting all available press releases to verify the extent of their involvement in the biotechnology sector, contacting the firms directly where such secondary data were unavailable.

We define 'biotechnology firms' as those that 'develop or use industrial technologies derived from the life sciences and technologies (and sometimes materials) that mobilize the properties of living organisms to produce goods or services (as proposed by the Industry Ministry, "Les 100 technologies clés à l'horizon 2000")' (Corolleur et al., 2003). The biotechnology industry is an appropriate and interesting context for the present study for two main reasons. First, the sector is populated with firms developing in a changing and volatile environment, so that not only is their vulnerability and the instability of their business environments responsible for significant population dynamics in terms of firm failures, but they are often also the targets of large established companies such as pharmaceuticals, agro-chemical, etc. Second, a basic characteristic of the biotechnology industry is that its smaller firms depend on strategic alliances to commercialize their intellectual capital via inter-organizational networks (Durand et al., 2008; Powell et al., 1996). Biotech product development is very costly: small 'research laboratory'-type firms need to form alliances with larger downstream organizations to acquire legitimacy, financial resources, and vertical affiliations (Oliver, 2001: 473) if they are to progress from the 'emergent' to the 'adolescent' stage. All these reasons make the biotechnology industry an appropriate field to explore the effects of the diversity of firms' alliance partners on their exit modes.

Most biotechnology industry studies have analyzed large American and Canadian biotech companies (Baum and Silverman, 2004; Niosi, 2003; Rothaermel, 2001; Zucker et al., 2002), which are typically designed on a well-identified business model. Such studies tend to concentrate on dedicated biotech firms involved in human therapeutic and diagnostic application and to ignore 'companies involved in veterinary or agricultural biotech, which draw on different scientific capabilities and operate in quite different regulatory climates' (Powell et al., 2005: 1148). Our article analyzes the French biotechnology industry, which differs from its North American counterpart in that French biotech start-up business models tend to be heterogeneous in terms of their scientific involvement and their access to public stock markets (Durand et al., 2008; Mangematin et al., 2003). Whereas at a continental level (such as North America) it may be relevant to select ex ante publicly traded human-therapeutic-centered biotech companies for study, such a course makes less sense at a European country level because (1) the number of high powered biotech companies is

quite small (e.g. the UK, Germany, and France have only around 300 such firms each), (2) fewer European biotech firms go public, but tend to focus their efforts instead on licensing products in development or on selling their businesses to large pharmaceutical companies, and (3) non-human-therapeutic biotech activities represent substantial elements in the national economies of some European countries (e.g. agricultural biotech and animal food in France) (European Association for Bioindustries, 2006). We chose 1994 as an appropriate starting date for constituting our French panel data as it both marked the point when, after years of promise, several companies were finally ready to launch products, and also saw both the beginning of the European Medicinal Evaluation Agency approval of biotech products (Reiss et al., 2004), and the establishment of several private and public biotech funds. These more generally resourceful conditions led to the founding of many new biotech firms, and marked the beginning of a new dynamic in European biotech efforts (Ernst & Young, 1999): according to the European Association for Bioindustries (2006), 75% of French biotech firms still operating in 2006 were created during our 1994–2002 focus period.

## *Dependent variables*

Two binary dummy variables were used to account for exit types: (1) *Shut-down* for cases when biotech firms either shut down voluntarily or closed as a result of bankruptcy (32 occurrences); and (2) *Sell-off* for cases where firms were acquired by others (33 occurrences). (Only one firm in our dataset reported its exit as a merger, and this case was excluded from the sample.) The data about firm exits were obtained from VERIF (www.verif.fr), the electronic dataset of operational information about all French companies: the average ages of biotech firms that were shut down or sold off was comparable – four and five years respectively.

## *Independent variable: Alliance portfolio diversity*

According to the conceptual definition of APD – the variety of alliance partners' positions in the value chain (horizontal, upstream, and downstream) – Blau's (1977) index of heterogeneity appears the most appropriate operational measure, and has been one of the most widely used in previous alliance diversity studies (Koka and Prescott, 2002; Lee, 2007; Powell et al., 1996). The formula is as follows:

$$APD = 1 - \Sigma\, p_k^2,$$

where $p_k$ is the proportion of alliance partners in the $k$th category which was computed based on a total number of a firm's active alliances in a given year. If alliance termination dates were unavailable, we treated all alliances as being active for five years from their announcement date, five-year windows being a standard assumption in alliance research (Lavie, 2007; Vasudeva and Anand, 2011). We used Blau's index of APD to count three categories of upstream, downstream, and horizontal partner types: the index's minimum value of 0 occurs when all alliance partners belong to the same category, and reaches its maximum ≈ 0.67 when a firm has alliances with all three types of partners.[3] As in Silverman and Baum (2002), we coded Blau's index as 0 in cases where a biotech firm had no alliances. Finally, to examine the trade-off between alliance partner benefits and costs, we use both Blau's index and its squared value to estimate the curvilinear relationship.

Several data sources were used to compile strategic alliance events. First, we searched the databases of two electronic industry newspapers: *Gazette du Laboratoire* (www.gazettelabo.fr) created in 1995 and publishing 10 issues per year covering biotechnology industry events, in both the

public (public research laboratories, universities, and institutes) and private spheres (pharmacy, chemistry, agro nutrition, environment, etc.) and *Pharmaceutiques* (www.pharmaceutiques.com), launched in 1992, again publishing 10 issues annually, whose internet site offers press reviews of more than 60 French and international journals and newspapers, including *Nature*, *Scrip*, *Financial Times*, *Le Monde*, *Le Figaro*, and *La Recherche*. The articles of interest were identified using four criteria: (1) *strategic alliances*, including any long-term collaborative activity that involved exchange of resources between firms; (2) *biotechnology industry* and its main applications, e.g. pharmaceutical, agro nutrition, environmental; (3) occurrence of the *keywords* 'alliance', 'partnership', 'agreement' in the article text; (4) items published between years 1994 and 2002 inclusive. We then parsed article headlines to filter out redundant elements, and retrieved information on the article's publication year as well as on firm names that matched those in the panel. We visited each biotech firm's website to complete and check information about its strategic alliances and, where such information remained incomplete, called them individually to get the required information first-hand. We lagged APD by one year to study its impact on our dependent variables.

