Reasoning the 'net-present-value' way: Some biases and how to use psychology for falsifying decision models

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Abstract.

This paper analyzes the net-present-value (NPV) model, a keystone in economics: Behaviors and lines of reasoning of NPV-minded decision makers are observed and analyzed. As a result, one finds out that the NPV methodology is biased and its decision makers fall prey to various forms of fallacies and inconsistencies. The normative side of the NPV paradigm is therefore challenged by psychological arguments. While the power of psychology in falsifying models and theories from a *descriptive* point of view is already recognized, it may be the case that psychology will prove useful in *normative* falsification of optimization models as well.

Keywords. Decision making, optimization, Net Present Value, psychology, biases, falsification.

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The reader: "If I read your paper, I forego the opportunity of reading another *equivalent* paper".
The author: "Yes, but you also forego the *non-equivalent* opportunities of playing tennis, talking with friends, write a bit for yourself, sleep a while, …".

Introduction

This paper focuses on the Net Present Value (or Discounted Cash Flow) maximizing model. It shows that the Net Present Value methodology, widely used for investment decisions in economics, exhibits biases when the formal analysis of its apparatus is dismissed and a thorough analysis of its behavioral implications is instead performed. While many models, more or less sophisticated, are available in the economic literature for various kinds of decision processes, the equivalent notions of net present value (NPV) and discounted cash flow (DCF) have a noble reputation in the economic literature, and the corresponding decision models are often taken as the theoretically sound paradigms a rational decision maker should conform to. Obviously some objections have been raised to the model (as it is common in economics and, in general, in science), but they always take the form of *external* criticism. For example, advocates of options pricing technique criticize the NPV model holding that it is not able to cope with *real options*, that is situations where there is some flexibility in the decision process (opportunity of deferring the investment, of expanding the scale of a business, of abandoning the project etc.). But evidently this does not touch the model in those cases where no flexibility is available: "The Net Present Value (NPV) of both certain and risky cash flow streams, in the absence of managerial flexibility, is currently the only available valuation measure consistent with the firm's objective of maximizing shareholders' wealth. Other valuation measures … are acknowledged to be inferior to NPV as discussed in standard finance textbooks." (Real Options Group, n.d.-a). Also, options pricing technique may not be used if the real option is non-replicable. In these cases other models are used (decision tree analysis, dynamic programming) which may be rephrased in NPV terms. As another example of criticism, decision theorists often invoke the use of utility functions in decision-making, but this objection may be countered in two different ways by the NPV supporters: It is not possible to use utility functions if the decision maker is an organization acting in the interests of many different individuals (e.g. shareholders in a company), since each individual has its own utility function and the notion of *corporate risk attitude* is still controversial (see Anselmo & Dyer, 1999; Smith, 2003). This paper does not defend the NPV model nor attacks it on external bases. It takes a radically different route: Firstly, *internal* criticism is adopted, i.e. assumptions and consequences of the NPV paradigm are accepted a priori. Secondly, a psychological perspective is followed, in that lights are shed on behaviors and lines of reasoning of NPV-minded decision makers. Criticism will then arise from inside the model, not from outside, and will be the result of the application of tools taken from the psychologist's toolbox: Observation of subjects via experiments, description and analysis of the observed behaviors, study of the cognitive content of that behavior, discovering of biases and possible explanations, behavioral analogies in other domains etc. To put it in different terms, we may say that this paper adopts the view of a psychologist that accepts the NPV paradigm and merely takes the logical consequences of the resulting behavior.

This work shows that a fundamental decision model in economics incurs contradictions and implies freakish behaviors. The current economic and psychological literatures present a high number of contributions dedicated to analyzing discrepancies between theoretical behaviors as

required by normative decision models and actual behaviors as encountered in real life. These researches may lead to a reconsideration or a falsification of the model at hand from a *descriptive* point of view, but not from a *normative* point of view. This paper just stresses the idea that psychology may point out fallacies or even invalidate a model in its *normative* implications. The NPV model is one such model: The behaviors of the NPV-minded decision makers are biased, self-inconsistent, frame-dependent, and lead to nonsensical and whimsical consequences.

The paper is then addressed to several categories of scholars: Economists advocating the use of the NPV paradigm, decision theorists or finance theorists favoring the replacement of the NPV with their beloved ones, cognitive and behavioral psychologists involved in decision-making. The first group of scholars, who recommend use of NPV, should perhaps be surprised in discovering that the model manifests *internal* flaws not yet recognized in the literature. The second group of scholars, who reject the NPV model, may welcome a radically different kind of criticism not based on *rejection*, but on *acceptance* of the NPV methodology. As for psychologists, they may note that their very perspectives lead to signal behavioral and logical flaws that call for invalidation of a decision model from a *normative* point of view. A fourth group includes philosophers of science involved in social and economic science, as long as the context of justification is split into two categories (descriptive falsification and normative falsification) and insofar as psychology is shown to permeate both sides. We might add mathematicians as well, to the extent that this paper shows that optimization is not a pure untouchable domain when it is applied to social and economic sciences, where psychological aspects have an outstanding role. All groups of scholars should be hopefully attracted by the idea that psychology may play a role in invalidating/corroborating models and theories not only as descriptive accounts, but also as normative paradigms. Psychology's scope may then result in a broader area of research, including *normative* invalidation of decision models. Since "psychology systematically explores human judgment, behavior, and well-being, it can teach us important facts about how humans differ from the way they are traditionally described by economists" (Rabin, 1998, p.11), but since psychology may as well scrutinize judgment and behavior that are logically implied by a decision model, it can also teach us important facts about the *reliability* of decision models as tools for helping make decisions. This is a new and stronger epistemological perspective about psychology.

The paper is organized as follows: The concepts of value, profit, opportunity cost are presented and a simple formalization is given of the notions of Net Present Value and Discounted Cash Flow (section 1). The relevance and importance of the DCF/NPV analysis in economics is underlined (section 2) and a presentation of the NPV model under uncertainty is given, pointing out the role of the *Equivalent Risk* tenet (section 3). A brief outline of choice behavior in real life is offered (section 4) where discrepancies are found between the actual choice behaviors and the normative behaviors implied by a meticulous application of the NPV model. Dispensing with the usual analysis of mismatch between actual and normative behavior, the focus is then turned to "observing" the choice behavior of those decision makers that rigorously employ the NPV model. In particular, section 5 deals with the decision process "to undertake a specific course of action or not"; section 6 is concerned with the decision process "to undertake either of two courses of action"; section 7 focuses on the decision process "to undertake a particular action now or to defer decision". These sections show that the lines of reasoning and the behaviors of the NPV-minded decision makers reveal some oddities, ambiguities, inconsistencies. Section 8 provides an outline of the role psychology currently plays in the philosophy of science, both in the context of discovery and in the context of justification of theories. Section 9 endorses the idea that psychology can in principle provide a vast array of logical anomalies and behavioral absurdities by studying the implied behavioral content of well-established decision models. This boils down to considering psychology as a tool for normative falsification of decision models, or, at worst, a signaling device for possible flaws.

1. Preliminary concepts

The concept of *value* is essential in economic and financial decision making. Suppose a decision maker wants to invest money in an asset (undertake a project, buy a security, purchase a firm etc.) whereby she will receive an expected sum of 110 euros after one period. What is the

value of such an asset? In economics, the value of the asset is the sum the decision maker would pay for investing in the best alternative (counterfactual) course of action at her disposal. To calculate it, she needs to know the so-called *opportunity cost of capital*. The latter is the rate of return she would earn if she invested in the best alternative investment. Suppose the opportunity cost of capital is 10%. Then, the value (today) of an amount of 110 (available at time 1) is 100=110/(1+0.1). Indeed, if she invested 100 in the alternative course of action she would have, after one period, 100 plus return on 100, that is $100 + (0.1)100 = 100(1 + 0.1) = 110$. So 100 is the value of 110 available at time 1. It is also usual to say that 110 is *discounted* at the rate 10% and 100 is the *present* value of 110. We can then say that the value of any asset is found by discounting the expected cash flow at a determined *discount* rate.

