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Abstract

This paper investigates the use of discounted cash flow (DCF) analysis for the valuation of exploratory projects. In order to account for the widespread use of a contested formula, while avoiding both over- and under-calculative explanations, it proposes to examine DCF as a valuation device, i.e. a material and discursive assemblage. The paper hence attempts to describe the worlds of DCF - the one sketched by its hypotheses and the one constructed through its use – by focusing on the valuation of joint research/licensing projects between pharmaceutical companies and biotechnology start-ups. Describing how the formula calculates sheds light on how it matters in practice. The paper shows that DCF acts as a coordination tool and plays a performative role, namely through nurturing market repertoires and through the effects that it induces in exploration activities.

Introduction

Among the many culprits held responsible for the crisis that shook financial markets in 2008, one is a rather unusual suspect: complicated formulae, like the Gaussian copula model, have reached beyond the intimate understanding of "quants" to become the object of public inquiry and sociological analysis (MacKenzie 2010; Tett 2009). Are mathematical models to blame for the crisis? Were they flawed? Or were they good tools placed in the hands of incompetent users – users who treated them unreflectively and blindly believed in their predictions?

In the ongoing controversy, mathematical models are depicted in a variety of ways: from neutral tools for the objective assessment of risk to dangerous lures threatening human rationality. Such debates on the role of formulae in the valuation of uncertain assets are neither new nor limited to financial markets. This paper proposes to shift attention to a different tool and a different setting: the use of the discounted cash flow (DCF) formula for the valuation of exploratory projects.

The basic mechanism of the DCF technique is easy to grasp: the current value of an investment is equal to the sum of the cash flows that it will generate in the future, with the latter being "discounted" due to their distance in time and, if applicable, to the risk that they may not occur. The difficulty to apply this formula to exploratory projects, which are highly uncertain, is equally clear: summing up future cash flows hardly makes any sense when the amount and the likelihood of these cash flows are unknown.

Faced with the problem of valuation under uncertainty, scholars have outlined two broad types of solutions. One is to fix the problem, by searching for more sophisticated mathematical techniques, such as real options (Kogut and Kulatilaka 2004). The other is to dismiss the problem, by reducing the process of valuation under uncertainty to political advocacy and negotiation (Freeman 1982). The paper argues that these solutions are not satisfactory, as they are either "over" or "under-calculative" (Beunza and Garud 2007). In order to enhance our understanding of the tools that instrument processes of valuation under uncertainty, I adopt an alternative approach and examine the DCF formula as a valuation device. Instead of considering it as a (more or less perfect) measurement of a given objective value, or as a symbolic artefact mobilized in organizational ceremonies (Meyer and Rowan 1977), I explore the ways in which the formula counts (i.e. both calculates and matters) for its

users and affects the market transactions in which it intervenes. In doing so, I build on the performativity perspective in economic sociology (Callon 1998; MacKenzie and Millo 2003) and on actor-network theory in science and technology studies (Callon 1986; Latour 1987).

The paper examines the DCF formula by depicting its "worlds": the one sketched through its underlying hypotheses and the one constructed through its usage (MacKenzie 2003). I attempt to provide a de-scription (Akrich 1992) of this mathematical object by outlining the hypotheses that are embedded in it and that are continually negotiated as it is put in practice. The empirical site chosen here is the valuation of early-stage drug development projects conducted jointly by pharmaceutical companies and biotechnology start-ups. I build on interviews with managers and consultants involved in the valuation of such exploratory projects, as well as on the analysis of practitioners' publications on this issue (textbooks, guidelines, scientific and press articles). The empirical material thus collected helps to understand how and why DCF has maintained its prevalence and usefulness in the valuation of exploratory projects in spite of its admittedly untrue calculations.

1) The DCF formula as a valuation device

1.1. The paradox of valuation under uncertainty

The challenge of valuation under uncertainty has been a key concern in the literature on innovation. In Freeman's (1982) seminal book on the economics of innovation, for example, a whole chapter is devoted to the issue of the estimation of research and development (R&D) projects. The chapter outlines the following paradox: there are various techniques for project estimation (e.g., discounted cash flow analysis); however, the estimates that they produce can only be true if project uncertainty is reduced; hence, accuracy can only be achieved if projects are rendered less innovative. Freeman puts forward two main solutions to this paradox. The first one is to rely on increasingly sophisticated techniques for the evaluation and selection of innovation projects. Albeit attractive, this solution fails the test of practice: while sophisticated estimation techniques (e.g., real options) are made readily available by statisticians and consultants, it appears that they are rarely used by practitioners whose preference goes to simple discounted cash flow (DCF) calculations and other methods which resemble more to rules of thumb than to sound financial mathematics. Recent empirical studies confirm the prevalence of the DCF formula in the practice of R&D project estimation: Hartmann and Hassan (2006), for example, show that it is the most widely applied method in the pharmaceutical industry (with a frequency of use ranging from 59% for early-stage projects to 100% for more advanced projects).

The second solution that Freeman hints at is to assert that valuation is not a rational but a political process driven by the confrontation of personal interests and power struggles. In this perspective, calculation gives way to what Keynes (1936) referred to as "animal spirits": the emotions and psychological motivations which influence the (supposedly rational) behaviour of *homo economicus*. [1] Freeman's empirical study tends to grant support

[1] Keynes (1936) emphasized the importance of such "animal spirits" in chapter 12 of "The General Theory of Employment, Interest and Money", as indicated in the following excerpts (emphasis added):
"If we speak frankly, we have to admit that our basis of knowledge for estimating the yield ten years hence of a railway, a copper mine, a textile factory, the goodwill of a patent medicine, an Atlantic liner, a building in the City of London amounts to little and sometimes to nothing; or even five years hence." (chapitre12, III)

to this view, as "it suggests strongly that the social context of project "estimation" is a process of political advocacy and clash of interest groups rather than sober assessment of measurable probabilities" (p.151). This - rather pessimistic - assessment raises the following issue: if valuation under uncertainty amounts to a political process in which power substitutes for rationality, what is then the role of calculation tools, be they rules of thumb, DCF calculations, or complex statistical techniques? For Freeman, evaluation techniques still matter, but in a different manner. The purpose that they serve is not cognitive, but social: "like tribal dances, [they] play a very important part in mobilizing, energizing and organizing" (p.167). While this explanation benefits from a certain exotic appeal and keys into discussions which, drawing inspiration from institutional theory, have examined the symbolic artefacts mobilized in organizational ceremonies (Meyer and Rowan 1977), it leaves unanswered one major question: why do some evaluation techniques thrive, while others fail? In other words, if the objective lies in "mobilizing, energizing and organizing", does it make any difference if one uses a DCF formula or any other calculation tool?