### *Moderators: Valuable resources and capabilities*

We measured firms' internal resources and capabilities via two variables – *International patents* and firm *Size*. International patents represent a biotech firm's technological capital, reflecting the uniqueness of its inventions both in its country of origin and abroad, as well as indicating the promise of future commercial gains through their application and licensing in different countries (Ernst, 2003). Patent data were obtained from the European Patent Office website (www.epo.org), which allows worldwide patent search. We searched by applicant (i.e. the biotech firm's) name – e.g. the European Patent Office database lists Anda Biologicals as having published 17 patents between 1981 and 2000. Each patent publication records a title, names of inventor(s) and applicant(s), classification codes, and protection priority date, as well as publication information containing country codes reflecting the territories where patent protection has been granted. Patents only covering one country are labeled with that country's specific code (FR for France, BE for Belgium, US for the USA, etc.); those covering more than one European country (referred to as 'European Patents') have patent information codes including the letters 'EP', and those filed under the 128 country-wide Patent Cooperation Treaty (PCT) are referred to as World Patents, and have the letters 'WO' in their codes.

For the purposes of this study, we define as 'international' any patent owned by a French biotech firm that provides patent protection beyond France, so covering cases where a French biotech firm had, for example, a US and/or Japanese patent, or a European or World Patent. (In fact, firms can change – and usually extend – the geographic coverage of their patents.) We considered both the patent title and its original patent information code to avoid double counting when coding patent data. Specifically, if in year $t$ a patent only provided protection in France, it was counted as national patent – if the same patent was extended in year $t+1$ to become a European patent, we then considered it an international patent, but no longer counted it as a national patent.

We used a dummy variable – *International patents* – to capture whether a biotech firm had any international patents, and also ran statistical models using two other variables measuring a firm's stock of patents – a continuous *Total number of international patents* measure and a *Ratio of international patents* (international patents divided by total number of patents). Although all of these highly correlated measures had similar effects on the probability of exit in terms of its direction, we retained the dummy *International patents* measure for two reasons – it produced more stable and significant results; and marked a distinctive trait that discriminated the firms of our population better: having *any* international patent seems to be what matters – the difference between having just one and having none is far more influential than that, say, between having four and having two.

We use a logarithmic measure of firm *Size* (in terms of the number of employees) as a proxy for the amount of its resources. Larger organizations have advantages in raising capital, can compete better for qualified labor, and possess bigger pools of financial and managerial resources that help to increase their survival (Mitchell, 1994). Using employee numbers to measure firm size is appropriate in our empirical setting, given the great importance of access to skilled human resources in the biotechnology industry (Niosi, 2003). The majority of biotech firms' staff consists of scientists who are knowledgeable about discoveries that may have commercial value (Zucker et al., 1998), so larger firms have higher levels of investments in intellectual human capital (Zucker and Darby, 1996), which certainly play in favor of sell-off when potential buyers evaluate a target company's resources, and against the odds of shut-down.

## *Control variables*

Research on firm exits has quite a long record, and previous studies have addressed different theoretical perspectives to stress particular factors responsible for firm population dynamics. Building on past research, we introduced several control variables, which were grouped into four categories: (1) *Financial resources* (previous performance, venture capital timing, equity, change in equity); (2) *Alliance types* (count of upstream, downstream, and horizontal alliances); (3) *Firm characteristics* (age, growth in number of employees, diversification, and area of specialization, i.e. pharmaceuticals, diagnostic, agriculture, and environment); and (4) *Environmental factors* (firm population density, industry sales growth, international exposure). Table 1 summarizes how our control variables were operationalized, and the theoretical rationale for including them in our statistical analysis.

## *Model specification*

As our research question deals with firms' exits, we use an event-history analysis method, which is designed for use in modeling 'time to event' data, and offers a range of techniques, including continuous-time parametric and semi-parametric models, and discrete-time models. Our choice of an appropriate statistical method was based on a careful examination of the data, as well as on a match between our hypotheses and the theoretical assumptions of the statistical model. The data have some particular features:

1. *Right-censoring*: the data contain a number of right-censored cases, where firms survived beyond the end of the observation period (2002), and so exit data do not exist: event-history analysis methods can deal with such cases so the phenomenon does not constitute a problem.
2. *Left-truncated cases*: left-truncated cases can create an estimation problem in analyzing survival data. Since firms founded before the observation period (1994) over-represent low risk cases (by having survived long enough to appear in the study's sample) statistical models can produce underestimates of exit rates for younger firms. But, as testing the models without the left-truncated cases (i.e. focusing only on ventures founded since 1994) did not alter the results, we choose to retain these incumbents in the dataset, while controlling for firm age.
3. *Bivariate dependent variables*: the dependent variables in this study represent two non-repeated mutually exclusive events: a firm can exit *either* by shut-down *or* by sell-off, so the occurrence of one type of event clearly removes a firm from the risk of the other. Thus two exit types can be assumed to be independent, allowing us to estimate separate event-specific survival models (Allison, 1995; Yamaguchi, 1991).

**Table 1.** Control variables description.

| Control variables | Description | Rationale |
|---|---|---|
| Performance | Net profit divided by turnover for a firm *i* in year *t–1* (ln) | Performance is mechanically related to a firm's exit. In addition, firms' initial resource endowments such as venture capital, equity, and subsequent change in equity can significantly decrease firms' probability of exit during its first years of existence. By consequence, we include these variables in our models. |
| Venture capital timing | Number of years since a firm received venture capital, *t–1* | |
| Equity | The debt–equity ratio represents the amount of a firm's debt divided by its equity (initial capital endowments), *t–1* (ln) | |
| Change in equity | Change in a firm's initial capital endowments from year *t–1* to year *t* | |
| Alliance types: upstream, downstream, horizontal | Three variables reflecting the count of a biotech firm's upstream, downstream, and horizontal alliances in year *t–1* (ln) | Each type of alliance provides a firm with a different kind of knowledge and resources transferred between alliance partners, generates different levels of competitive intensity (Silverman and Baum, 2002) and requires a different amount of alliance management capability (Rothaermel and Deeds, 2006). These differences are likely to impact the probability of firm exit, therefore, we control for alliance types. |
| Age | Number of years since a firm's founding (ln) | Existing studies showed that younger firms are often at a higher risk of exit due to the liability of newness (Stinchcombe, 1965), so it's important to control for firms' age. |
| Growth of employees | Change in a firm's number of employees from year *t–1* to year *t* | Growth of employees indicates positive outcomes and potential for a firm. It is also a selection criterion for investors and potential acquirers. As such growth of employees may affect a firm's exit. |
| Diversification | An ordered variable capturing whether a firm is present on 1 market (value is 1), 2 markets (value is 2) or 3 and more markets (value is 3). | Diversification can be associated with relatedness advantages and risk reduction, and hence impact a firm's exit. |
| Specialization: pharmaceuticals, diagnostic, agriculture, and environment (baseline category) | Four dummy variables taking value of '1' if a firm is mainly engaged in one of the sectors (e.g. pharmaceuticals) and value of '0' otherwise. | Previous research underlined that biotech firms operating in different sectors (e.g. pharmaceuticals, diagnostic, agriculture, and environment) draw on different scientific capabilities and operate in quite different regulatory climates (Powell et al., 2005: 1148). Given these differences it is important to control for specialization. |