As seen, to measure the value of an asset one has to refer to an alternative course of action and to the concept of opportunity cost, i.e. the rate of return of the alternative one sacrifices when deciding to invest in the alternative under examination. The notion of opportunity cost principle is fundamental in economics (see Buchanan, 1969, for a historical survey) and the idea that cost is the value of a foregone opportunity has been developed by Austrian economists (in particular Ludwig von Mises) as well as by economists of the London School of Economics such as Hayek, Coase, Thirlby, Shackle:

> The person is faced with the possibility of taking one or other of (at least) two courses of action, but not both. He considers the relative significance to him of the two courses of action, and finds that one course is of higher significance than the other. He 'prefers' one course to the other. His prospective opportunity of taking the less-preferred course of action becomes the prospective cost of his taking the more preferred course. (Thirlby, 1946, pp. 33–34)

> The cost of doing anything consists of the receipts which could have been obtained if that particular decision had not been taken. When someone says that a particular course of action 'is not worth the cost', this merely means that he prefers some other course … This particular concept of costs would seem to be the only one which is of use in the solution of business problems, since it concentrates attention to the alternative courses of action which are open to the businessman. Costs will only be covered if he chooses, out of the various courses of action which seem open to him, that one which maximizes his profits. (Coase, 1938, p.123, as quoted in Buchanan, 1969, p.28)

In this light, cost is not money outlay but an outcome that might occur (ex ante analysis) or that might have occurred (ex post analysis) if the decision maker selected or had selected a different course of action. Cost is then "subjective, it exists in the mind of the decision-maker and nowhere else" (Buchanan, 1969, p.43), for "outcomes cannot be matters of fact but are things imagined by the decision-maker. They exist in his imagination" (Shackle, 1961, pp.ix-x), and "are figments of imagination … figments of the individual mind (no matter of whether in some later actuality they shall be observed to have come true)" (*ibidem*, pp.9–10). Such a concept is nowadays used by economists, analysts, managers, professionals etc., and, being the result of a counterfactual reasoning, it is used by all individuals in daily life as well, though often unconsciously (see Roese & Olson, 1995, on use of counterfactuals in daily life). It is just this concept that gives rise to the equivalent notions of Net Present Value (NPV) and Discounted Cash Flow (DCF). These notions originate in turn a decision-making model which is firmly-entrenched in the literature and in the practice, and is considered reliable for evaluation purposes and for helping decision makers solve many kinds of decision-making process. The consequent decision rule is easily understandable and very simple to apply, so it is of a great appeal to both scholars and practitioners. To give some insights, just imagine a decision maker holds a sum X and wants to invest it for one period. Suppose she knows that she can alternatively invest the sum in a one-period financial operation[1]

[1] By "financial operation" I mean any sequence of cash flows of different sign (therefore I mean any financial contract, any investment in capital markets, any industrial project of any kind, any strategic investment, etc.)

(let us call it A1), which pays the sum X' after one period. Would she invest in such an investment? If she aims at maximizing her wealth she may reason as follows:

> I aim at maximizing my wealth, so I will invest in A1 if it is the best available alternative, that is the one that maximizes my wealth (or increase in my wealth, which is the same). To this end, I can shape the decision process into two steps: first, I find all alternatives at my disposal other than A1 and choose the best alternative among them, i.e. the one (among them) associated with the highest increase in wealth after one period. Once I have selected it (let us call it A2), I compare A1 and A2 and choose the better one.

So, if r_2 is the rate of return of alternative A2, the decision maker will invest in A1 if

$$X' > X + r_2 X = X(1 + r_2). \tag{1}$$

Eq. (1) may be rewritten as

$$\frac{X'}{(1 + r_2)} > X. \tag{2}$$

The left-hand side of (2) is the present value of X'. Eq. (2) tells us that the decision maker will invest if the present value of X' is greater than the cost X. The most common form for (2) is given by

$$-X + \frac{X'}{(1 + r_2)} > 0. \tag{3}$$

The left-hand side of (3) is called the *Net Present Value* of alternative A1 (that is, net of cost *X*). The NPV rule says that the decision maker should invest in A1 if and only if the Net Present Value of A1 is greater than 0, for this implies that investment increases wealth optimally. The rate r_2 is the opportunity cost of capital: As anticipated, it is an opportunity cost in the sense that if a decision maker invests in A1 she foregoes the opportunity of earning r_2 on her capital *X*. The opportunity cost of capital is then a yardstick, a threshold that should be used to evaluate investments. It is the rate of return of the best available alternative other than the one under consideration. The NPV rule formally translates a maximization problem by selecting first the best alternative among the other available ones (this process is realized by the market) and then comparing it with the alternative under examination (this process is realized by the evaluator). The opportunity cost of capital (and the corresponding counterfactual alternative) is then taken as a norm (in the sense of Kahneman & Miller, 1986). In general, if you face two or more mutually exclusive courses of action, you should calculate their NPVs by discounting cash flows at the opportunity cost of capital and choose the one with the highest NPV (for the investment with the highest NPV will maximize the increase in wealth).[2] Therefore, letting A be the set of alternatives available to the decision maker, the NPV procedure implies that the decision maker should take the alternative $x \in A$ which maximizes the NPV:

$$\max_{x \in A} \ \mathrm{NPV}(x). \tag{\#}$$

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undertaken by any kind of decision maker (be it an individual or a group or a manager or an analyst and so forth).

[2] Any time one discounts cash flows (as in the NPV rule) one is applying what financial economists call a discounting cash flow method (so I will use the terms NPV and DCF interchangeably).

2. The DCF/NPV concepts

The NPV model has an infinite spectrum of applications and is a fundamental maximizing tool which is thought to lead to the maximization of the decision maker's wealth;[3] consequently, a rational decision maker should employ it in making decisions. It is used in a massive way for evaluating any kind of investments (operating, strategic, financial) as well as for governance purposes and for firms' evaluations (see Bierman & Smidt, 1992; Rao, 1992; Damodaran, 1999; Copeland, Koller & Murrin, 2000; Brealey & Myers, 2000; Fernández, 2002). The equivalent concepts of Discounted Cash Flow (DCF) and Net Present Value (NPV) are the bricks of a normative building deep-rooted in the maximizing tradition of economics. The idea of maximizing NPV traces back to Fisher (1930), whose analysis is carried out under assumption of certainty, but "the technology of discounting is not an invention of twentieth century" (Miller & Napier, 1993, p.640): Discounted-cash-flow analysis was known and (sometimes) employed since eighteenth century (Brackenborough, McLean & Oldroyd, 2001. See also Edwards & Warman, 1981 for an example of merger valuation in nineteenth century) but its origin dates even earlier, one of the first examples being that of Simon Stevin (1548–1620), a Dutch mathematician, scientist, engineer, and accountant, who used the net present value for choosing between alternative loans (Parker, 1968). The idea of net present value maximization is now commonplace in economic theory: "The firm attempts to maximize the present value of its net cash flow over an infinite horizon" (Abel, 1990, p.755); "the net present value rule is also the basis for the neoclassical theory of investment … Much of the theoretical and empirical literature on the economics of investment deals with issues of this sort" (Dixit & Pindyck, 1994, p.5). The NPV analysis is equivalent to that of Jorgensen (1963) and to the *q* theory of investment (Tobin, 1969): "In all of this, the underlying principle is the basic net present value rule" (Dixit & Pindyck, 1994, p.5), which essentially translates in formal terms the notion of *excess* (or *economic*) *profit* (Marshall, 1890).[4] Most concepts and models used in financial economics are strictly connected with the notion of net present value, e.g. Adjusted Present Value, Weighted Average Cost of Capital, Economic Value Added, tax shield evaluation (see Modigliani & Miller, 1958, 1963; Myers, 1974; Miles & Ezzel, 1980, 1985; Chambers, Harris & Pringle, 1982; Stewart, 1991). Decision tree analysis and stochastic dynamic programming are also used to assess the value of the alternatives. In these cases, the decision maker should maximize a function by application of the well-known Bellman equation (Bellman, 1957; Beckmann, 1968), but it turns out that such a maximization is actually just a DCF/NPV analysis where NPVs relating to different alternatives are compared (Dixit & Pindyck, 1994). The NPV model encounters a great success in business economics (Copeland, Koller & Murrin, 2000), agricultural economics (Gittinger, 1982; Meek, Whittier, & Dalsted, 1999; Souza de Abreu, Ibrahim & Manig, 2003), advance manufacturing technology (Kulatilaka, 1984; Kaplan, 1986; Park & Son, 1988), construction industry (Goto et al., 2000), in production-inventory problems (Grubbström, 1998, 1999; Hill & Pakkala, 2005) and project scheduling problems, where NPV maximization is taken "as the more appropriate objective" (Herroelen, Demeulemeester & Van Dommelen, 1997, p.97; see also Yang, Talbot & Patterson, 1992). Even fuzzy versions of this model are now commonplace in the fuzzy-logic literature (Ward, 1985, 1989; Chiu & Park, 1994; Abdel-Kader, Dugdale & Taylor, 1998; Dimova, Sevastiynov & Sevastiynov, 2000; Buckley, Eslami & Feuring, 2002).

As any other model in economics its reliability has been debated and its scope of application investigated. Though some criticism has been directed toward the NPV criterion, its validity has been always defended by most economists: Theoretical soundness, formal elegance, intuitive appeal, easiness of application have led many theorists to consider it the standard and conventional tool for investment decisions: "The present-value rule is the more or less standard

[3] See how Rubinstein (1973, footnote 10), proves that the use of the NPV for corporate decision-making leads to the maximization of shareholders' wealth.