1.2. Valuation devices

These two solutions to the paradox of valuation under uncertainty echo the "over-calculative" and "under-calculative" views that Beunza and Garud (2007: 19) identify in their study of securities analysts' reports. The former view envisages the values produced by securities analysts as reflecting the intrinsic qualities of the entities (here, corporations) that are described, while the latter emphasizes the social mechanisms of belief and imitation which drive the formation of an agreement on value. The authors propose an alternative to these two interpretations: they suggest that the reports produced by analysts (e.g., on the new venture that was Amazon.com in the late nineties) provided "calculative frames" composed of categories (Amazon.com is an "internet company", or a "book retailer"), analogies (this company is comparable to Dell, or to Barnes&Noble), and key metrics (its value lies in its revenue, or in its profits). Materialized in reports and Excel spreadsheets, competing calculative frames circulate among investors, serving as inputs for the valuation of publicly traded companies.

In this alternative perspective, calculative tools are examined as "market devices" (Callon, Millo and Muniesa 2007: 2): the "material and discursive assemblages that intervene in the construction of markets". The concept of market devices is rooted in a stream of literature, situated at the crossroads of economic sociology and science and technology studies (Pinch and Swedberg 2008), which emphasizes the material and relational aspects of economic activities. Markets imply "calculative agencies" (Callon 1998: 3) whose emergence can hardly be understood by resorting solely to cognitive or institutional explanations: the source of calculativeness, Callon argues, lies in networks which are made of social ties but

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"Even apart from the instability due to speculation, there is the instability due to the characteristic of human nature that a large proportion of our positive activities depend on spontaneous optimism rather than on a mathematical expectation, whether moral or hedonistic or economic. *Most, probably, of our decisions to do something positive, the full consequences of which will be drawn out over many days to come, can only be taken as a result of animal spirits — of a spontaneous urge to action rather than inaction, and not as the outcome of a weighted average of quantitative benefits multiplied by quantitative probabilities.* Enterprise only pretends to itself to be mainly actuated by the statements in its own prospectus, however candid and sincere. Only a little more than an expedition to the South Pole, is it based on an exact calculation of benefits to come. Thus if the animal spirits are dimmed and the spontaneous optimism falters, leaving us to depend on nothing but a mathematical expectation, enterprise will fade and die; — though fears of loss may have a basis no more reasonable than hopes of profit had before." (chapitre12, VII)

also of tools and instruments. Drawing attention to the agency of nonhuman entities (Callon 1986; Latour 1987) and the distribution of cognition (Hutchins 1995), the notion of market devices emphasizes the relations between people and the instruments that they use as well as on the interactions between human agents as mediated by the material entities that they put into circulation.

While the study of market devices has embraced various empirical settings, it has proved particularly fruitful for understanding the functioning of financial markets. For example, Beunza and Stark (2004) demonstrate that the practice of arbitrage involves a calculation that is distributed across the different desks of a trading room, the various tools, such as screens and computer programs, with which arbitrageurs continuously interact, and the arbitrageurs themselves. This paper proposes to adopt a similar perspective in a different empirical setting: corporate finance and, more precisely, the valuation of collaborative R&D projects between pharmaceutical companies and biotech start-ups. The device on which I focus is the DCF formula (which I shall simply call "DCF" in the remainder of this paper).

Examining DCF as a market device introduces a twofold shift. On the one hand, it allows moving beyond the alternative of "over-" or "under-calculative" explanations which both recognize the flaws of DCF and either propose to replace it with more sophisticated techniques (e.g., real options) or dismiss its relevance by diluting the process of project evaluation to a political game in which estimates play no more than a symbolic role. On the other hand, it further investigates the notion of market device by examining its relevance in an atypical setting: inter-firm partnerships, i.e. a configuration that is halfway between arms' length market transactions and hierarchical integration. Therefore, in the remainder of the paper, I shall use the term "valuation device", extending the notion of market devices to the material and discursive assemblages that intervene in processes of valuation.

1.3. Controversies and performativity

DCF is a peculiar valuation device. Its long history (which seems to date back to Fibonacci's "Liber Abaci" published in 1202) and its widespread use (Hartmann and Hassan 2006) contrast with the fierce criticism that it has received.[2] Miller (1991) describes the heated debates that DCF triggered among British accountants in the 1930s. He explains the unlikely success that DCF finally achieved by the association between this method and broader concerns for investment and growth in the UK, and by the active role that governmental agencies and new forms of managerial expertise played in the promotion of DCF techniques. The current prevalence of the formula has not put a halt to criticism though. In particular, its applicability to the valuation of exploratory projects, which are marked by a high degree of uncertainty and may span long periods of time, has provoked controversies among scholars and practitioners alike.

In this regard, DCF resembles other valuation devices such as business models and business plans in entrepreneurship (Doganova and Eyquem-Renault 2009) or the "magic quadrant" in the field of information technologies (Pollock and Williams 2009). Like DCF, these tools are both widely used and harshly criticized. Their role can hardly be understood within a realist perspective, for the analysis then seems to inevitably slip into the over- or under-calculative views outlined above. Conversely, a pragmatic perspective - which is

[2] To my knowledge, a comprehensive history of DCF techniques' birth and expansion into corporate and market finance is still to be made. Elements of history are present in a few studies that shed light on different stages of the development of DCF techniques (Goetzmann 2004; Rubinstein 2003, 2006; Faulhaber and Baumol 1988).

interested in processes instead of stabilized entities, in valuation instead of value, in verification instead of verity (Dewey 1939; James 1907) - appears better positioned to capture the work of such valuation devices. Doganova and Eyquem-Renault (2009) adopt such a perspective and argue that, rather than a (more or less faithful) description of a new venture and of the value that it can offer to customers and investors, a business model is a demonstration which plays a performative role by drawing, equipping and composing, through its circulation, an entrepreneurial collective. In a similar vein, Pollock and Williams (2009) note the criticism that has been addressed to the "magic quadrant" (namely due to its lack of objectivity), but instead of explaining its success by the arbitrary force of conventions, they analyze it "as a socio-technical agencement to show how it implies and gradually enacts a new world" (p.135).

A pragmatic approach to valuation devices puts the performativity hypothesis in the centre of the analysis: the notion that tools such as theories, models and formulae bring into existence that which they describe (Callon 2007). The performativity in question is "generic" as well as "Austinian", to use MacKenzie's (2004: 305) terms. On the one hand, it refers to the idea that values are not pre-given inputs but the result of (metrological) performances and negotiations. On the other hand, it characterizes statements which not only record but also perform, which not only say but also "do things with words" (Austin 1962) – and with numbers, should we add in the case of formulae.