**Table 1.** (Continued)

| Control variables | Description | Rationale |
|---|---|---|
| Firm population density | Total number of biotech firms operating in France in year *t–1* (ln) | With increased density, both legitimacy and competition increase, which should impact the life chances of firms. |
| Industry sales growth | Change in French biotechnology industry sales from year *t–1* to year *t* | Increase in market size captures the extent of increase in demand, which has been found to be positively related to firm survival. |
| International exposure | A ratio of national versus international co-publications aggregated at a regional level in year *t–1* | Co-publications with international institutions and organizations at a regional level capture the cluster effect (e.g. knowledge spillovers, broader opportunities for collaboration, etc.) resulting from biotech firms being located in regions of France with different exposure to international research (Corolleur et al., 2003; Mangematin et al., 2003). |

Within the event-history analysis framework, we used a semi-parametric proportional hazards model (also known as a Cox regression model) where the hazard function is given by:

$$h(t|x_j) = h(t)\exp(\beta x)$$

where h(t) denotes a baseline hazard function, $x$ is a vector of (time-dependent) covariates and β is a vector of unstandardized regression coefficients (Allison, 1995; Cleves et al., 2008). Post-estimation commands for the Cox regression model provided by STATA software also allow us to estimate the predicted hazard function at different levels of the independent variable (i.e. in this study, *Alliance portfolio diversity*). Table 2 reports descriptive statistics and correlations for the variables used to run the study's statistical models. Overall no high correlations were detected among the independent variables expect for the correlations between the measures of alliances in different stages of the value chain (the coefficients of correlation range from 30% to 44%), which may create a multicollinearity problem if all these measures are included in the model. In order to detect issues possibly due to collinearity we ran our models with a variable *Total alliances* substituting for the measures of upstream, downstream, and horizontal alliances. Our results remained consistent. Further, we ran models excluding any controls for the number of alliances and our results held as well. Thus, in order to ensure that the effects of APD are not spurious we kept the controls for the number of upstream, downstream, and horizontal alliances.

## Analysis and results

We tested two sets of models, with the dependent variable as *Shut-down* in Models 1–6 (see Table 3), and as *Sell-off* in Models 7–12 (see Table 4). In each set, the first model contains only control variables, with the moderating variables, the main effects of APD and APD squared and interaction variables being added in subsequent models.

**Table 2.** Descriptive statistics and correlations.

| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 Shut-down | | | | | | | | | | |
| 2 Sell-off | −0.021 | | | | | | | | | |
| 3 APD | 0.081* | 0.004 | | | | | | | | |
| 4 Performance | −0.089* | 0.010 | 0.056* | | | | | | | |
| 5 Venture capital timing | 0.022 | −0.020 | −0.053* | −0.212* | | | | | | |
| 6 Equity (ln) | 0.015 | 0.024 | 0.024 | 0.017 | 0.053* | | | | | |
| 7 Change in equity | −0.011 | −0.038 | −0.081* | −0.115* | 0.110* | 0.010 | | | | |
| 8 Upstream alliances (ln) | −0.043 | 0.019 | −0.307* | −0.046 | 0.121* | −0.004 | 0.091* | | | |
| 9 Downstream alliances (ln) | −0.019 | 0.047 | −0.064* | −0.063* | 0.162* | −0.015 | 0.083* | 0.437* | | |
| 10 Horizontal alliances (ln) | −0.022 | 0.067* | −0.042 | −0.036 | 0.059* | −0.001 | 0.003 | 0.311* | 0.292* | |
| 11 International patents | −0.037 | 0.009 | −0.124* | −0.134* | 0.253* | 0.191* | 0.062* | 0.113* | 0.095* | 0.051 |
| 12 Age (ln) | −0.031 | 0.086* | 0.081* | 0.132* | 0.024 | 0.152* | −0.085* | 0.022 | −0.003 | −0.024 |
| 13 Size (ln) | −0.050 | 0.078* | −0.029 | −0.010 | 0.129* | 0.284* | −0.023 | 0.009 | 0.022 | 0.010 |
| 14 Growth of employees | 0.005 | −0.084* | −0.001 | 0.001 | 0.011 | 0.072* | 0.076* | 0.000 | 0.013 | 0.007 |
| 15 Diversification | 0.025 | 0.030 | 0.008 | 0.071* | −0.099* | −0.051 | −0.026 | −0.084* | −0.014 | 0.073* |
| 16 Pharmaceuticals specialization | −0.021 | −0.017 | −0.035 | −0.225* | 0.203* | 0.118* | 0.055* | 0.041 | −0.005 | −0.060* |
| 17 Diagnostic specialization | −0.008 | −0.028 | −0.079* | −0.043 | 0.006 | −0.045 | 0.040 | 0.132* | 0.045 | 0.112* |
| 18 Agriculture specialization | 0.047* | −0.005 | 0.072* | 0.078* | −0.037 | −0.067* | −0.034 | 0.001 | −0.032 | −0.035 |
| 19 Environment specialization | −0.001 | −0.024 | −0.048 | 0.032 | −0.062* | 0.005 | −0.026 | 0.125* | 0.185* | −0.038 |
| 20 Firm population density (ln) | 0.075* | 0.116* | 0.000 | −0.084* | 0.187* | −0.020 | 0.020 | 0.071* | 0.084* | 0.120* |
| 21 Industry sales growth | 0.005 | 0.054* | −0.007 | 0.048 | −0.150* | 0.011 | 0.003 | −0.064* | −0.059* | −0.058* |
| 22 International exposure | 0.005 | 0.076* | −0.028 | −0.118* | 0.019 | 0.145* | 0.028 | −0.068* | −0.089* | −0.005 |
| *N* | 1750 | 1750 | 1400 | 1401 | 1749 | 1400 | 1681 | 1401 | 1401 | 1401 |
| Mean | 0.02 | 0.02 | 0.38 | −1.03 | 0.50 | 5.57 | 0.11 | 0.40 | 0.18 | 0.14 |
| SD | 0.14 | 0.14 | 0.35 | 4.82 | 1.37 | 2.19 | 0.31 | 0.61 | 0.44 | 0.38 |
| Min | 0 | 0 | 0 | −61.94 | 0 | 0 | 0 | 0 | 0 | 0 |
| Max | 1 | 1 | 0.67 | 0.73 | 9 | 13.34 | 1 | 2.40 | 2.77 | 2.30 |

*Notes:* Correlation coefficients are significant at * $p < .05$.