[4] Many synonyms have been coined to mean economic profit, e.g. 'excess realizable profit' (Bell, 1961), 'excess income' (Kay, 1976), 'abnormal earnings' (Peasnell, 1981), 'supernormal profit' (Begg, Fischer, & Dornbusch, 1984, p.121), and others. The concept of 'Goodwill' (Preinrich, 1936) is also strictly related to that of excess profit.

guide supported by a great many theorists" (Hirshleifer, 1958, footnote 8). The reliability of the NPV criterion is maintained by academics, scholars, analysts and practitioners, who use it in real-life decision making: "We believe that the NPV approach is the best one for evaluating capital budgeting projects" (Ross, Westerfield & Jaffe, 1999, p.134); its use is justified by "the objective of maximizing … wealth" (Myers, 1968, p.1) and the procedure is considered to be "entirely appropriate from a theoretical standpoint" (*ibidem*, p.2). The "Net Present Value … *always* provides the correct financial criterion for selection between projects" (Franks & Broyles, 1979, p.50) and is "the only conceptually correct valuation method" (Fernández, 2002, p.37) since "shareholder value is maximized by choosing projects with positive *Net Present Value*" (Jagannathan & Meier, 2002, p.2, internet version); the importance of the NPV criterion and its prestige in financial economics are often highlighted: "It is almost impossible to overstate the importance of the net-present-value concept … most financial decisions can be viewed in terms of net present value" (Emery & Finnerty, 1997, p.94) and, inevitably, "no student can leave the introductory finance course without having mastered the net-present-value rule" (Ross, 1995); its *normative* use is often suggested: "Companies contemplating investments in capital projects should use the net present value *rule*" (Graham & Harvey, 2002, p.10). The NPV model is intended to work for individuals and for organizations (such as companies of all kinds) as well. In the latter case, as "the objective of the firm is to maximize the wealth of its shareholders [and given that] the net present value criterion is ... consistent with shareholder wealth maximization" (Copeland & Weston, 1988, p.18), managers should invest only in positive NPV projects and the significance of the NPV for decision-making should be self-evident: "Like most good ideas, the net present value rule is obvious when you think about it [and investors should give] the manager one simple instruction: "Maximize present value""(Brealey & Myers, 2000, p.1007).

The high status of the NPV is so established that some authors hold that the NPV notion is one of the (seven) most important ideas in finance (Brealey and Myers, 2000, ch.21); some others heave a sigh of relief whenever they find out that decision makers' behaviors match the normative prescriptions of the NPV model: "it is encouraging that NPV is much more widely used as a project evaluation method than it was ten or 20 years ago" (Graham & Harvey, 2002, p.21). And some others (jocularly) idolize it and make the search for positive-NPV investments the right behavior that any decision maker should pursue:

> Analyst's Prayer
>
> Give me the intellect to seek the knowable; give me peace of mind to accept the unknowable.
>
> Give me the strength to reject the investments with negative NPV and the wisdom to select the projects with positive NPV.
>
> Most importantly, give me the inspiration (preferably the correct risk-adjusted cost of capital) to know the difference between a good investment and a bad investment. (Tham & Vélez-Pareja, 2004, p.VII).

3. Uncertainty and Equivalent Risk tenet

As anticipated, the NPV translates in present-value terms the notion of *excess* (or *economic* profit), which is massively used in economics:

> Economic profit is the excess profit that is gained from an investment over and above the profit that could be obtained from the best alternative foregone. That is
>
> Economic profit from investment= wealth increase — wealth increase from best alternative foregone. (Rao, 1992, p.87).

Formally, we may rewrite (1)-(3) as

$$X' - X > r_2 X \tag{4a}$$

or as

$$[X' - X] - r_2 X > 0. \tag{4b}$$

The left-hand side of (4b) is the economic profit, that is the difference between two profits corresponding to the factual and counterfactual alternative respectively, or, in Rao's terms (see above), the difference between wealth increase and wealth increase from the best alternative foregone. The NPV is then the excess (economic) profit disguised as a present value.

Unfortunately (or not?) most investments are undertaken under uncertainty (as most actions in our life) and the NPV rule as such is inadequate: We cannot say *a priori* that, for example, an *expected* return of 100 is better than an *expected* return of 90 if the former is riskier than the latter. None of the two dominates the other: One is preferable in terms of return, the other one is preferable in terms of risk (risk-aversion is assumed). So, if our alternatives are not equivalent in risk, the NPV rule should not be adopted, since it only creates a *partial* ordering among alternatives. But economists stick at it and introduce what I like to name the Equivalent Risk (ER) principle: According to this tenet the alternative under examination should be compared with an alternative equivalent in risk. In this view the aforementioned alternative A2 should be an alternative equivalent in risk to A1. In such a way, the comparison between the two alternatives is (apparently) legitimate: Given that risk is equivalent, the alternative selected will be the one offering a higher expected (increase in) wealth. So, eq. (3) is retained where r_2 "has the interpretation of opportunity cost of capital, and therefore it should equal the return the investor could have earned on other investment opportunities with comparable risk characteristics" (Dixit & Pindyck, 1994, p.114). Thus, a two-dimension decision problem (risk/return) is diverted to a one-dimension problem (return) via the ER principle and the NPV is safeguarded. In the minds of financial economists the following equation holds:

Wealth Maximization=NPV+ER=rational procedure to evaluate alternatives.

Decision makers should then maximize NPV with respect to the subset $A^* \subset A$ of those alternatives which are equivalent in risk:

$$\max_{x \in A^*} \text{NPV}(x) \ . \qquad (\#\#)$$

The restriction of the domain makes it possible to dismiss any issue of preference: If alternatives have equivalent risk, then the solution does not depend on decision makers' preferences! But, analyzing the decision maker's behavior implied by such a restriction, we will see that the idea of restricting the function's domain is illusory. Indeed, we will see that, while apparently flawless, the constrained optimization problem in (##) is artificial, cognitively absurd, behaviorally inapplicable and produces frame-dependent solutions. Quoting the authors of a finance textbook:

> Wealth maximization as a goal for financial decisions ... leads to logical decision rules for decision-makers –rules which can be applied in 'real world' situations.
> (Archer, Choate & Racette, 1979, p.7)

Sections 5 to 8 will be devoted to showing that when these 'logical' rules are examined with the psychologist's eyes (in particular, when the choice behavior of the NPV-minded decision maker is studied), they give rise to contradictions and freakish behaviors. As a result, decision makers contemplating investments should reconsider the use of the NPV rule as suggested in (##).

4. Actual choice behaviors

As seen, the "rational" economic agent should maximize the NPV using a discount rate that reflects the risk of the asset under evaluation. This brief section is concerned to analyzing the real-life behaviors of economic agents and answering the following question: Do investors use the NPV model for decision-making as a tool for making decisions? And when they use it, do they apply it in a correct way?

To understand decision makers' behaviors a common method in experimental finance is to send a questionnaire to firms or to perform experiments recruiting various kinds of decision makers dealing with (or pretending to deal with) investment decisions and financial evaluations: Top-ranking executives, chief financial officers, participants of MBA or of executive program classes,

financial analysts, graduate business students, doctoral students etc. Browsing through the relevant literature it seems that the use in practice of the discounted-cash-flow method was disregarded until late Fifties (Istvan, 1961), whereas its academic reliability was already consolidated. The use of the NPV gradually increased in the Sixties and the Seventies; "during the 1970s evaluating projects started to be predominantly based on methods like the net present value that take into account the time value of money" (Jagannathan & Meier, 2002, p.8)[5] and "by the late 1970s financial executives are familiar with discounted cash flow analysis" (p.10). Hammer (2003) reports past surveys from 1970 to 2001 (Table 1, p.2) showing increasing values for the use of the DCF model: 57% (Klammer, 1972), 63% (Gitman & Forrester, 1977), 86% (Moore & Reichert, 1983), 92% (Poterba & Summers, 1995), 96% (Ryan & Ryan, 2002). More recently, Graham and Harvey (2002), on the basis of responses from 392 companies representing a wide variety of firms and industries, affirm that "most companies follow academic theory and use discounted cash flow (DCF) and net present value (NPV) techniques to evaluate new projects" (p.9). Yet, there is also awareness in the financial literature that when applying the NPV methodology many decision makers do not rigorously adhere to it. Although the latter claim that they use the NPV model, they report values of the discount rate that seem to be independent of risk. So they do discount cash flows as prescribed by the NPV, but they do not use a discount rate reflecting the opportunity cost of capital; they instead resort to a subjectively-determined cutoff rate that acts as a threshold for acceptability: In the jargon of financial economists, they use a *hurdle* rate, not a *cost of capital*; in the jargon of cognitive and behavioral psychologists, they act as satisficers (hurdle rate=satisfactory level. See Simon, 1955, 1956). Brigham (1975) surveyed 33 large, relatively sophisticated firms. Although 94% of them used DCF methodology, only 61% of the firms using DCF adopted the cost of capital as the discount rate. Summers (1987) surveyed corporations on investment decision criteria finding that 94% of reporting firms use the NPV rule employing a discount rate independent of risk; McDonald (2000) writes that "firms making capital budgeting decisions routinely do a number of things that basic finance textbooks say they should not do [among which:] Projects are taken based on whether internal rates of return exceed arbitrarily high discount rates (often called "hurdle rates")" (p.13). "Finance scholars have always been puzzled by the durability of … the hurdle rate rule" (Ross, 1995); in actual facts, "we know that hurdle rates ... are used in practice" (McDonald, 2000, p.30) and "it appears common for firms to use investment criteria that do not strictly implement the NPV criterion" (*ibidem*, p.13), so that their "actions do not reflect the application of current financial theory" (Gitman & Mercurio, 1982, p.29).[6] Graham and Harvey (2002) affirm that "small firms are significantly less likely to use the NPV criterion" (p.22). They find that sometimes the use of hurdle rates is explicitly acknowledged: "small firms were inclined to use a cost of equity determined by "what investors tell us to require" [and a] majority (in fact, nearly 60%) of the companies said that they would use a single-company wide discount rate to evaluate a new investment project, even though different projects are likely to have different risk characteristics" (*ibidem*, p.12).