1.4. The worlds of a formula

One of the most famous examples of the performativity of valuation devices is MacKenzie and Millo's (2003) study of the Black-Scholes formula. In his analysis of this "equation and its worlds", MacKenzie (2003: 851) accounts for its great success in the following manner:

> "That the world came to embrace the Black-Scholes equation was in part because the world was changing … and in part because the equation … changed the world."

In other words, the formula was not merely a neutral tool which represented the prices of options in a more or less accurate way; rather, it intervened in the world that it purported to describe, bringing it closer to its assumptions. MacKenzie (2003) outlines several mechanisms through which the Black-Scholes equation became performative, two of which are of particular interest here. First, putting the equation into use (this occurred through a service which sold sheets with "theoretical" option prices, i.e. the prices calculated by the formula, to market participants who could then spot the options whose price was too high or too low and conduct arbitrage operations) altered observable option prices and thus improved the validity of its predictions. Second, "in its mathematical assumptions, the equation embodied a world" (p.852). This world, devoid of transaction costs and characterized by a high volume of continuous exchanges, was certainly not "realistic" when the formula was making its first steps. However, it became more and more real – thanks to, MacKenzie claims, the formula that described it.

It thus appears that a formula has (at least) two worlds: one sketched by its hypotheses (e.g., a world without transaction costs) and one constructed through its uses (e.g., a world in which market participants know the prices of options). By analogy with the "de-scription" of technical objects (Akrich 1992), examining a formula then means investigating both the design (e.g., the scripts that its inventors have built into it) and the usage (e.g., the ways in which users tinker with the equation in their everyday practice) thereof. It requires drawing

the network which makes the formula hold, and which the formula holds in turn, for it is only within a network of mobilization that an equation can have force and make a difference (Latour 1987).

This is what the paper proposes to do: examine DCF as a valuation device, by describing it and sketching its worlds. The objective is to account for the widespread use of this contested formula, while avoiding both over- and under-calculative explanations. The question addressed is the following: why and how does this formula count, that is, both calculate and matter? The approach is pragmatic, in so far as it focuses on the process of valuation and on the practical consequences of DCF, the effects that it induces in practice. The empirical site chosen here is the valuation of early-stage drug development projects conducted jointly by pharmaceutical companies and biotechnology start-ups. It offers a good opportunity for the analysis of DCF as the application of the formula here is both crucial and highly controversial. On the one hand, the calculation of the value of a project is central in the negotiation of the price of the deal that the two parties are to strike. On the other hand, the uncertainty inherent to such exploratory projects challenges the hypotheses of the formula and the relevance of the results that it produces.

2) Description of a controversial formula: DCF and the valuation of collaborative exploratory projects in life sciences

The press releases that celebrate the establishment or extension of partnerships between pharmaceutical companies and biotechnology start-ups may remind the reader of wedding announcements: a feeling of happiness leaks out of the presentation of synergies, complementarities, commitments, and promises that the future partners exchange and recognize in each other. The comparison stops here though, for press releases are punctuated with numbers and prices, such as: [3]

> "For its contribution, [Biotech] will receive approximately 25 million euros in a combination of an upfront payment, R&D funding and preclinical milestone payments during the three-year period. [Biotech] will also be eligible for remuneration of developmental and regulatory milestones (up to approximately 25 million euros per drug candidate, from first [Investigational New Drug Application] to first commercial sales), as well as to royalties on future product sales."

One can find the same compulsory figures in most partnership press releases: the partners *praise* their collaboration while putting a *price* on it. The price in question has a specific structure: it is composed of an "upfront payment" (a sort of admission fee, which is paid for the collaboration to begin), "R&D funding" (corresponding to the number of researchers who will devote their time to the joint project), "milestone payments" (which will occur when, and if, the project reaches a given stage in its development, e.g. phase I of clinical trials), "royalties" (the percentage on sales that the pharmaceutical company will transfer to the biotech start-up if the project succeeds and results in the commercialization of a new drug). What this price buys is a licence: the pharmaceutical company actually acquires

[3] This section builds on my interviews with managers from the partnership departments of two pharmaceutical companies and with consultants specialized in valuation in the life sciences, as well as on the analysis of practitioners' publications on this issue (textbooks, guidelines, scientific and press articles). The quotations used in the paper are extracted from the empirical material thus collected (unless stated otherwise, emphasis is added by the author), except when another reference is explicitly mentioned. For confidentiality reasons, the names of people and organizations are not mentioned.

the drug that *may* result from the partnership. The calculation of the different components of such a research and licence contracts becomes all the more complicated as some projects are "bought" while they are still in an exploration phase. In this case, there is no drug to buy or to sell; the object of the transaction is a compound, a molecule, or even no more than a new target mechanism, which *may* prove to be efficient in one (or more) therapeutic indication(s) and give rise to a new drug one day (that is, a number of years – sometimes even ten years - after the transaction has taken place).

How do transacting parties then manage to calculate, and agree on, the price of molecules whose identity and characteristics are unknown, whose success probabilities (i.e., the odds that the molecule in question moves from one phase of (pre)clinical trials to the next in order to become an approved drug) are often derisory, and whose market potential (expressed in the amount of sales) will only be known in ten years' time? The task seems impossible, but the managers whom I interviewed point to the numerous books which help them in their valuation endeavours. I was referred, for example, to a book entitled "Early-Stage Technologies: Valuation and Pricing" (Razgaitis 1999) which enumerates the following valuation methods, presented in order of increasing sophistication: industry standards, scoring, DCF, advanced techniques (Monte Carlo simulations, decision trees, real options), and auctions. Surveys of corporate valuation practices indicate that DCF figures prominently among these methods (Hartmann and Hassan 2006). This section attempts to understand how, why, and with what effects DCF is applied for the valuation of collaborative exploratory projects in the field of life sciences, by describing the formula and its worlds.

2.1. A rigid shape

A simple principle lies at the heart of DCF: one euro today is worth more than one euro tomorrow. The formula computes the "net present value" (NPV) of an investment by summing up the future "cash flows" (CF) that it will consume (negative CF) or generate (positive CF) in the future, with each cash flow being "discounted", that is, reduced by a certain factor according to its distance in time (t) and the probability that it actually occurs (p):

$$NPV = \sum_{t=0}^{T} p_t * CF_t * (1+r)^{-t}$$

The principle is simple, but the difficulty, explains one consultant, lies in "estimating the input parameters", i.e. "development duration (how long will the development phases last?), the costs of the development for each phase, the probability of success for each phase (…), the sales expectations (…) and the discount rate".