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.146* | | | | | | | | | | | |
| 0.254* | 0.359* | | | | | | | | | | |
| −0.018 | 0.000 | 0.079* | | | | | | | | | |
| −0.052* | 0.031 | −0.084* | 0.021 | | | | | | | | |
| 0.127* | −0.011 | 0.192* | 0.010 | −0.370* | | | | | | | |
| 0.014 | −0.074* | 0.023 | 0.003 | −0.008 | −0.094* | | | | | | |
| −0.123* | 0.069* | −0.040 | −0.008 | −0.185* | −0.207* | −0.083* | | | | | |
| −0.033 | −0.050 | −0.109* | −0.015 | −0.129* | −0.082* | −0.033 | −0.073* | | | | |
| 0.142* | 0.024 | −0.014 | 0.032 | 0.032 | 0.017 | 0.024 | −0.097* | −0.007 | | | |
| −0.043 | 0.007 | 0.005 | 0.000 | −0.003 | −0.024 | −0.023 | 0.017 | 0.005 | −0.124* | | |
| 0.136* | 0.014 | 0.149* | 0.054* | 0.041 | 0.174* | 0.065* | −0.218* | −0.049* | 0.148* | 0.013 | |
| 1749 | 1401 | 1686 | 1401 | 1729 | 1750 | 1750 | 1750 | 1750 | 1497 | 1678 | 1696 |
| 0.18 | 1.66 | 3.81 | 2.83 | 1.64 | 0.19 | 0.04 | 0.15 | 0.03 | 5.24 | −0.10 | 0.56 |
| 0.38 | 0.62 | 1.43 | 16.79 | 0.85 | 0.39 | 0.19 | 0.36 | 0.17 | 0.36 | 0.22 | 0.11 |
| 0 | 0 | 0 | −203 | 1 | 0 | 0 | 0 | 0 | 4.28 | −0.73 | 0.03 |
| 1 | 3.81 | 5.655 | 180 | 3 | 1 | 1 | 1 | 1 | 5.67 | 0.18 | 0.74 |

**Table 3.** Results of Cox regression with shut-down as a dependent variable.

| Variables | Model 1 | | Model 2 | | Model 3 | | Model 4 | | Model 5 | | Model 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Control variables* | | | | | | | | | | | | |
| Performance | −0.036 | (0.025) | −0.048*** | (0.020) | −0.057*** | (0.024) | −0.056** | (0.024) | −0.057** | (0.026) | −0.055*** | (0.021) |
| Venture capital timing | 0.007 | (0.130) | 0.075 | (0.110) | 0.061 | (0.101) | 0.062 | (0.102) | 0.083 | (0.104) | 0.069 | (0.103) |
| Equity | 0.071 | (0.087) | 0.096 | (0.082) | 0.102 | (0.088) | 0.103 | (0.089) | 0.107 | (0.088) | 0.088 | (0.090) |
| Change in equity | −0.442 | (0.631) | −0.275 | (0.624) | −0.231 | (0.622) | −0.239 | (0.626) | −0.271 | (0.623) | −0.577 | (0.780) |
| Upstream alliances | −0.778 | (0.517) | −0.900* | (0.549) | −0.566 | (0.662) | −0.628 | (0.829) | −0.459 | (0.628) | −0.456 | (0.627) |
| Downstream alliances | −0.290 | (0.624) | −0.022 | (0.598) | 0.012 | (0.640) | −0.052 | (0.641) | −0.188 | (0.697) | 0.008 | (0.626) |
| Horizontal alliances | −0.180 | (0.569) | −0.025 | (0.540) | 0.040 | (0.615) | −0.013 | (0.635) | 0.145 | (0.644) | −0.076 | (0.600) |
| Age | −0.564 | (0.357) | −0.441 | (0.356) | −0.560 | (0.393) | −0.559 | (0.394) | −0.530 | (0.410) | −0.421 | (0.419) |
| Growth of employees | −0.003 | (0.002) | −0.005** | (0.003) | −0.005** | (0.003) | −0.005** | (0.003) | −0.004 | (0.002) | −0.006** | (0.003) |
| Diversification | 0.699 | (0.559) | 0.676 | (0.571) | 0.699 | (0.586) | 0.688 | (0.589) | 0.751 | (0.597) | 0.461 | (0.593) |
| Pharma specialization | 0.392 | (0.660) | 0.639 | (0.687) | 0.638 | (0.684) | 0.629 | (0.686) | 0.664 | (0.676) | 0.488 | (0.652) |
| Diagnostic specialization | 0.129 | (1.105) | 0.336 | (1.101) | 0.310 | (1.157) | 0.265 | (1.231) | 0.275 | (1.208) | 0.338 | (1.117) |
| Agriculture specialization | 1.451*** | (0.586) | 1.421** | (0.620) | 1.447*** | (0.617) | 1.438*** | (0.598) | 1.474** | (0.659) | 1.264** | (0.618) |
| Firm population density | −6.746*** | (1.222) | −6.609*** | (1.261) | −6.610*** | (1.288) | −6.613*** | (1.293) | −6.633*** | (1.312) | −6.289*** | (1.290) |
| Industry sales growth | 1.359*** | (0.418) | 1.153*** | (0.422) | 1.300*** | (0.419) | 1.294*** | (0.416) | 1.343*** | (0.399) | 1.250*** | (0.429) |
| International exposure | −1.194 | (1.584) | −0.463 | (1.626) | −0.827 | (1.705) | −0.835 | (1.705) | −0.919 | (1.701) | −0.925 | (1.703) |
| *Moderators* | | | | | | | | | | | | |
| International patents | | | −2.210** | (1.088) | −2.217*** | (1.144) | −2.220** | (1.125) | −2.403* | (1.289) | −2.128** | (1.077) |
| Size | | | −0.220** | (0.113) | −0.217*** | (0.110) | −0.216** | (0.111) | −0.217** | (0.108) | 1.261 | (0.785) |
| *Independent variables* | | | | | | | | | | | | |
| APD | | | | | 0.983*** | (0.510) | 1.685 | (4.399) | 1.117** | (0.543) | −0.142 | (0.200) |
| APD squared | | | | | | | −0.734 | (4.529) | | | | |
| *Interactions* | | | | | | | | | | | | |
| APD × International patents | | | | | | | | | | | −1.999* | (1.168) |
| APD × Size | | | | | | | | | | | −0.172 | (0.260) |
| *N* observations | 1349 | | 1340 | | 1340 | | 1340 | | 1340 | | 1340 | |
| *N* firms | 304 | | 304 | | 304 | | 304 | | 304 | | 304 | |
| Wald chi2 | 123.00*** | | 147.11*** | | 153.98*** | | 154.02*** | | 152.98*** | | 155.65*** | |

*Notes:* Coefficients are significant at ***$p < .01$, **$p < .05$, *$p < .08$.