Implicitly or explicitly, many decision makers do not abide by the prescriptions of the NPV model and use a *rule of thumb* for evaluating investments. If one were to adopt the heuristics-and-biases-program perspective (Tversky & Kahneman, 1974; Kahneman, Slovic & Tversky, 1982; Gilovich, Griffin & Kahneman, 2002) one would call "bias" the mismatch between actual investment behavior and normative behavior, and some explanations could be advanced in order to account for this empirical finding. While some finance theorists do try to give explanations to such a "bias" (e.g. McDonald, 2000; Jagannathan & Meier, 2002) and while a growing bulk of financial literature is devoted to find deviations from normative models (e.g. Howell & Jägle, 1997; Graham & Harvey, 2001, 2002; Miller & Shapira, 2004), I abstain from taking this perspective. The end here pursued is not that of analyzing and explaining the behaviors of those decision makers that

[5] All quotations from this paper refer to the internet version.

[6] According to Jagannathan and Meier (2002), the fact that decision makers claim that they do use the NPV model and the cost of capital as a discount rate, may be due to a bias explained by the *social desiderability hypothesis*, well documented in the psychological literature (e.g. Singer and Presser, 1989; Tanur, 1992).

deviate from the model's prescriptions, but, much to the contrary, that of setting sights on the behaviors and reasoning of those (actual or potential) decision makers that strictly comply with the NPV. The following four sections take this very perspective and are dedicated to a thorough observation of the NPV-minded decision makers' reasoning and behavior.

5. NPV-minded choice behavior: "To do or not to do"

As attention is drawn on NPV-minded decision makers, one can legitimately recruit such decision makers to have them solve investment decisions. Hence, one can analyze the solutions obtained as well as the way those solutions have been reached. The experiments are, for example, of the following kinds:

Experiment 1

Each participant is given 100 euros and assigned the following task:

> *You have the opportunity of investing the money you have just received in investment A1, whose expected payoff is 120 after one year. Do you invest in A1?*
> *You may ask the experimenter for any other piece of information you need.*

Experiment 2

Each participant is given the following task:

> *Suppose you aim at investing 1000 euros. You are offered project A whose expected cash flow is 1200 after one year. Do you invest in A?*
> *You may ask the experimenter for any other piece of information you need.*

To those who do not accept the project one more question is asked:

> *In alternative, you have the opportunity of investing those 1000 euros in project B whose expected cash flow is 1300 after one year. Do you invest in B?*
> *You may ask the experimenter for any other piece of information you need.*

The results of Experiment 1 and Experiment 2 are clear and unambiguous.

> **Experiment 1's results**: As participants are NPV-minded, each of them will ask the experimenter for the rate of return of the best alternative equivalent in risk to A1. Suppose it is 15%. The NPV is positive. As a result, 100% of the participants will accept the project.
> **Experiment 2's results**: The NPV-minded decision makers will ask the experimenter for the return of the best alternative equivalent in risk to A. Suppose it is 25%. The NPV of A is negative and all of them will reject A. Facing then project B, they will ask for the return of the best alternative equivalent in risk to B. Suppose it is 23%. The NPV of B is positive and all of them accept B.

While I cross-refer readers to section 10 for description of these experiments and justification of their use, in sections 5 to 8 lights will be shed on different scenarios involving investment decisions and on the way NPV-minded decision makers reach the solutions of their maximization problems. All scenarios are ideally derived from experiments similar to Experiments 1 and 2. The results of experiments such as 1 and 2 appear flawless and seem to be just the logical consequence of the NPV paradigm. While it is true that they are a logical consequence of the model, it is not true that they are flawless: An accurate interpretation of them will enable us to unearth cognitive, behavioral and logical anomalies.

Suppose a decision maker is willing to invest X euros. She has the opportunity of investing in alternative A1 and she uses the NPV criterion to solve the decision process "to undertake A1 or

not". Let us first answer the following question: Where does the amount *X* come from? There are three cases:

1) *X* is an amount which increases the investor's wealth (for example, it comes from salary, stipend and the like);
2) *X* is already part of the investor's wealth (for example, *X* is withdrawn from a current account, or some financial assets are sold to get *X* etc.);
3) *X* is obtained from an external source (it is raised by a lender).

Let us begin with case 2. This means that if the decision maker invests in alternative A1 she withdraws the funds from some assets she already owns (let us call B such an asset). Suppose alternative A2 is the (best) alternative investment that mirrors A1 in terms of risk. Then the decision maker calculates the NPV of A1 by using A2's expected rate of return r_2.

a) Suppose the NPV of A1 is positive. Therefore, positive excess profit is expected from A1, so the investor undertakes A1, as suggested by the NPV+ER rule. In particular, she withdraws the amount *X* from asset B and invests it in A1. Here we have the first anomaly: If the investor accepts to deflect funds from B to A1, then it means that A1 is preferred to B. Indeed, accepting a course of action (A1) amounts to rejecting the other one (B). But then a comparison (implicit or not) is actually accomplished between A1 and B. In general, A1 and B have different risk, so the ER principle is violated.
b) Suppose the NPV of A1 is negative. This implies that A2 should be preferred to A1 (for it is equivalent in risk but offers a higher return) and, consequently, A2 should be undertaken. But not so for financial economists: The decision maker is suggested to undertake neither A1 nor A2, which means she should keep funds in asset B. But the NPV rule is then transgressed (because A2 should be undertaken), that is the NPV is not maximized. Moreover, to keep money in asset B means that B is preferred to A2, and, in general, this comparison is not equivalent in risk. The ER principle is then violated as well (or, which is the same, the domain A is not narrowed to A^*, as prescribed in (##)).[7]

As one can see, the decision-making process is distorted and an alternative A2 is exogenously introduced, which has nothing to do with the alternatives at hand: The decision maker is asking herself whether she should invest in A1 or not. 'Not' means that she will do nothing, or, in other terms, that she will leave money invested in B (or, in general, in her current investments). The decision problem is "to do A1 or not to do A1" or, equivalently, "to do A1 or to do non-A1".[8] Alternative A2 is fictitious, its role is merely auxiliary, and it only serves the scope of making the comparison homogeneous. But it will never be undertaken, even if the NPV is negative. Therefore, the NPV-minded decision maker disguises the decision process in a convenient way. In other terms the issue at hand is "A1 or non-A1" but the decision problem is reshaped as "A1 or A2" so as to make the NPV applicable. But this distortion brings about serious consequences, for if "A1 or A2" were the real decision problem, then if A2 is better than A1, A2 must be undertaken. But the decision maker is willing to do A1 or to do non-A1: A2 is not considered at all by the decision maker, so whenever it happens that A2 is better than A1, the NPV+ER procedure may not suggest decision makers to invest in A2; on the contrary, it tries to comply with the real decision process and suggests the decision maker to undertake non-A1 (i.e. leaving things unvaried, keeping current investments). We have then the following line of reasoning:

(i) a decision maker is faced with two alternatives, A1 and non-A1;
(ii) A1 and non-A1 are not homogeneous in risk;
(iii) the decision maker is not allowed to compare two alternatives different in risk;

[7] The reader should not be discomforted by the fact that if the NPV is negative the investor will not invest in A1 so that she does not probably know from which asset B she would have withdrawn the money if she had invested in A1: One may replace 'asset B' with the more general 'current investments' and the line of argument is not infirmed.
[8] Henceforth, I use the term "non-A1" to mean "leaving money where they are".

(iv) the NPV rule as such is not capable of comparing two alternatives different in risk;
(v) it is then asserted that decision makers must introduce a third alternative A2, equivalent in risk to A1;
(vi) although it is asserted that one has to compare A1 and A2 neglecting non-A1, if A2 turns out to be better than A1, then non-A1 must be recovered and selected by the decision maker.

Argument sub (i)-(vi) is awkward and invalid. A2 is introduced as a standard, a norm, a benchmark, a yardstick (call it as you want). The idea of a standard, of a norm in human decisions is commonplace (e.g. the above mentioned norm theory of Kahneman & Miller, 1986), but here we see that an anomaly appears: Decision makers abiding by the NPV+ER methodology cannot prevent themselves from comparing alternative courses of actions which are different in risk. This would not be a problem for a psychologist nor for ordinary human decision makers, but it is a problem for the "rational" decision maker maximizing wealth according to the NPV+ER procedure. To see it as a deductive argument, let us consider the case where A2 is preferable to A1. The NPV+ER-minded reasoner accomplishes the following deduction:

The set of available alternatives is $A^* \subset A$

$A1 \in A^* \ \wedge \ A2 \in A^*$

non-A1 $\notin A^*$

A2 is better than A1

---

non-A1 is selected

If the conclusion is true, then the first assumption does not hold, that is the decision maker is not selecting alternatives from $A^* \subset A$, as (##) requires. Logic (and the ER tenet) is violated.