The available statistics transform what looks like an impossible exercise (given the uncertainty that weighs upon each of these parameters) into a copy-paste-like task. Indeed, numerous publications (textbooks, articles published in scientific journals and in the specialized press, newsletters, consultants' reports, etc.) provide data on the mean values of each of these parameters. Table 1 summarizes such data, based upon a textbook on valuation in life sciences (Bogdan and Villiger 2007).

********** Table1 **********

Once the input parameters have been estimated, all one needs to do is to multiply, divide, and sum: cash flows are multiplied by the probability that they occur (p) and divided by the discount rate (r) raised to the power of their distance in time (t). The NPV is equal to the sum of the thus adjusted cash flows. Its sign provides a simple decision criterion: a positive NPV means buy, while a negative NPV means abandon the project. Valuation consultants, who master and promote such formulae, keep reminding their clients that knowing a project's value confers a significant (price) power:

> "Those entrepreneurs foolhardy enough to ignore the need for a proper valuation before they begin seeking capital not only may find themselves at a disadvantage in negotiations with investors, but also may have no way of rectifying a situation if the company valuation is suboptimal. In contrast, those who prepare a thorough valuation of their venture often gain a strong negotiating position, even in a buyer's market. Every startup should thus *enter financing negotiations with a clear understanding of its value drivers to obtain a fair and full valuation*." (Frei and Leleux 2004: 1049)

In the consultants' perspective, transacting parties, once they have determined the intrinsic value of the compound that they intend to sell or buy, may enter into negotiations equipped with knowledge and confidence. For they know what the value of the transaction is. They will, of course, ask for a higher (if selling) or a lower (if buying) price, but in any case they will know how much leeway they have, and the task of pricing will be left to the negotiators' talents. If price may then appear as the result of a political process, value benefits from the status of rationality that only calculation can lend. From here stems the importance of the DCF formula. The strength of the formula, however, hangs by a thread, or rather a network of threads - worlds which it both inhabits and holds together but which, at times, are in danger of collapsing. It is to the exploration of these worlds that I now turn.

2.2. Flexible contents

The user wishing to apply DCF to the valuation of a compound (to be bought or sold) faces several difficulties. The estimation of cash flows becomes particularly troublesome when the compound to be valued is yet undefined. If the transaction occurs while the drug development project is still in an exploration phase (which is often the case, for early stage projects are much cheaper to buy), the characteristics of the compound that is to be exchanged and the market thereof (i.e., the therapeutic indication for which it will be commercialized; the competitors that are likely to appear during the ten or more years necessary for its development) are both unknown. Let us examine how this difficulty is addressed in practice.

How could the cash flows, composed of the R&D investment as well as the sales generated and the corresponding operational costs, be calculated while the very identity of the compound to develop and commercialize is uncertain? As far as the R&D investment is concerned, the issue can be easily solved: one can read the mean values of the costs incurred by each development phase in textbooks and other publications, or ask the contract research organizations to which clinical trials are generally subcontracted. The issue of sales, though, is trickier:

> "There's no standard way of defining peak sales, so *everybody can come up with a different figure*. Everybody will come up with a different figure. I have never seen one standard way. I've been at forecasting conferences to see what they are doing and everybody is doing it differently. It's not only how high the sales are, it's when they're

going to be reached, how quick they will be reached, how quick they will be lost. *The whole curve that you are expecting, every year, you can fight for.*"

The estimation of sales would then be just "a matter of opinion", notes one consultant, while describing two main types of methodologies one can rely on:

"In advanced projects, we know relatively well the drug profile, the formulation, the indication, etc. We then apply *a bottom-up approach*: how many patients are there, how many have access to doctors, how many will be diagnosed, how many receive a medical treatment, how many will be treated with our drug, for how long, and how do we penetrate the market? This is the standard procedure. It is described in [this] book on pharmaceutical forecasting."

An alternative method, applicable to projects in earlier stages, takes a "top-down approach" and relies on the mean values that one can find in the specialized literature:

"If we do not even know what the indication is, we can take *the average sales in this pharmaceutical domain*. In cancer, for example, a molecule makes 500 million dollars of peaks sales on average."

Instead of reasoning upon the compound's particular characteristics or the market's mean values, one can also take the project as a basis for the calculation:

"You can calculate *what sales are necessary in order that it makes sense to continue the project*. This is something that we always have as an output when we do a valuation: it tells you the threshold of development."

Cash flows are a surprisingly flexible term in the DCF equation. Their positive component, i.e. sales, can be calculated through a variety of intermediary formulae whose complexity ranges from the mere equivalence with the mean values observable on the market, to the pursuit of a long translation chain that step by step transforms the future drug's "medical benefit" to a line in the corporate operating accounts. The same holds for the negative component of cash flows, i.e. costs. The production, marketing and commercialization costs that the achievement of sales will require can be estimated in great detail, including, for example, the cost of the conferences to which it will be necessary to participate in order to promote the drug. Alternatively, these costs can simply be deduced from the amount of revenues, through the percentage of the operational margin that the company aims to obtain or usually applies.

Thus, the value of cash flows may result from a highly complex and detailed calculation, as well as from the mere replication of mean values observed in the past. In the first case, it is the distinctiveness of the compound that counts: it is better or worse than other entities sharing the same "label", and thus acquires a numeric (dis)advantage. In the second case, it is the similarity of the compound that counts: it is comparable to a set of other entities, because they have a common therapeutic domain, and it can therefore take the value of the mean. In both cases, the formula can operate only if the world of the object that it calculates is put into words and into numbers by extended metrological chains. Its flexibility has a price: a continuous work of classifying, standardizing, and measuring.

2.3. Forms

This tension between flexibility and standardisation becomes all the more apparent when the formula is envisaged not only as a mathematical equation, but also as an object. In

practice the DCF formula comes in a "form" (Callon 2009; Giraudeau 2009), which is called here a "valuation model" and is materialized in a file that can be generated with an Excel spreadsheet or with one of the specialized software programs that are developed by consultancy companies in this field. Figure 1 illustrates the valuation, on an Excel spreadsheet, of a drug development and licensing partnership project embracing two compounds whose value turns out to be equal to 77.7 million euros:

********** Figure1 **********

The Excel file gives material shape to the DCF formula: its columns order the passage of time, while its rows embed the cash flows and their adjustments (due to time and risk). Some cells contain Excel formulae that link, through arithmetic operations, different components of the table between themselves or with the input parameters (costs and success rates, for each phase of the clinical trials, and revenues, for each year after the drug's commercial launch) that are stored in a different sheet. These intermediary formulae automate calculation while allowing users to play with the parameters, to vary output values by modifying underlying hypotheses and questioning their validity. Such manipulation becomes even easier when specialized valuation software substitutes for the Excel spreadsheet. Then "all you need to do is enter the input parameters: the financial modelling is already done", as explained the designers of one of these software programs which I shall call "Valsoft" hereinafter:

> "What makes [Valsoft] better [than Excel] is that in Excel you are not flexible: if you change by one year, you usually have to change one more row, it can be complicated. While [in Valsoft] you put how many months it is, it tells you how much it… you know, you have *a database on how long it takes, how costly it is, what are the drugs*… You have everything in it – [a database] with costs, success rates and everything."