**Table 4.** Results of Cox regression with sell-off as a dependent variable.

| Variables | Model 7 | | Model 8 | | Model 9 | | Model 10 | | Model 11 | | Model 12 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Control variables* | | | | | | | | | | | | |
| Performance | 0.004 | (0.037) | 0.009 | (0.037) | 0.011 | (0.036) | −0.008 | (0.032) | 0.013 | (0.039) | 0.024 | (0.045) |
| Venture Capital timing | −0.198 | (0.166) | −0.152 | (0.153) | −0.153 | (0.153) | −0.252 | (0.181) | −0.170 | (0.175) | −0.182 | (0.168) |
| Equity | 0.037 | (0.100) | −0.001 | (0.098) | −0.009 | (0.101) | 0.048 | (0.102) | 0.008 | (0.100) | 0.025 | (0.107) |
| Change in equity | −1.809* | (1.036) | −1.882 | (1.018) | −1.887** | (0.990) | −2.110** | (0.995) | −1.943** | (0.992) | −2.050** | (1.062) |
| Upstream alliances | −0.167 | (0.382) | −0.061 | (0.381) | −0.103 | (0.378) | −0.476 | (0.466) | −0.377 | (0.504) | −0.374 | (0.438) |
| Downstream alliances | 0.405 | (0.347) | 0.446 | (0.330) | 0.462 | (0.328) | 0.125 | (0.329) | 0.350 | (0.375) | 0.153 | (0.370) |
| Horizontal alliances | 0.620 | (0.483) | 0.565 | (0.475) | 0.577 | (0.454) | 0.134 | (0.339) | 0.402 | (0.487) | 0.277 | (0.454) |
| Age | 0.366 | (0.368) | 0.221 | (0.328) | 0.252 | (0.324) | 0.459 | (0.324) | 0.333 | (0.323) | 0.284 | (0.351) |
| Growth of employees | −0.008*** | (0.003) | −0.007*** | (0.003) | −0.007*** | (0.003) | −0.634* | (0.402) | −0.008*** | (0.003) | −0.007*** | (0.003) |
| Diversification | 0.708* | (0.423) | 0.679* | (0.417) | 0.688* | (0.420) | 0.811** | (0.421) | 0.850** | (0.428) | 0.788* | (0.432) |
| Pharma specialization | −0.365 | (0.586) | −0.564 | (0.583) | −0.566 | (0.587) | −0.008 | (0.507) | −0.471 | (0.616) | −0.537 | (0.642) |
| Diagnostic specialization | −0.475 | (0.602) | −0.475 | (0.602) | −0.475 | (0.602) | −0.475 | (0.602) | −0.475 | (0.602) | −0.475 | (0.602) |
| Agriculture specialization | 0.550 | (0.617) | 0.445 | (0.617) | 0.460 | (0.603) | 0.594 | (0.624) | 0.628 | (0.610) | 0.581 | (0.610) |
| Firm population density | −5.414*** | (1.267) | −6.011*** | (1.347) | −6.097*** | (1.374) | −6.124*** | (1.467) | −6.550*** | (1.551) | −5.954*** | (1.338) |
| Industry sales growth | 2.317*** | (0.564) | 2.366*** | (0.561) | 2.327*** | (0.570) | 2.407*** | (0.526) | 2.355*** | (0.552) | 2.445*** | (0.560) |
| International exposure | 7.774*** | (2.595) | 7.773*** | (2.578) | 7.863*** | (2.593) | −0.182 | (0.166) | 7.054*** | (2.890) | 6.428*** | (2.699) |
| *Moderators* | | | | | | | | | | | | |
| International patents | | | −0.621* | (0.384) | −0.668* | (0.408) | −0.409 | (0.333) | −3.253*** | (0.989) | −0.803** | (0.414) |
| Size | | | 0.232** | (0.104) | 0.245** | (0.107) | 0.279*** | (0.113) | 0.203* | (0.121) | 0.035 | (0.182) |
| *Independent variables* | | | | | | | | | | | | |
| APD | | | | | −0.325 | (0.432) | 4.019* | (2.520) | 5.796 | (6.424) | −1.183 | (0.927) |
| APD squared | | | | | | | −5.634** | (2.581) | −4.448* | (2.570) | 0.052 | (0.226) |
| *Interactions* | | | | | | | | | | | | |
| APD × International patents | | | | | | | | | 11.126*** | (2.922) | | |
| APD2 × International patents | | | | | | | | | −7.913*** | (2.949) | | |
| APD × Size | | | | | | | | | | | 0.920** | (0.505) |
| APD^2 × Size | | | | | | | | | | | −1.159** | (0.562) |
| *N* observations | 1349 | | 1340 | | 1340 | | 1340 | | 1340 | | 1340 | |
| *N* firms | 304 | | 304 | | 304 | | 304 | | 304 | | 304 | |
| Wald chi2 | 141.14*** | | 159.95*** | | 159.96*** | | 135.09*** | | 169.77*** | | 162.72*** | |

*Notes:* Coefficients are significant at ***$p < .01$, **$p < .05$, *$p < .08$. [Robust standard errors are reported in parentheses.]