Let us focus on case 3, where the investor raises *X* from a creditor.

c) Suppose *X* is raised from a creditor and let j be the contractual rate. Let *W* be the investor's wealth at time 1 if A1 is rejected and let $Z = X(1 + j)$ be the sum to be reimbursed after one period by the investor. At time 0, the net amount is $X - X = 0$ (since *X* is received from the creditor and then paid out for investing in A1), while at time 1 the expected amount is $S = X' - Z$ (i.e. $X +$ return on $X -$ debt reimbursement). In this case, it is easy to see that to apply the NPV rule is equivalent to verifying the sign of *S*. But in so doing the decision maker cannot prevent herself from comparing two alternatives that are not equivalent in risk: alternative A1 plus financing (i.e. holding the sum *W*+*S* at time 1) against doing nothing (i.e. holding the sum *W* at time 1). The ER principle is violated.

Let us focus now on case 1. The decision maker receives *X* and aims at investing it in some assets.

d) Suppose she faces the opportunity of investing in A1. She adopts the NPV rule and compares A1 with the (best) alternative equivalent in risk, say A2. Suppose the NPV of A1 is negative. Then she will not invest in A1: According to the procedure this does not amount at all (as we have seen) to saying that she should invest in A2. But if so, the very NPV rule is disdained, for when equivalent-risk assets are compared, the *best* one should be preferred. So the NPV+ER maximizing procedure is not fulfilled.
e) Suppose (just for clarity of exposition) that the investor's wealth is entirely invested in one financial asset, say B (if you prefer, think of B as the current investments, as in

footnote 8). Suppose she faces the opportunity of investing in A1. She adopts the NPV rule and compares A1 with the (best) alternative equivalent in risk, say A2. Suppose the NPV of A1 is positive. Then she invests in A1. This means that she prefers investing *X* in A1 to investing it in B. But these two options are in general not homogeneous in risk. So, again, the ER principle is not obeyed. (Participants of Experiment 1 commit this fallacy).

Finally, the following behavioral anomaly holds for either case 1, 2 and 3:

f) Suppose the decision maker is willing to invest *X* euros and faces the opportunity of investing in A1. She adopts the NPV rule and compares A1 with an alternative equivalent in risk, say A2. Suppose the NPV of A1 is negative. Then she does not undertake A1 and searches for another investment alternative. Suppose she comes across alternative B1. She evaluates this course of action against an equivalent-risk alternative, say B2. Suppose the NPV of B1 is positive. Then she invests in B1. But such a decision-making process implies that the ER principle is infringed. In fact, the decision maker owns the amount *X* and she rejects alternative A1 while accepting alternative B1. So B1 is preferred to A1, which means that B1 and A1 are compared, though indirectly. The decision maker cannot prevent herself from accomplishing such a comparison, which is illicit from the very point of view of the ER principle, since, in general, A1 and B1 are different in risk. (Participants of Experiment 2 commit this fallacy).

Let us then concentrate on f). When A1 is discarded (via comparison with A2) the decision-making process is not over. So, to compare B1 and B2 is only apparently legitimate. It seems to me that if I am willing to invest *X* euros my decision-making process is over *only* once I have selected the investment alternative. Before that moment the decision process is not completed. So, no matter the way I arrive to the solutions of the decision problem, if I deliberately and explicitly discard A1 and choose B1, then this amounts to saying that I prefer investing in B1 to investing in A1. But if B1 is preferred to A1, then I have compared two alternatives which are different in risk. Now, again, this is not a problem for all human beings, who in daily life accomplish evaluations of alternatives different in risk, but it is a problem for those who aver that heterogeneous comparisons cannot be made: It is logically impossible to induce a "rational" decision maker to compare only homogeneous alternatives.

Let us now paraphrase the line of reasoning *sub* f) in different domains in order to clarify the clumsy reasoning and choice behavior of the NPV-minded decision maker. Such a behavior is equivalent to those of the following decision makers:

Guido is willing to go out for a concert after dinner and must decide where to go. He takes the newspaper to search for the available events in Rome. He reads that tonight there is a concert performed by the Wiener Philarmoniker (A1). To decide whether to go or not he looks for a comparable alternative, for example other classical music concerts. He reads that there will be a concert of the Berliner Philarmoniker too (A2). He prefers Berliner to Wiener, so he decides not to go to the Wiener Philarmoniker's concert. He goes on searching for a concert and finds that pianist Enrico Pieranunzi will be playing jazz in a theatre (B1). To decide whether to go or not he looks for a comparable alternative, for example other jazz concerts. He reads that jazz pianist Keith Jarrett will play tonight in Rome as well (B2). Guido prefers Pieranunzi to Jarrett so he decides to go to Pieranunzi's concert.

Carl must decide whom he should go out with. He thinks he could meet Laura, with whom he could spend a romantic night in a romantic place (A1). To decide, he retrieves in his mind another girl with whom he could go out, say Barbara (A2). He prefers Barbara, so he decides not to meet Laura. Then he thinks he can go out and play tennis with Peter (B1). To decide he considers that David is also a good friend to play tennis with (B2). But he prefers Peter to David, so he decides to go out and play tennis with Peter.

These seem to be grotesque behaviors. And they are obtained by rigorously adhering to the prescriptions of the NPV+ER model, whose purpose is that of providing a device that any "rational" decision maker should use. Furthermore, in addition and *regardless of* these behavioral bizzarreries, Guido has discarded Wiener and selected Pieranunzi, and Carl has discarded Laura and selected Peter. As a result, the allegedly illegitimate comparisons Wiener/Pieranunzi and Laura/Peter have actually been accomplished. One cannot escape: A1 is rejected and B1 is chosen, and this presupposes that B1 is preferred to A1, which means that B1 is judged a better choice than A1, which in turn presupposes a comparison between the two. Indeed, there is no way to focus on *one* norm, *one* standard; any decision maker inevitably faces multiple norms in our daily life, and financial decisions are no exceptions: We may not speak of an (equivalent) opportunity *cost*, but, rather, of several (non-equivalent) opportunity *costs*. To avoid non-homogeneous comparisons is an impossible task for the NPV-minded decision maker: This causes distortions of the original decision problem, and the decision maker's behavior is biased in that she does not manage risk in a consistent way (true, it seems that she does not manage risk at all).

The methodology under examination fails from several points of view (behavioral, cognitive, logical) and does not allow the decision maker to abide by the ER tenet. Among fallacies, inconsistencies and ambiguities, meticulous users of the rule are trapped in a cognitive illusion, which one could name *self-deception*: The NPV-minded reasoner thinks she is choosing between equivalent-risk assets whereas she is not. She pretends to be selecting one among equal-risk alternatives, i.e. to be solving the constrained decision problem in (##) but in fact she is not. She is not managing risk at all, and so she is deceiving herself.

6. NPV-minded choice behavior: "To do this or to do that"

It is worth analyzing the case where the two alternatives are not of the kind "to do or not to do" (as I have assumed at the outset), but, rather, of the kind "to invest in C1 or to invest in C2" where C2 is not equivalent to non-C1 (i.e. to leave things unvaried) and differs from C1 in terms of risk (e.g. C1=expand the scale of your current business, C2=invest in stocks or bonds of a traded firm). The following quotation describes the procedure to be employed:

> How does one compare mutually exclusive projects? The obvious answer is to compare their Net Present Values. The largest NPV is the most favourable to the shareholders and adds most to the value of the company … if two or more alternatives involve different risk, they are not directly comparable since they require different discount rates. Each must first be compared to the capital market and the following questions answered: 'Are any of the alternatives profitable?' 'Which of the profitable alternatives has the largest Net Present Value?' (Franks & Broyles, 1979, p.88).[9]

The statements may be rephrased in more familiar terms:

> If two (or more) alternatives have different risk, then the decision maker should compare them indirectly, by first comparing each project with its own norm, thus finding the excess profit for each, and then select the one with the highest excess profit (the highest distance from the norm).[10]

But again, the latter comparison is not legitimate from the very point of view of the ER principle. In fact, each comparison is made *with respect to the equivalent-risk alternative* (the norm or standard). That is, C1 is compared with its equivalent-risk alternative and the same is done with C2. The difference between the return on one alternative and the return of its standard is the excess profit (see (4b)). If we compare the excess profit of C1 with the excess profit of C2 we compare excess profits which are different in risk. For example, if C1's return is higher than its equivalent-risk alternative by 3 and C2's return is greater than its equivalent-risk alternative by 2, then C1 should be preferred to C2, because to get 3 is better than to get 2. But this reasoning is awkward, for it is comparing oranges and apples. This line of reasoning is tantamount to the following arguments:

Roberta is taller than the average woman by 5cm, Franco is taller than the average man by 3cm. Then Roberta is taller than Franco. (*)

Ralph prefers maccheroni to spaghetti by more than he prefers water to wine. Then he prefers maccheroni to water. (**)

To put it differently, it is as if one said that if it is true that 7>2 and 9>6, then it is also true that 7>9 because 7–2>9–6!