The specialized software includes not only the formula strictly speaking but also the world which enables it to work: a world made of categories and means. The integration of this database within the software renders the formula more robust, for it reinforces statistical coding and delimits the content of the equation terms. At the same time, by framing and measuring the world of the formula, the form creates flexibility within the frontiers of the world thus covered. It operates a passage between the market, with its repertoires, and the particular compound that is to be evaluated. It hooks on the nominal, ordinal, and numeric scales of valuation (Guyer 2004) through categories and means: naming, or "labelling", a compound allows the evaluator to place it in a category, to position it relative to other comparable compounds, and hence to express its value in numbers by anchoring the calculation in the category's mean. The form enables translating a variation on one of the valuation scales into an equivalent variation on another scale. The user can then go up and down the range of words without losing anchor in the range of numbers.

It sometimes happens that the would-be partners exchange their valuation models (i.e., not only the final values produced but also the underlying Excel or Valsoft model and input parameters). The equivalences established between different valuation scales can then be put back into discussion. What therapeutic indications could the compound claim and which ones will be included in the partnership and hence taken into account in the common calculation? Would the compound's qualities position it above or below the mean? What additional trials must be conducted in order to learn this? Who would take these trials in charge? Then shouldn't success rates be revised? How do the revised success rates impact the value of the

project and the components (upfront, milestones, royalties) of its price? It should be emphasized that, while such questions flow and the (Excel or Valsoft) form recalculates, partners gain three types of knowledge: knowledge about the value of the compound that is being transacted upon, about the characteristics of this compound (e.g., therapeutic indications, probability of success), and about the joint activities that they will have to carry out in order to bring these qualities into existence (e.g., scientific investigations, clinical trials). In other words, the formula operates as a passage point between, on the one hand, the *valuation* of an entity and, on the other hand, the *exploration* of the characteristics of this entity. I will revert to this point later.

2.4. Experimentations

As noted above, available databases provide information relative to average sales, development costs and success probabilities in various therapeutic indications and domains. They also store data on the terms of past deals, that is, on the amount and structure (upfront, milestones, royalties) of prices that pharmaceutical companies have hitherto paid to acquire drug candidates. A search in these databases allows a transacting party to propose a few possible deal terms which differ by the weight that they put on the different components of the price (e.g., a high upfront payment, which is often crucial for a biotechnology start-up, would need to be offset by a lower level of royalties). But how can one know if the proposed deal terms correspond to "fair" (Bogdan and Villiger 2007) licence contracts? This is where the DCF formula steps in again.

The components of the price to be paid are part of the cash flows that need to be integrated in the calculation of the compound's net present value: the upfront is the first term of the sum, while the milestones and the royalties intervene, respectively, in the R&D and commercialization phases. Different price structures therefore result in different values. The values thus obtained can be compared to the "total value" of the development project (which is computed independently from the transaction, that is, without taking the price into account). A price structure will be deemed "fair" or "realistic" if its ratio to the "total value" of the project is in line with the "value shares" observed in the market. Here again, consultants play a crucial part, for they codify such "value shares": for example, valuation guides tell us that, for a compound in a pre-clinical stage of development, a licensee (that is, most often, the pharmaceutical company buying the R&D project) should capture 80-90% of the total value, while this percentage falls down to 40-60% for a compound in phase IIb/III of clinical trials. As one consultant explains:

> "You know that a phase I compound will usually get 20% of the value for biotech, a phase II – 30%, a phase III – 40-50%, so you know how much percent of the value you should capture with your deal. Then you go, *you put all your input parameters in the valuation model and you make the first hypothetical deal*, let's say a million upfront blablabla. Then you see that in this contract you get 50% of the value. So you know it's *unrealistic*. Then you start *turning around*, then you get 30%, and then you know this is a *realistic* deal."

By integrating price within the calculation of value, the DCF formula paves the way to a new set of experimentations, which are not only concerned with the value and the characteristics of the object that is being transacted upon, but also with its price. The compound's price is approached through trial and error: different price structures are put on the test by being introduced into the formula which in turn produces different values (and

value shares). In order to do so, the formula builds on the market prices that databases store. These market prices resemble to what Caliskan calls "prosthetic" prices, that is, prices that are leveraged as tools, or prostheses, in order to realize the "actual" prices at which transactions will actually be concluded. Prices are thus tinkered with, as part of a valuation arrangement composed of formulae, their forms, and their users. This arrangement produces a "real" price, which in turn becomes inscribed in market repertoires and transformed into yet another prosthetic price ready to equip future transactions.

2.5. Contested hypotheses

While the contents of the DCF formula seem to be extremely flexible, its structure appears rigidly robust. Through the mechanism of discounting, the equation favours the cash flows that are close in time. In the case of exploratory R&D projects, these cash flows are negative, because it requires years before any return on investment, which is moreover highly improbable, starts to materialize. As a result, the net present value of drug development projects that are still in an exploration phase (namely, in the stage of discovery or pre-clinical trials) often turns out to be negative. The negative values produced by DCF make the promoters of exploratory projects feel uncomfortable:

> "Companies have undertaken negative NPV (net present value) projects consistently, citing strategic importance. These were not intrinsically "bad" business decisions, but the valuation methodology produced negative figures. Correspondingly, however, some were *uncomfortable with the purely subjective decisions taken in the face of negative valuations*." (Pandey 2003: 968)

Faced with this problem, several scholars and practitioners have proposed the use of more sophisticated valuation techniques, namely real options analysis. Building on financial options and the Black-Scholes pricing equation, the real options technique envisages a research and licensing partnership as an option: the buyer who pays an admission fee (the upfront) acquires the possibility (if clinical trials are successful) to commercialize the resulting drug, if any. The advantage of real options analysis, as compared with DCF, is to offer a formula that takes into account the partners' room for manoeuvre in adjusting and redirecting the project as its potential becomes clearer: which manager, indeed, would keep constant the value of a project whose characteristics are changing as new data is generated? Yet, real options appear to be seldom used (Hartmann and Hassan 2006). Criticized for its complexity and for its unrealistic hypotheses, this rival formula and its practical application trigger heated debates in the literature (Pandey 2003; Jacob and Kwak 2003).