## Control variables effects

In the case of the shut-down of biotech firms (see Table 3) the effects of different types of alliances were generally not significant across the models, although the coefficients were negative, which is consistent with the expected negative effect of alliances on the probability of firms' failure. As might be expected, firms with better financial results (*Performance*) were less likely to shut down. Compared to specialization in environmental biotechnology (our baseline category) specialization in agriculture increased the probability of this type of exit, but other types of specialization (including pharmaceuticals and diagnostics) showed no significant effects. Such constraints as anti-transgenic movement, which is active in France, and the French Code of Environment requiring special authorization for selling genetically modified products (article L.533-5 of the Code) could explain lower survival rates of biotech firms specialized in agriculture. Faster growing companies in terms of number of employees were less likely to shut down. Further, higher firm population density decreased the probability of shut-down, while increased industry sales growth was associated with a higher probability of this type of exit. As regards our moderating variables, firms' internal capabilities (as measured by international patents and firm size) decreased the likelihood of shut-down ($\beta_{\text{International patents}} = -2.210$ and $\beta_{\text{Size}} = -0.220$ at $p < .05$, see Model 2 in Table 3).

In the case of the sell-off of biotech firms (see Table 4), we found that firms with recent increases in equity were less likely to be sold off, but that those that were located in regions with higher *international exposure* or that operated in more than three biotechnology domains (*diversification*) were more likely to be acquired. Greater population density reduced the likelihood of exit by sell-off, but greater industry sales increased it. In Model 8 (Table 4), the independent effect of our moderating variable *International patents* is negative, meaning that it decreased the likelihood of exit by sell-off ($\beta_{\text{International patents}} = -0.621$ at $p < .08$), while the independent effect of firm *Size* was positive ($\beta_{\text{Size}} = 0.232$ at $p < .05$), meaning larger firms were more likely to exit in this way.

## APD main effects

Hypotheses 1 and 2 predicted curvilinear associations between APD and firms' probability of exit – a U-shaped curve for shut-down and an inverted U-shaped curve for sell-off. Model 3 (Table 3) and Model 9 (Table 4) report linear APD effects. We found significant statistical evidence that APD has a positive linear effect on the probability of exit by shut-down ($\beta = 0.983$ at $p < .01$), but the linear effect of APD on the probability of firm sell-off was not significant. Model 4 (Table 3) and Model 10 (Table 4) include both the linear and square measures of APD. We found no evidence of a curvilinear relationship between APD and the probability of firms being shut down – thus denying support for Hypothesis 1. But in the case of firm sell-off, the coefficients for both the linear and square terms of APD were significant ($\beta_{APD} = 4.019$, $p < .08$ and $\beta_{APD^2} = -5.634$, $p < .05$, with the inflexion point at APD = 0.35[4]), providing strong support for Hypothesis 2. Figure 1 illustrates the main effects of APD on the likelihoods of the two types of exit, showing that the magnitude of APD's effect on the probability of sell-off is higher than on the chance of shut-down, although this difference decreases at higher APD levels.

## Moderating effects

Hypothesis 3a predicted that biotech firms' internal capabilities would negatively moderate the curvilinear relationship between APD and shut-down by shifting the U-shaped curve downwards.

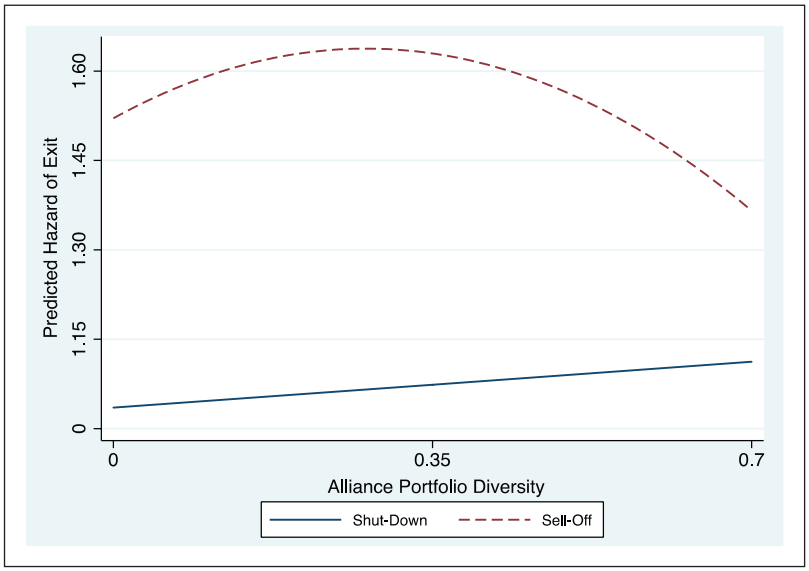


**Figure 1.** Differing effect of alliance portfolio diversity on biotech firms' exit by shut-down and sell-off.

Model 5 (see Table 3) reports a marginally significant ($p = .08$) coefficient of the interaction term *APD* × *International patents* ($\beta = -1.999$), which indicates that biotech firms with international patents are at a marginally lower risk of being shut down compared to those without such patents, but we find no direct support for the moderating effect of firm *Size* on the probability of biotech firms' shut-down. Model 6 (Table 3) reports a coefficient of the interaction term *APD* × *Size* ($\beta = -0.172$), which is not significant, but it shows that the moderation effect is in the predicted direction. The two panels of Figure 2a represent each effect: on the left we can see that having at least one international patent significantly reduces the probability of shut-down, even for higher levels of APD, and the right provides some evidence of the effect of firm size as a negative moderator of the APD–shut-down relationship, although the coefficients were not found to be significant. Thus, Hypothesis 3a – that firms with higher capability levels (as measured by them having international patents) are less likely to be shut down at any level of the diversity of their alliances – received only some support.

Hypothesis 3b proposed that firms' internal resources would reinforce the positive relationship between APD and the likelihood of biotech firms being sold off by shifting the inverted U-shaped curve upwards. When we introduced an interaction term (Model 11 in Table 4), both independent and interaction effects for *International patents* were found to be significant ($\beta_{\text{International patents}} = -3.253$, $\beta_{\text{APD} \times \text{InternPatents}} = 11.126$, $\beta_{\text{APD\^2} \times \text{InternPatents}} = -7.913$ at $p < .01$). As the left panel of Figure 2b shows, for companies with international patents the probability of sell-off is magnified. In the case of firm size, we found that the relationship between APD and the probability of sell-off is also amplified for larger firms (Model 12 in Table 4): $\beta_{\text{APD} \times \text{Size}} = 0.920$, $\beta_{\text{APD\^2} \times \text{Size}} = -1.159$ at $p < .05$). The right panel of the figure shows that the presence of internal capabilities in a firm pushes the inverted U-shaped curve representing the relationship between its APD and the probability of it being sold off upwards and slightly to the right – meaning that larger firms are less likely to be sold off than smaller ones at higher levels of APD: overall, then, Hypothesis 3b is supported.