Furthermore, in addition to and *regardless of* this conceptual flaw, the ER tenet is again defied, since to compare 3 and 2 means to compare two differential profits relating to different-risk pairs of alternatives. So, the decision maker deceives herself when she believes that she is applying the ER tenet (obviously, the anomalies seen in the previous sections hold as well).

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[9] And "if two investments have the same NPV … they are equally attractive, *regardless of the amount of … risk to which they expose the investor*" (Ogier, Rugman & Spicer, 2004, p.170, italics supplied).

[10] For projects with equal revenues (machine replacement problems), the highest NPV alternative is the one "with the lowest discounted cost" (Copeland & Weston, 1988, p.414).

It is worth spending some words on such a biased perspective. This outlook is equivalent to the perspective employed for judging the *Best in Show* in a dog Show. Best in Show is a contest among dogs of different breeds. Dogs taking part to a dog Show are judged according to breed standards. To win Best in Show a dog must possess qualities that *most closely* match the standard of its particular breed. So, each dog is judged against a typical dog which ideally represents the best of that breed. For example, suppose there are two dogs competing in Best in Show, a Bullmastiff and a Labrador Retriever. Suppose the Bullmastiff wins Best in Show. This means that its closeness to the standard Bullmastiff (in terms of qualities) is greater than the closeness of the Labrador Retriever to the standard Labrador Retriever; but (as any judge may confirm) this does not amount to saying that that particular Bullmastiff is more beautiful than that particular Labrador Retriever. Back to our decision problem "C1 or C2": If we replace 'dog' with 'alternative', 'breed' with 'risk' and 'aesthetical qualities' with 'return' (increase in wealth) we find out that the procedure employed for selecting C1 or C2 mirrors the Best-In-Show procedure, except that a decision maker should choose the alternative which *less closely* matches its standard (i.e. the alternative which has the highest difference between its return and the return of the standard alternative). In other terms, minimization of divergence in quality from the standard is replaced by maximization of divergence in return from the standard. I will call such a reasoning *reverse-Best-In-Show reasoning* (henceforth often RBIS).[11] Actually, in the application of the NPV+ER maximization, C1 and C2 are compared to their own standard (equivalent-risk) alternatives and the one is selected which less closely matches its standard alternative (i.e. the one which has the highest distance from the norm).

From an optimization point of view, the maximization problem may be formally described as follows: Let A be the set of available alternatives and let A_{z_1}, A_{z_2} be the set of all alternatives equivalent in risk to C1 ad C2 respectively. The RBIS reasoning implies a maximax strategy of the following kind:

$$\max_{A_z \in \{A_{z_1}, A_{z_2}\}} \; \max_{x \in A_z} \; \mathrm{NPV}(x); \qquad (\#\#\#)$$

eq. (###) is a particular case of the more general optimization problem

$$\max_{A_z \in \mathrm{P}(A)} \; \max_{x \in A_z} \; \mathrm{NPV}(x) \qquad (\#\#\#\#)$$

where $\mathrm{P}(A) = \{A_z : z \in A, \text{ and } x \in A_z \text{ iff } x \text{ has the same risk as } z\}$ is the partition of the equivalent-risk classes in A.

As we have seen, procedures (###) and (####), though formally impeccable, are quite an absurd technique for choosing between alternatives. Further one cannot deny that (*regardless* of this conceptual flaw) from the very point of view of an ER-minded evaluator an illegitimate comparison is being accomplished.[12]

Not only is the ER tenet violated and an abstruse procedure employed: The very RBIS reasoning is equivocal. To understand why, let us quote Mark Rubinstein, a leading authority in financial economics, who explicitly refers to different-risk alternatives and writes:

> The firm should accept the project with the highest excess expected internal rate or return weighted by its cost ... This result … is equivalent to accepting the project with the highest net present value". (Rubinstein, 1973, p.174)

[11] Best-In-Show procedure is very common in daily life. For example, some TV quiz shows often adopt it for determining the winner: Each participants selects a discipline to be tested on. The winner will be the one with greater competence in his discipline. For the quiz show's purposes the winner is (conventionally) better than his rivals, but, as the disciplines vary across subjects, this does not amount to say that he is *in general* better than his rivals.

[12] It is worth noting that the fallacy sub f) in section 4. turns out to be a particular case of RBIS reasoning, where the excess profit of C1 is negative and the comparison of C1 and C2 is sequential rather than simultaneous.

Rubinstein's methodology is just the RBIS reasoning. But he refers to the latter in two different manners, corresponding to two different maximization processes: Maximization of excess profit in terms of return (first sentence), maximization of excess profit in terms of present values (second sentence). According to Rubinstein the two maximizations are equivalent. It is simple to show that this alleged equivalence does not exist and that the two maximization processes are two incompatible interpretations of the concept of wealth maximization. Let r_1 and r_2 be the rates of return for C1 and C2. Let y_1 and y_2 be the corresponding opportunity costs of capital (i.e. the rates of return of the standards of C1 and C2 respectively). Assuming, with no loss of generality, that the initial outlay is *X* for both alternative, Rubinstein's first sentence is formally translated as follows:

C1 should be preferred to C2 if and only if

$$X(r_1 - y_1) > X(r_2 - y_2). \tag{5}$$

Note that (5) compares the two expected excess rates of return weighted by its costs *X* (i.e. the two expected excess profits). This is the first version of the RBIS reasoning. A different formal translation of the RBIS reasoning is derived from the second sentence in the quotation:

C1 should be preferred to C2 if and only if

$$-X + \frac{X(1+r_1)}{(1+y_1)} > -X + \frac{X(1+r_2)}{(1+y_2)}. \tag{6}$$

Eq. (6) compares the two NPVs of C1 and C2 respectively. But contrary to Rubinstein's words, (5) and (6) are not equivalent: From (5) one gets to $r_1 - y_1 > r_2 - y_2$, whereas (6) leads to $r_1 - y_1 > r_2 - y_2 + (y_1 r_2 - r_1 y_2)$, which in general differs from the former.

If C1 and C2 had the same risk, then (5) and (6) would indeed be equivalent (because we would have $y_1 = y_2$); therefore, if the decision process were "to do or not to do" (which implies $y_1 = y_2 = r_2$) no such an ambiguity would arise. But with two different-risk alternatives at hand, maximization of wealth becomes ambiguous: Should we rely on excess profit as formalized in (5) or on a comparison of the NPVs as in (6)? Contrary to Rubinstein's statement, they are not equivalent. If we assume one of the two above interpretations, then the other breaks down.

As a consequence, the RBIS reasoning (and the resulting choice behavior) is fallacious, disobeys the ER tenet and is mathematically, cognitively, behaviorally ambiguous.

7. NPV-minded choice behavior: "To do now or to wait and see"

The reverse-Best-In-Show reasoning is just the procedure some scholars employ when dealing with the case where the alternatives are "to do now" (DN) and "to wait and see" (WS). This means that an investor has an option to wait: She may invest immediately or wait and invest after some time only if it turns out to be profitable. This is an important case in the literature and it is called (*defer*) *real option*.[13] The most common mathematical tools adopted for treating real options are options pricing technique, also known as *contingent claims analysis* (see Black & Scholes, 1973; Cox & Rubinstein, 1979), and stochastic dynamic programming (see Kamien & Schwartz, 1991; Dixit & Pindyck, 1994). The two methods are formally equivalent and may be actually seen as an application of a DCF analysis. Smith and Nau (1995, pp.799-800) show that options pricing is equivalent to the comparison of two NPVs where two different discount rates are used. Dixit and Pindyck (1994) show as well that options pricing and stochastic dynamic programming are formally equivalent and explicitly assert that decision makers using the NPV rule reach the same results: "one can always say that the rule "invest if NPV is positive" holds … as long as they are

[13] Other examples of real options are abandonment options, growth options, expansion options, suspension options, switching options.

careful to include all relevant option values in the definition of NPV" (p.7).[14] Contingent claims analysis may be applied only if real options are replicable in capital markets, but this is hardly ever the case. Stochastic dynamic programming does not have such limits so I will briefly concentrate on the latter, assuming that the real option is not replicable. The use of dynamic programming (and therefore of an implicit NPV rule) for valuing real options generates two anomalies. The first one is as follows: Decision makers should compare alternatives DN and WS by making use of their respective standard alternatives. This step is accomplished via NPV procedure (whereby DN is compared with its own standard and WS is compared with its own standard). This means that the evaluator is supposed to formally apply a RBIS reasoning in order to decide which course of action should be taken.[15] Therefore, two alternatives are compared (DN and WS) which are, in general, different in risk. The ER principle is again disobeyed. The second anomaly lies in the fact that the RBIS reasoning is sometimes applied in a wrong way. In fact, a "correct" RBIS reasoning implies that DN and WS should be compared with their respective standards, which formally means that the two NPVs should be calculated by using two different opportunity costs of capital, as in (6) (in this case, one opportunity cost relates to DN and the other relates to WS). On the contrary, the two NPVs are sometimes calculated using the same opportunity cost of capital. For example, Dixit and Pindyck (1994) implicitly and explicitly suggest the use of a single rate: "We specified this discount rate exogenously" (p.114), "the discount factor between any two period is $1/(1+\rho)$" (p.99), "the objective function is … the present value … calculated using a … discount rate" (p.121), "this investment rule is based on an arbitrary … discount rate, ρ" (p.147), "the solution will be subject to an assumed discount rate" (p.152), "there is no theory for determining the "correct" value for the discount rate ρ"*(ibidem)*, "we can use dynamic programming with an exogenously specified discount rate ρ" (p.185), and their examples are consistent with these statements. Jagannathan and Meier (2002) do the same: They evaluate both DN and WS by using one single discount rate. The error is made even in other types of real options. For example, Bonini (1977) deals with an abandonment real option (an option to abandon the project at any time) and uses a single discount rate in the dynamic recursion. All these authors are committing both aforementioned fallacies.[16]