Such controversies are an opportunity for the analyst, for they make visible the world sketched by the hypotheses of DCF (by contrasting them to those of the real options technique) and the network that holds it together. According to its defenders, the superiority of the real options formula stems from the fact that it recognizes (i.e., grants value to) "managerial flexibility" (Jacob and Kwak 2003: 294):

> "(…) the NPV method is static, in the sense that it does not recognize that a company can control its future cash flows by decision-making as a project progresses and as more information becomes available. Thus, *the NPV method can undervalue projects, especially those with greater uncertainty and greater flexibility; in effect, it does not value abandonment options*." (Pandey 2003: 969)

The user profile sketched by the DCF formula implies an inflexible manager at grips with a constant value measured at the present moment. Hence its inadequateness (if one can thus call the feeling of discomfort created by the negative values that the formula produces) for exploratory projects in which the compound to be valued can only be brought into existence after – and as a consequence of – the transaction. But how can then one explain the widespread use of DCF, which embraces the valuation of compounds that are still in the very early stages of their development.

One part of the explanation lies in the resistance that the supporters of DCF put up to its detractors. Their defence strategy centres on two main axes. The first one consists in disqualifying rival formulae. For example, in a newsletter entitled "*How not to value biotech"* a valuation consultancy company specializing in life sciences dissects the P/E[4] formula that some analysts use to value biotechnology start-ups. It identifies the "flaws" of P/E valuation, and declares its delight with the fact that "most of the analysts use [DCF], even if the P/E method is widespread". The second axis of defence lies in stabilizing the DCF formula, by restricting the liberties that some take with its use. In another newsletter, entitled *"Charlatanry in valuation"*, the same consultancy company quotes "several examples – sometimes funny, sometimes even frightening – of how valuation should not be done". In its line of sight happen to be, for example, the financial manager of a biotechnology start-up according to whom "if one uses success rates, then the attrition risk is already taken into account and pharmaceutical companies' discount rates should be used", or the author of a Harvard Business School article who claims that "value = DCF without success rates (because compounds are not comparable) but discounted with a rate of 50%".[5]

Yet, consultants' persuasion talents are only part of the explanation of DCF's success. In order to account for its use – apparently inadequate and yet extremely widespread – in the valuation of exploratory projects, one needs to turn back to the locus of its practice. Let us make this last detour, through an excerpt from an interview with a manager from the partnerships department of a pharmaceutical company. The interviewee explains that, in order to calculate the present value of a partnership project, a sales forecast is usually established, even for compounds whose characteristics are yet unknown. This forecast is tentative, by definition, and often turns out to be untrue. However, this does not really matter, for, as the respondent explains, it is not sales that "drive value":

> "Even for very early stage program they will have worked up to the, you know an outline clinical development program, an outline marketing program, an outline sales forecast. It's just that those *don't really drive the value in the same way*."

What is then that drives value, and why? It is the mathematics of the formula that, eventually, provides an explanation:

> "Something that's not even in human, it's extremely difficult to put a lot of confidence into that, which is where I think… risk is more about managing the downside and making sure that we don't pay over the odds for what we're having to do. (…) *You can afford to put in whatever single digit percentage royalty (…) and you can put in sales milestones, but these would all be so discounted down the road, they are not going to have the same impact as the early stage* where it's got a much higher chance of failing."

[4] The Price Earning (P/E) Ratio is the ratio between the price of the share of a company and the profit that the company generates (per share).

[5] The authors conclude by calculating with these different methods the value of a particular compound. The DCF indicates a value of 39 million euros. The use of a pharmaceutical company's discount rate raises this value to 112 million euros, while a discount rate of 50% brings it down to -2.6 million euros.

So, DCF reduces the value of exploratory projects. But what is interesting is that in doing so, the formula gives these projects the flexibility that they require:

> "(…) *for smaller deals, below a certain threshold, then things are a little bit more flexible*. If the investment isn't that high, then you don't need to… at the end of the day you don't need to say exactly what it will reach on the market, *you just need to be able to justify that it will make sense*: there is potential for it scientifically, it is interesting, risk-wise we haven't identified anything out of the way, *so we have to spring it into the portfolio and explore*."

To sum up, while DCF is strongly criticized for its unrealistic hypotheses (which assume an inflexible manager who measures the value of a project only at its beginning and does not adjust valuation to the new knowledge generated through exploration), the formula appears to maintain its relevance in practice for at least two reasons. The first one has to do with the network in which DCF is embedded: various actors (among which consultants figure prominently) endeavour to both standardize and promote the use of the formula. The second one has to do with the mathematics of the equation: by decreasing the value of exploratory projects, the formula endows the managers and researchers involved in them with greater flexibility - and hence with the possibility to adjust activities as exploration unfolds.

3. Discussion

Given all the investments necessary to explore the technical and commercial potential of a molecule (experiments, trials, meetings, discussions…), how come has a market – that is, a mode of coordination that has high requirements in terms of liquidity and information - emerged in which the peculiar economic goods that are molecules are being exchanged on a regular basis? The study of valuation devices sheds light on this question. The valuation of goods involves formulae. These formulae rely on material, literary, and social technologies (Shapin and Schaffer 1985): they are materialized in forms (Excel spreadsheets or specialized software); they are the subject of a flourishing literature (which ranges from academic articles published in finance and management journals, to consultancy companies' newsletters); they embody and are embedded in social relations (e.g., the interactions that occur at various valuation workshops and seminars, the conventions incorporated in the categories that organize the industry databases). These material, literary and social technologies codify the passages between the nominal, ordinal and numeric scales of valuation (Guyer 2004), thereby reducing the complexity of an otherwise impossible calculation and facilitating the achievement of a compromise on value. Thus, formulae play a crucial part in coordinating market actors.

In this regard, formulae resemble to other devices that contribute to the process of making markets. In the field of microprocessors, Moore's law announces that the complexity of semi-conductors will double every two years without entailing an increase in prices. It sounds like a magic formula; however, its translation in a particular form – the technological roadmap – enacts this prediction by guiding market participants' investment decisions. Miller and O'Leary (2007) analyse this formula and its form as "mediating instruments", which link different actors (e.g., semi-conductor manufacturers and their suppliers), imperatives (technological innovation and cost reduction), and domains (science and the economy). We can note similar observations in Poon's (2009) analysis of the FICO score (i.e., a rating that assesses borrowers' creditworthiness). By reducing the diversity of the calculations that are otherwise carried out, locally and in an idiosyncratic manner, by various market participants,

this score produces significant "coordination effects". Embedded in information processing infrastructures, it "aligns" the calculative activities of many different actors and thus contributes to market liquidity – a quality that requires the possibility of a rapid agreement on the qualities and values of exchanged goods.