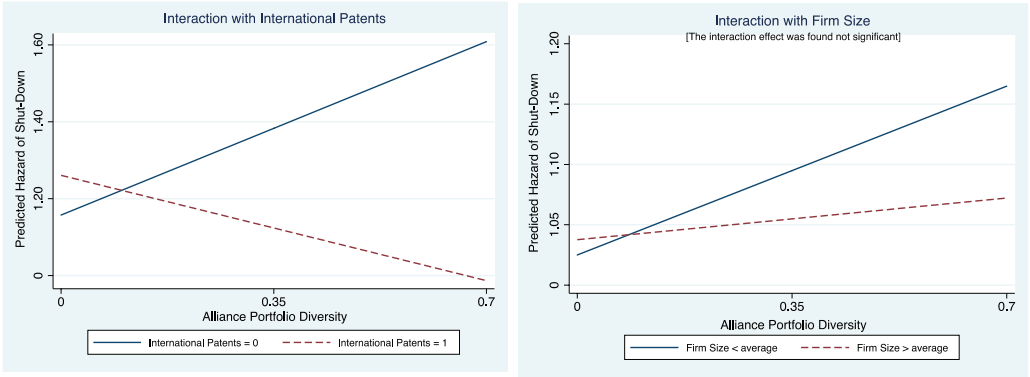


**Figure 2a.** Moderating effects of valuable resources and capabilities on biotech firms' shut-down.

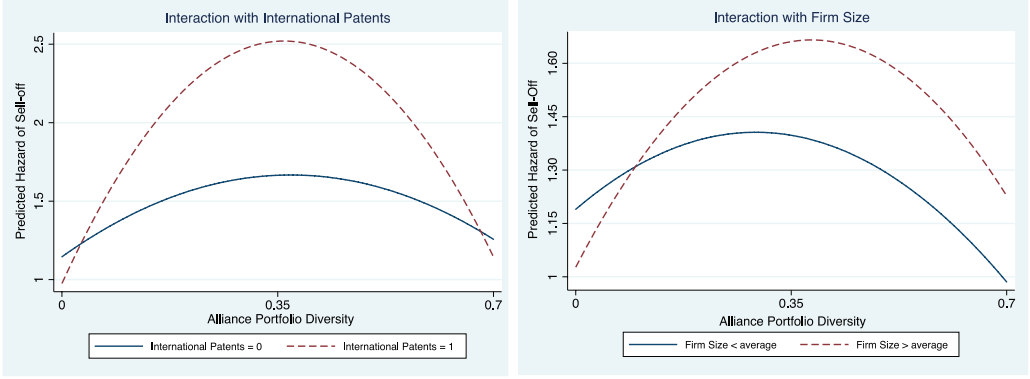


**Figure 2b.** Moderating effects of valuable resources and capabilities on biotech firms' sell-off.

## *Robustness checks*

We conducted a series of robustness checks. First, we ran Cox regression post-estimation tests (particularly, Cox–Snell residuals and deviance residuals analyses) as provided by STATA software to estimate the fit of the chosen statistical model. In a well-fitting model, Cox–Snell residuals will follow a standard exponential distribution with a hazard ratio of 1.0, while positive deviance residuals mean that hazard rates are not overestimated (Box-Steffensmeier and Jones, 2004). Overall, the post-estimation tests showed that the Cox regression models we chose to estimate APD's effect on firms' exit modes were correct.

Second, to understand more about what these findings reveal about the differing effects of APD on the two exit modes of biotech firms, we ran a log-likelihood ratio test to verify whether it was statistically appropriate to run two separate models with *Shut-down* and *Sell-off* as dependent variables, rather than one aggregated model pulling both exit modes together – in other words, we tested whether our *Shut-down* and *Sell-off* models were actually nested within a full *Exit* model. The results of the log-likelihood ratio test showed that, while the *Shut-down* model is nested within the full *Exit* model (LR $\chi^2 = 315.27$ with prob > $\chi^2 = .000$), the *Sell-off* model is not (LR $\chi^2$ was not

significant): in other words separately run models (with the two exit types as dependent variables) together explained the probabilities of exit better than the full undifferentiated model.

Third, given the complementarity across different event-history analysis methods, we ran multinomial logistic regressions as an alternative method to test our hypotheses. Logistic regression is appropriate to use for discrete event times when durations are measured in discrete time units such as years (Allison, 1984; Steele, 2005), and the method has several advantages. Logistic regression does not lead to downward bias standard errors or spell-splitting, or to unobserved correlations across multiple records (Teachman et al., 1993), and can handle differences in variance/covariance structures between firms based on dichotomous outcomes (Mitchell and Singh, 1996). Among different types of logistic regressions we chose multinomial logistic regression (*mlogit* command in STATA) that fits maximum likelihood models with discrete dependent (left-hand-side) variables when the dependent variable has more than two possible outcomes (in our case exit is coded 0 if a firm survived, 1 if a firm was shut down, and 2 if a firm was sold off) which have no natural ordering (Cleves et al., 2008). The results were materially equivalent to those obtained from the Cox regression tests except for a few coefficients.[5] The most noticeable difference was in the moderating effect of size on APD–sell-off relationship, where the coefficients of the interaction terms were smaller in the *mlogit* model than in the equivalent Cox model, although the significance level in the *mlogit* model was higher ($p < .01$). Overall, the coefficients for the main and moderating effects were of similar magnitude and significance, confirming the robustness of our findings.

## Discussion

This study was motivated by the desire to understand better the influences of a firm's alliance portfolio diversity on the types of a firm's exit from the industry beyond the effect of a firm's portfolio size. We argued that, based on its relative benefits (network centrality and composed development favored by stakeholders) and costs (inter-partner competition and complexity management), APD affects the likelihood of the firm being successfully sold off or alternatively being forced to shut down operations. Our findings show that a balanced APD increases the probability of biotech firms exiting the industry, linearly for shut-downs and in an inverted U-shaped curve for sell-offs, and these results hold even when controlling for different types of firm alliances – upstream, downstream, and horizontal – giving additional empirical evidence of the significance of the APD effect beyond the effect of alliance numbers.