8. Psychology and philosophy of science

In the philosophy of science it is usual to separate the context of scientific discovery from the context of justification of theories. Psychology plays a role in both contexts being concerned with: *(i)* Study of the processes that govern formulations of hypotheses in science and, in general, study of scientific creativity, *(ii)* study of possible discrepancies between rational behavior and human behavior in (social and) economic sciences, resulting in the falsification of theories as descriptive accounts of human behavior. This section outlines functions *(i)* and *(ii)*, while section 10 endorses a third function, pertaining to the domain of justification, which I here anticipate: *(iii)* Study of possible discrepancies between normative-minded behavior and rational prerequisites of consistency, applicability, non-ambiguity. The latter function implies that psychology may be used as a tool for falsifying/corroborating decision theories and models as normative paradigms.

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[14] However, whether or not one sees dynamic programming as equivalent to the NPV rule is not restrictive, it is just a matter of terminology (should the NPV rule and dynamic programming be viewed as different, then we would be facing not just one but two biased maximizing tools).

[15] The case "to do or to wait" is just a particular case of the case "to do this or to do that" just examined.

[16] Other scholars are aware of the second anomaly: Copeland, Koller and Murrin (2000) realize that the DCF approach "uses an *ad hoc* discount rate that is incorrect for the riskiness of cash flows being evaluated" (p.405). Copeland and Antikarov (2001) thoroughly study the same problem reaching the conclusion that the comparison between two NPVs calculated with the same discount rate "seems to be a good approach, but on close reflection … is wrong" (p.90). Nau and McCardle (1991), Smith and Nau (1995), Fernández (2002, ch.22) point out this anomaly as well. This kind of error is typical of the so-called Decision Tree Analysis: "The error in the traditional DTA approach arises from the use of a single (or constant) risk-adjusted discount rate." (Real Options Group, n.d.-b). However, all these authors assume that the option is replicable.

Historically, function *(i)* is intertwined with the role of hypotheses in science. The latter was recognized as fundamental only in nineteen century, when science became to be considered an *opus conjecturale* and the context of scientific discovery was conceptually separated from the context of justification (Naville, 1880). According to this view, discovery depends on an anticipated idea that constitutes the *primum movens* of any scientific reasoning and is then controlled by experiments. In actual facts, scientists make hazardous conjectures (Whewell, 1840) and sometimes even "suppositions which are wholly *inconceivable* in a certain sense of the word (Jevons, 1877, p.510), so much so that the Baconian method is insufficient to account for scientific invention, which is instead based on a marriage of hypotheses and experiments, the latter being employed just to "to confirm or refute hypothetical anticipations of nature" (Whewell, 1840, p.504). It is then deduction, rather than induction, the only form of reasoning (Bernard, 1865). Since late nineteenth century, a vast group of scholars were became involved in developing an epistemology according to which theories emanate from a process of hypothesizing (e.g. Hertz, 1894; Enriques 1926; Pearson, 1911; Duhem, 1914; von Mises, 1933. See also Claparède, 1933, on the genesis of hypothesis). This led to Popper's hypothetico-deductive model and to the idea that creativity, involved in the production of hypotheses, plays an outstanding role in science. Next step was then to define scientific creativity. A possible perspective is to view hypotheses as the result of *genius* (Naville, 1880). In this light, the act of conceiving a theory is due to intuition and fertility of imagination (Whewell, 1840; Jevons, 1877; Pearson, 1911), ideas originate from a flash of lightning and no rule exists for discovery (Bernard, 1865). The hypothetico-deductive method is actually strictly connected with the idea that no logical path can be taken for formulating hypotheses (Einstein & Infeld, 1938), that hypotheses depend on an intuition *à la* Bergson, i.e. on an irrational element based on a sympathetic understanding of experience (Popper, 1959).[17] In other words, axioms, premises, assumptions, conjectures are the result of an *alogical* process based on intuition and inspiration (Medawar, 1967, 1969). This *genius* perspective on scientific discovery traces back to Galton (1869, 1874) and see creativity as a rare phenomenon (Johnson-Laird, 1993) that consists of nonrational components such as interest, motivation, inventiveness (see Csikszentmihalyi, 1988, 1996). It is defined by several features such as: A high intellectual ability (Galton, 1869; Simonton, 2002, 2004a); an endowment of "extensive chains of images … mutual contact of widely different trains of ideas … and richer connection of the contents of memory (Mach, 1896, p.167) or, in other terms, associative richness (Mednick, 1962; Feist & Gorman, 1998); an unusual openness to experience and divergent thinking (McRae, 1987; King, McKee Walker & Broyles, 1996); a defocused attention (Kasof, 1997); a so-called *Janusian* thinking (Rothenberg, 1996). And it is also correlated with some other features such as versatility (Simon, 1974; Hargens, 1978), independence of judgment, self-confidence, attraction to complexity (Barron & Harrington, 1981), willingness to overcome obstacles, willingness to take sensible risks, tolerance for ambiguity, self-efficacy, willingness to stand up conventions (see Sternberg & Lubart, 1995, 1996), mental attitudes and aesthetic inclination (Koyré, 1955; Panofsky, 1956; Wechsler, 1978), tastes and passions (Smith, 1999), philosophical perspective **(**Koyré, 1959), even psychopathological inclination (Post, 1994; Ludwig, 1995). Contrasting this outlook, some scholars dismiss the 'myths' of genius (Weisberg, 1993) and claim that creativity is analogous to any other guise of problem solving, which is a process governed by logical procedures (Newell, Shaw & Simon, 1958; Simon, Newell & Shaw, 1962; Simon, 1973, 1977, 1988). As a result, discoveries may originate from heuristics similar to those implemented in the solutions of problems. Rediscoveries of scientific laws are provided (Langley et al., 1987; Shrager & Langley, 1990) as well as genuine discoveries (see Muggleton, King & Sternberg, 1992, for prediction of protein secondary structure), which show the usefulness of logic and artificial intelligence, although, admittedly, they do not diminish the role of human minds, which necessarily feed the machine with a background knowledge (i.e. heuristics) to operate on (Gillies, 1996). A third view dispenses with the dichotomy logic-illogic: Chance superintends creativity (Mach, 1896), since the latter's products are unpredictable and unexpected events. They materialize as automatic or involuntary

[17] See Antiseri (1989) for a beautiful and pellucid survey on the origins of contemporary epistemology and the relationships between hypotheses and creative drives.

illuminations popping up abruptly, even when the scientist is engaged in mundane behavior (Platt & Baker, 1931), and are based on blind variations (Campbell, 1960) and serendipitous events (Cannon, 1940; Shapiro, 1986; Roberts, 1989), whose occurrences can even set the course of scientific history in new directions (Kantorovich & Ne'eman, 1989). A four perspective maintains that creative products as discoveries and inventions are the inevitable results of the *zeitgeist*, that is they are strictly dependent on the sociocultural milieu the scientist is immersed in (Merton, 1961a), as multiple discoveries would testify (Merton, 1961b, Lamb & Easton, 1984). While this perspective seems to have no connection with psychological-driven factors, Simonton (2002) shows that "Not only may sociocultural influences operate by means of psychological processes, but also psychological processes may to some extent shape those very influences [which means that] both the zeitgeist and the ortgeist may be partly a function of the human psyche" (p.432); also, creativity "exhibits tremendous cross-sectional variation even for those who are active in the exact same zeitgeist and ortgeist [so that] some sociocultural phenomena might be the causal offshoot of underlying psychological mechanisms" (*ibidem*, p.433). Furthermore, zeitgeist and creativity are often negatively correlated in that creativity calls for "independence or autonomy in order to avoid the constraints of conventional views" (Simonton, 2003, p.484), so it is worth underlining "the importance of a scientist not being completely immersed in the prevailing zeitgeist" (Simonton, 1988, p.199).