The DCF formula is similar to these devices in that it sketches a plan, establishes milestones, makes explicit future collective activities (like Moore's law and its technology roadmaps), while at the same time capturing the value of a project in a single number and thereby allowing for comparison (like the FICO score). But it differs from them in that it displays a surprising flexibility and triggers vivid controversies. While firmly linking the terms of the equation, it leaves leeway in their definition: the rules of adding and discounting cash flows are strict, but how the amounts of these cash flows are determined ranges from the mere replication of means and averages to the most sophisticated calculations. Beyond its flexibility, the DCF formula is distinctive by the controversies that it generates. It is blamed, in particular, for being incorrect, because of its inaccurate representation of a "manager" whose capacity to learn and adapt is neglected by the formula.

The criticism addressed to DCF rests upon a realist perspective, which assumes that the formula's main function is to represent (e.g., a manager, a compound that has inherent characteristics and intrinsic value) and hence becomes sensitive to any mismatch between the formula and the exterior world that it is supposed to reflect. The performativity perspective invites us, instead, to pay attention to what the formula does, to the effects that it induces in practice, to how it changes the world that comes to embrace it. So what does the DCF formula do? It acts as a "mediating instrument" (Miller and O'Leary 2007) by building several links: between the partners engaged in the transaction; between the compound that is the object of the transaction and its market (through databases, categories and averages); between the nominal, ordinal and numeric scales of valuation; between the compound's value and its price; between the valuation of an entity and the exploration of its characteristics. When it intervenes in the valuation of exploratory projects, the DCF formula becomes a mediator, instead of an intermediary (Hennion 1993), because by ensuring the coupling and the back and forth movement between worlds, it takes part in their construction. Herein lies its performativity.

In closing, let us revert to one of the formula's mediations: that between the activity of *valuation* and the activity of *exploration*. Let us imagine a biotechnology start-up and a pharmaceutical company that envisage a partnership and hence face the following question: how much is worth a molecule that may produce a drug in the future but about which hardly anything is known in the present? The DCF formula configures the encounter between the would-be partners: it aligns their evaluations by aligning them, literally, in front of the form that calculates and that they make recalculate. The discussion is organized by the terms of the equation which are displayed in the form (e.g., the rows and columns of an Excel spreadsheet, or the graphs of specialized valuation software) and manipulated by the partners. Any adjustment in the formula's cash flows or probabilities entails an adjustment in the characteristics of the compound and in the trials that would be necessary to test and demonstrate these characteristics: the partners seamlessly move from the regime of valuation to that of exploration.

The formula is not only an excuse to meet, a symbolic artefact that triggers social interaction; its materiality matters. It can be hypothesized that the way in which DCF espouses the unfolding of an exploratory project helps explain its surprising resistance to the attacks of rival formulae, namely real options. Certainly, the real options technique is superior to DCF because it takes into account managers' flexibility and learning capacity. Yet, a real options calculation remains a "black box" (Bogdan and Villiger 2007: 40). The opacity of the

exponential function on which real options calculations rely contrasts with the evidence (both in terms of visibility and proof) afforded by the DCF formula. There is a striking homology between the structure of the DCF formula and the structure of the pipeline through which every drug in development goes through. The formula and the pipeline differ in the material they are made of - probabilized cash flows, for the former, and molecules and chemical compounds, for the latter -, but they embrace the same temporality: linear, discontinuous, phase-based. This homology in structure hooks on mathematical symbols to joint development activities and their financial returns. It may thus endow the DCF formula with an "inductance property" between the worlds of valuation and exploration (Lévi-Strauss 1958).[6]

Conclusion

By examining the discounted cash flow (DCF) formula as a valuation device, this paper has attempted to provide three main contributions. First, it improves our understanding of the construction of markets by depicting the coordination work carried out by a valuation device such as DCF. Second, it extends the socio-technical analysis of valuation (Beunza and Stark 2004), which has been mainly focused on financial markets, to the field of corporate finance. Third, it adds to the burgeoning research on performativity by asking why certain economic objects succeed in bringing into existence that which they describe, while others fail. In other words, it sheds light on the "felicity conditions" (Austin 1962) necessary for performativity to occur. The paper has put forward two such conditions. The first one is related to infrastructure: if the formula can function and shape future prices and values through nurturing market repertoires, it is because it is embedded in a network composed of databases, publications, consultants, workshops etc. The second one has to do with the instrument itself: if the formula can induce effects in the conduct of exploration activities and reshape the entities that it values, it is because (and not in spite) of the material shape that it takes and the "untrue" results that it produces.

[6] I borrow the term "inductance property" (my translation of "propriété inductrice") from Lévi-Strauss's analysis of symbolic efficacy (Lévi-Strauss 1958: 231).