Our findings of the APD linear effect on the probability of shut-down is contrary to our Hypothesis 1 – that expected first a reduction in hazard and then an increase as APD levels increased – but is consistent with existing evidence about the negative effect of alliance partners' diversity on larger firms' financial performance (Goerzen and Beamish, 2005; Jiang et al., 2010). Where firms exit their industry by shutting down, we suggest that either the expected benefits of moderate level APD do not materialize, or if they do, are insufficient to outweigh the associated costs. Benefits in terms of favorable appraisals by stakeholders – clients, agencies, banks, etc. – may be more symbolic than material, and existing studies show that biotech firms have trouble appropriating rents from their alliances with larger organizations (Alvarez and Barney, 2001; Bae and Gargiulo, 2004; Durand et al., 2008). Also, as APD increases, the benefits of both resource access and variety may not compensate for the costs of intra-partner competition – even when these are reduced by alliance diversity – and of managing more complex portfolios – expenses such as alliance formation, portfolio monitoring, coordination, and relational governance (Sarkar et al., 2009). Dealing with different partners often requires focal firms to be able to balance all

their diverse interests and goals: thus universities (who often lack commercial interests) may want to conduct a long-term broad research program with a focal biotech company, but its downstream partners – e.g. established pharmaceutical firms – will favor applied research which can yield quick results in terms of putting a product on the market. In situations where different partners are all trying to 'hog the blanket', biotech firms are unlikely to have sufficient alliance management capability to extract benefits from diversity. Note that a moderately balanced APD puts firms in a better position to achieve a sell-off (giving support to our second hypothesis), but high levels of diversity are expected to decrease the probability of firms being acquired.

In sum, these findings show that high APD does not help firms avoid shut-down and at the same time as the diversity increases, the materialization of benefits of a firm's balanced APD will proceed until the point where the costs increase too much and more than offset benefits thus diminishing the firm's probability of sell-off. Overall the magnitude of the effect of APD on the probability of exit is higher for the sell-off than for the shut-down mode (see Figure 1), indicating that APD may be a particularly important factor in predicting acquisitions.

Our study shows also that resourcefulness puts a firm in a better position to extract benefits from its alliances with diverse types of partners. Specifically, possession of valuable resources and capabilities (in terms of international patents) moderates negatively the probability of a biotech firm's shut-down for any APD level above zero. A possible explanation of the non-significant interaction effect of firm size and APD on the probability of firm's shut-down could be that large firms in high tech still remain relatively small and may not necessarily reach the efficiency threshold to manage complexity implied by a balanced portfolio. Internal resources and capabilities moderate the relationship between APD and the probability of sell-off positively: larger firms and firms with international patents having moderately balanced APD are more likely to be acquired. In general, consistent with our predictions, firms with higher levels of valuable resources and capabilities are less at risk of failure (negative linear effect on shut-down) and more likely to be able to realize a sell-off.

Overall, our findings extend previous research in several ways. First, we highlight the theoretical underpinnings to, and offer empirical evidence of, APD's effect on the exit modes of high tech firms, obtaining this effect after considering the number of allies for each type of value chain position, so establishing diversity as an impactful attribute of firms' alliance portfolio. Second, we distinguish theoretically and empirically between two key exit types (shut-down and sell-off) and demonstrate that APD has differing effects on their probability – linear in the case of shut-down and curvilinear (inverted U curve) in the case of sell-off. This represents a step forward in developing an adequate theory of firms' strategy and industry dynamics that accounts better for the different nature of various exit modes that prior research has tended to conflate. Third, we establish the significant moderating effect of firms' valuable resources and capabilities on their ability to extract benefits from diversity, which broadens our understanding of how different APD levels can affect firm's performance and survival.

Our results also have potential implications for managers. Although in the biopharmaceutical industry there is an emerging perspective on managing alliances as a portfolio in order to exploit synergies and more effectively manage coordination costs,[6] most companies still approach the design and management of their business partnerships by focusing on optimizing each individual alliance (Parise and Casher, 2003). The results of our study urge managers to consider diversity of their firms' alliance portfolios as it may have both beneficial and detrimental effects on the survival chances of their firms. Particularly, the negative consequences of APD for firm shut-down may be due to establishing alliances with the wrong partners (e.g. not increasing legitimacy), partnering for the wrong reasons (e.g. increasing inter-partner rivalry), or managing the portfolio wrongly

(e.g. being unable to control the cost of complexity). We therefore suggest high tech firms should develop critical alliance experience and consider seriously the diversity of their alliance portfolio. Founders or managers looking to sell off their businesses should also pay particular attention to their firm's APD – while diverse alliance partners offer greater visibility and varied sources of complementary benefits, increasing APD beyond a certain point may not always 'play well' as a strategy in terms of increasing their firms' attractiveness as targets for purchase.

We conclude with some cautionary remarks about generalizing this study's findings and interpretations. This research has focused on a single industry and a unique national context – French biotechnology – and its findings may not apply directly to other countries with distinct institutional and economic conditions, or to other industries. For example, the French biotech industry during the 1994–2002 period was considered as lagging behind the US, with a smaller critical mass of biotech firms and less available funding (European Association for Bioindustries, 2006), which implies the biotech firms in our study may have operated in less favorable conditions than their American counterparts and so faced higher risks of exit. Another potential limitation of this article is its assumption that all partners in the same category (horizontal, upstream, downstream) will exhibit the same characteristics. Horizontal and vertical alliances obey different principles, so combining them into an aggregate (like APD) may neglect partner-specific information: while we control for that possibility, under other conditions (at country or industry stage, for instance) this aggregate may need to be decomposed. Nevertheless, our point remains that the compositional diversity of a firm's alliance partners has a significant and different effect on firms' exit modes. Useful extensions to this article and others (Goerzen and Beamish, 2005; Jiang et al., 2010) need to analyze a firm's alliance portfolio according to the partners' identities, status, resources, and other characteristics. Finally, future research may want to further explore endogeneity effects, since alliances are at the same time causes and consequences of different organizational and environmental factors.

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## Notes

1. Missing data reduced our final sample to 304 firms and 1340 firm-years.
2. Ministere de l'Education Nationale, de la Recherche et de la Technologie – the French ministry in charge of research and technology.
3. The maximum value of Blau's (1977) index of heterogeneity depends on the number of categories, $k$: which is 3 in our case. The index formula is $(k – 1)/ k$, so the maximum value in our case is $(3 – 1) / 3 \approx 0.67$.
4. The inflexion point of the curvilinear relationship – APD = 0.35 – corresponds to a moderate diversity level. As defined earlier, moderate levels of APD reflect the situation when a firm has different numbers of alliance partners in all three categories – upstream, downstream, and horizontal (APD ranges between 0 and 0.67).
5. The multinomial logistic regression results are not reported here due to space constraints, but are available from authors.
6. See for instance the Rhythm of Business research titled 'The practice of alliance management in the biopharmaceutical industry' (11 January 2010) and available at: www.rhythmofbusiness.com/news.php?id=8.

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