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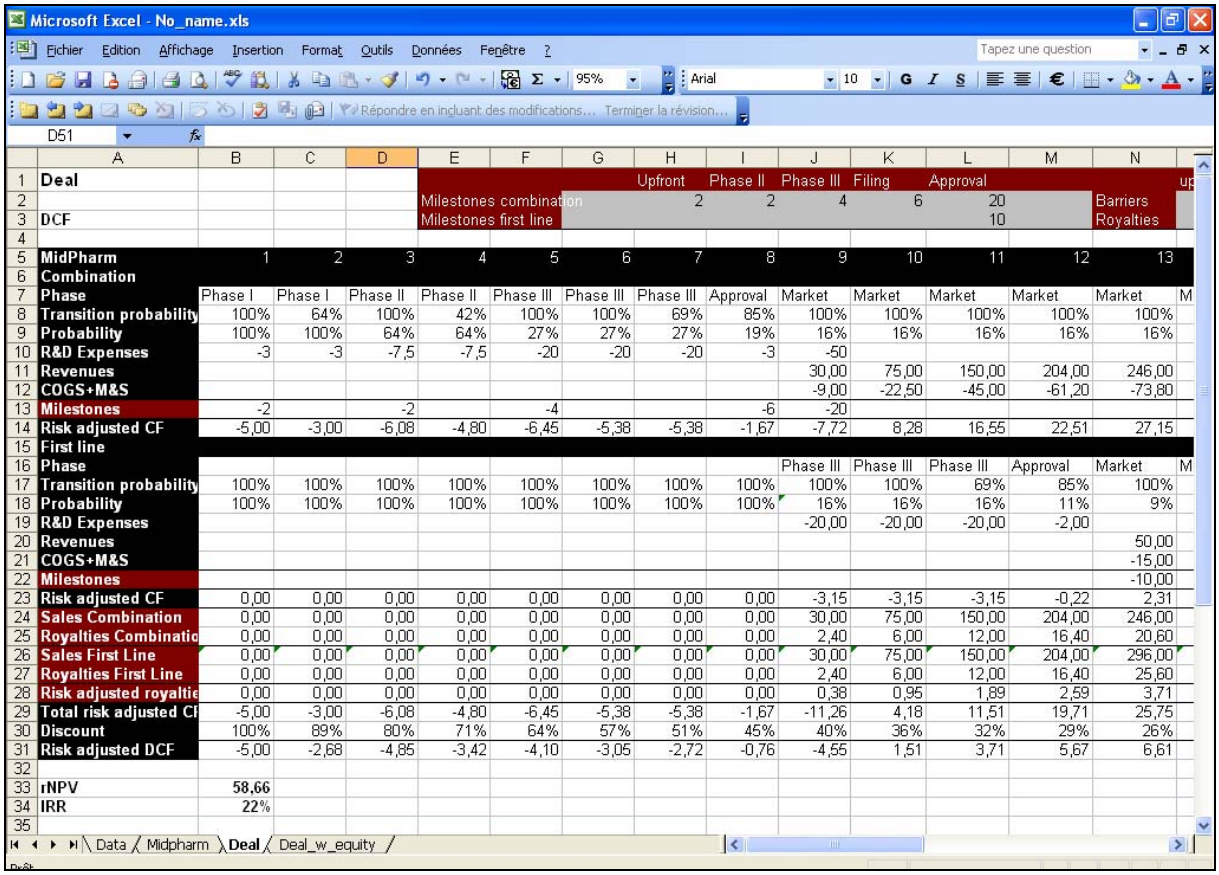
Tables and figures

Table 1. The parameters of the DCF formula

Parameter	Definition	Statistical support	Value
Time (t)	How many years will cash flows spread over?	Mean duration of drug development phases: discovery (or research) and clinical trials (preclinical, phase I, phase II, phase III, approval phase, phase IV)	Total duration ranging between 116 to 154 months (source: textbook)
Cash flows (CF)	What amounts are spent or received in each phase?	Mean amount of sales, of the costs of research and clinical phases, and of operational costs Amount and distribution of the terms (upfront, milestones, royalties) of recent deals on comparable molecules	See section 2.2
Attrition risk (p)	What is the probability that these uncertain cash flows will actually occur?	To each phase of the R&D process is associated a success rate that corresponds to the probability that a project that enters in this phase will reach the following phase.	*"(…) when you look at the probabilities of success for phase III, [it is] in the 60-80% region. If it is something that is just entering phase II, it is going to be let's say 30% chance of reaching the market. Something in phase I, it is going to have a 10% chance of reaching the market."* (source: interview)
Discount rate (r)	How to account for the cash flows' distance in time and for their uncertain amount?	A company can apply to its investments its own discount rate, which corresponds to its cost of capital, i.e. the rate at which shareholders wish their capital to grow. The cost of capital can be computed through complicated calculations that rely on their own formulae. In practice, it often turns out to be known, at least for public companies (see the examples in the next column).	For example, a pharmaceutical company like Lilly applies a discount rate of 18.75% in 2004 (source: textbook, referring to the company's annual report), while a biotechnology company like Genentech applied a discount rate of 20-28% in 1990 and of 19% in 1999 (source: textbook, referring to the company's website).

Figure 1. The form of the DCF formula: example of a "valuation model"



Microsoft Excel - No_name.xls

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	**Deal**							Upfront	Phase II	Phase III	Filing	Approval		up
2					Milestones combination			2	2	4	6	20		Barriers
3	**DCF**				Milestones first line							10		Royalties
4														
5	**MidPharm**	1	2	3	4	5	6	7	8	9	10	11	12	13
6	**Combination**													
7	**Phase**	Phase I	Phase I	Phase II	Phase II	Phase III	Phase III	Phase III	Approval	Market	Market	Market	Market	Market
8	**Transition probability**	100%	64%	100%	42%	100%	100%	69%	85%	100%	100%	100%	100%	100%
9	**Probability**	100%	100%	64%	64%	27%	27%	27%	19%	16%	16%	16%	16%	16%
10	**R&D Expenses**	-3	-3	-7,5	-7,5	-20	-20	-20	-3	-50				
11	**Revenues**									30,00	75,00	150,00	204,00	246,00
12	**COGS+M&S**									-9,00	-22,50	-45,00	-61,20	-73,80
13	**Milestones**	-2		-2		-4			-6	-20				
14	**Risk adjusted CF**	-5,00	-3,00	-6,08	-4,80	-6,45	-5,38	-5,38	-1,67	-7,72	8,28	16,55	22,51	27,15
15	**First line**													
16	**Phase**									Phase III	Phase III	Phase III	Approval	Market
17	**Transition probability**	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	69%	85%	100%
18	**Probability**	100%	100%	100%	100%	100%	100%	100%	100%	16%	16%	16%	11%	9%
19	**R&D Expenses**									-20,00	-20,00	-20,00	-2,00	
20	**Revenues**													50,00
21	**COGS+M&S**													-15,00
22	**Milestones**													-10,00
23	**Risk adjusted CF**	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-3,15	-3,15	-3,15	-0,22	2,31
24	**Sales Combination**	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	30,00	75,00	150,00	204,00	246,00
25	**Royalties Combinatio**	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,40	6,00	12,00	16,40	20,60
26	**Sales First Line**	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	30,00	75,00	150,00	204,00	296,00
27	**Royalties First Line**	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,40	6,00	12,00	16,40	25,60
28	**Risk adjusted royaltie**	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,38	0,95	1,89	2,59	3,71
29	**Total risk adjusted Cl**	-5,00	-3,00	-6,08	-4,80	-6,45	-5,38	-5,38	-1,67	-11,26	4,18	11,51	19,71	25,75
30	**Discount**	100%	89%	80%	71%	64%	57%	51%	45%	40%	36%	32%	29%	26%
31	**Risk adjusted DCF**	-5,00	-2,68	-4,85	-3,42	-4,10	-3,05	-2,72	-0,76	-4,55	1,51	3,71	5,67	6,61
32														
33	**rNPV**	**58,66**												
34	**IRR**	**22%**												
35														

Data / Midpharm / **Deal** / Deal_w_equity /