Whatever the intellectual stance one is willing to espouse and whether psychology is used as a science (Simonton, 2004b) or as a metascience (Simonton, 1988; Gholson et al., 1989), it is evident that psychology plays a major role in function *(i)* in both senses: In the former sense, psychology is deeply involved in understanding how human minds work and creates (new) ideas; in the latter sense psychology is a science of science, devoted to understanding the determinants of scientific discoveries:

> Without the addition of a psychological dimension … it is impossible to appreciate fully the essence of the scientific imagination. And without this appreciation, the origins of science, the emergence of new ideas about natural phenomena, must escape our grasp. Psychology is mandatory if we wish to comprehend the scientific genius as the generator of science. (Simonton, 1988, p.200)

While history, philosophy, sociology of science chronologically precede psychology of science as metasciences studying the genesis of scientific discovery, nevertheless "Of the four major metasciences mentioned … the psychology of science has the deepest commitment to understanding scientific creativity" (Simonton, 2004a, p.14). And it is in the field of psychology of science that a new perspective has emerged about scientific discovery: It smoothes over conflicts among chance, genius, logic and zeitgeist, providing us with their integration and offering a unified view of scientific creativity (Simonton, 2004), which is subsumed under a Darwinian theory of creativity (Simonton, 1999) and regards discoveries and hypotheses in science as the output of a constrained stochastic genius (Simonton, 2003).[18]

Until recently, function *(i)* was the only role psychologists were entitled to play in epistemology and the context of justification was thought to pertain to *logic* only. Falsification and corroboration have to do with the logical consequences of a given theory. In particular, the theory is tested against nature, so to say, to ascertain whether empirical data do or do not conform to the conclusions drawn (I name it *falsification by empirical testing*). Deductive logic is implicated in this process and this kind of falsification is the epistemological equivalent of the deductive rule called *modus tollendo tollens* (see Popper, 1959). If empirical data do not match the logical consequences of a set of assumptions, then the latter are to be refuted; formally, letting H=set of hypotheses and D=empirical data, we have

[18] A beautiful account of how genius, chance, logic, and sociocultural elements interact in the formulation of scientific hypotheses may be gleaned from Watson's (1981) autobiographical reconstruction of the discovery of DNA's double helix.

$$((H \rightarrow D) \wedge (\text{not-}D)) \rightarrow (\text{not-}H).$$

In words, if D is derivable from H and D is false, then H also is false.

The rise of social and economic sciences in the last century have given psychology a second unexpected role in the very domain of justification of theories: The use of *modus tollendo tollens* has here to do with mismatch between actual behavior (nature) and logically deducted behavior (logical consequences of the theory), and as long as economic sciences are concerned with human behavior, psychology is now entitled to serve function *(ii)* and decree the falsification by empirical testing of a given theory or model. In addition, psychologists' concepts, tools, knowledge enrich our understanding of theories and human nature as well and provide us with possible explanations about behaviors, biases, and with new insights and ideas for further research and for the betterment of those theories and models. While until some decades ago economists ignored the findings of cognitive and behavioral psychology based on experimental research, the situation has tremendously changed in the recent years:

> Once an esoteric specialty of a small cadre of cognitive psychologists, experimental research on judgment and choice has now become psychology's leading intellectual export to the social sciences as well as to a host of applied fields. The influence of this research program has spread (critics might say "metastasized") into such diverse domains as public opinion, international relations, finance, organizational behavior, marketing, medical diagnosis, and the law. (Tetlock, 2002, p.451).

> We think it is simply unwise, and inefficient, to do economics without paying some attention to good psychology. (Camerer, 2004).

The success psychology currently encounters in various fields and the respect it has gained in economics are accredited, among other things, by the 2002 Nobel Prize to Professor Kahneman. The influence of psychology is epitomized by the heuristics-and-biases program (Kahneman, Slovic & Tversky, 1982; Kahneman & Tversky, 1996; Gilovich, Griffin & Kahneman, 2002), which studies deviations of actual behavior from rational behavior of normative paradigms. It is widely accepted that such discrepancies (often called "biases" or "cognitive illusions") show that human minds' reasoning is not always rational because the resulting choice behavior is nonoptimal (but see Gigerenzer & Murray, 1987; Cosmides & Tooby, 1994a, 1994b, 1996; Gigerenzer, Todd & the ABC Research Group, 1999; Gigerenzer, 2000; Gigerenzer & Selten, 2001, for an alternative account of such phenomena and the resulting notion of ecological rationality). For example, it is commonplace that expected utility (von Neumann & Morgenstern, 1947) and subjective expected utility (Savage, 1954) are not valid as a description of how people make decisions. Possible explanations are then looked for and new models are proposed and studied in order to provide a rationale for the vast empirical data collected in recent decades (e.g. Kahneman & Tversky, 1979; Bell, 1982; Loomes & Sugden, 1982; Machina, 1982, 1987; Crawford, 1990; Hey, 1991; Tversky & Kahneman, 1992; Wu & Gonzalez 1999; Fox & See, 2003; see also Wu, Zhang & Gonzalez, 2004, for a review). As another example, it is highly recognized in the literature the systematic departure from normatively correct Bayesian reasoning (e.g. Kahneman & Tversky, 1973; Bar-Hillel, 1983; Shafir, Smith & Osherson, 1990; Kahneman & Tversky, 1996). An entire line of research is devoted to trying to explain the nonbayesian reasoning of individuals, and numerous contributions have appeared for recommending and providing *debiasing* methods (e.g. Arkes et al., 1987; Russo & Schoemaker, 1989; Plous, 1993. See Gigerenzer & Hoffrage, 1995; Hertwig & Gigerenzer, 1999; Gigerenzer, 2000; Gigerenzer, 2002, for the frequentist approach; see Politzer, 1986; Macchi, 1995, 2003; Mosconi & Macchi, 2001, for the pragmatic approach.[19] See also Mellers, Hertwig & Kahneman, 2001, for a heuristics-and-biases/frequentist adversarial

[19] As for the frequentist and pragmatic approaches, it is debatable whether they provide debiasing methods or, rather, provide evidence that people are not biased at all.

collaboration).[20] The success of the heuristics-and-biases program spreads over various disciplines and enables scholars to invalidate classical models of rationality as descriptive accounts of human behavior, helps find explanations for the existence of biases, suggests new lines of research and directions for debiasing people and/or replacing the falsified models with more appropriate ones. For example, researches in economic, financial, managerial decision-making and in behavioral decision theory directly stem from the heuristics-and-biases program and include a broad range of decision processes: Various anomalies are documented in intertemporal choices (Tversky, Slovic & Kahneman, 1990; Loewenstein & Prelec, 1992) such as misvaluation of the exponential function which underlies the discount utility model (Benzion, Shachmurove & Jagil, 2004); the economic principle of fungibility is violated (Thaler, 1999a); infringement of rationality occurs in managerial decision making, not only in individual but also in organizational judgment such as multiparty decisions where a negotiation takes place, and negotiation effectiveness is said to be improved by improving the judgmental abilities of negotiators (Bazerman, 2002. See also Bazerman, 2005); violations of standard finance theory's results is reported regarding capital structure decisions (Graham & Harvey, 2001, 2002); managers' assessments of real options are shown to deviate from normative models (Howell and Jägle, 1997); nonsystematic approach for real options evaluation is found in organizations (Busby and Pitts, 1997); failure of real options analysis in attracting decision makers is pointed out, and suggestions are provided to fill the gap between practice and normative theory (Lander & Pinches, 1998); biases in evaluations of put and call options are discovered (Miller & Shapira, 2004); the use of the NPV model is challenged by the finding that people use hurdle rates (see references in section 4); entrepreneurs' susceptibility to costly cognitive biases is highlighted (Palich & Bagby, 1995; Busenitz & Barney, 1997; Baron, 1998, 2000, 2001); every-day life decision processes are analyzed and suggestions for overcoming biases are provided (Hammond, Keeney & Raiffa, 1999); in general, the significance of economic agents' psychology is stressed (Elster, 1988; Rabin, 1998; Hirshleifer, 2001) and new branches of research are originated, such as behavioral economics (Camerer & Loewenstein, 2002; Daniel, Hirshleifer & Teoh, 2002; Camerer, Loewenstein & Rabin, 2003; Smith, 2005) and behavioral finance (De Bondt & Thaler, 1985; Thaler, 1993, 1999b; Glaser, Nöth & Weber, 2004).[21]

9. Psychology and the falsification of models from a normative point of view

The aforementioned researches exemplify the falsification-by-empirical-testing role proper to psychology. Falsification by empirical testing resides in the descriptive power of psychology: It is just the emphasis on description, peculiar to psychology, along with its careful analyses, that enables scholars to disclose possible mismatches between *actual* behavior and *rational* behavior intrinsic in normatively accepted paradigms. The dichotomy actual/rational just pertains to function *(ii)*, that is the invalidation of social and economic models in their *descriptive* contents. Yet, as long as economic sciences are concerned with the *rational* economic agent's behavior, the *normative* validity of decision models is currently unchallenged: The models continue to reach consensus among scholars and to prescribe the behavior a decision maker should rationally adopt in decision-making processes (but see Simon, 1955, 1956; Nozick, 1969, 1993; Cohen, 1981; Klein, 1993, for normative attacks to rational paradigms), and *normative justification* is still considered only a logic's affair. Normative justification in (social and) economic sciences has to do with mismatch between behavior logically deducted from the model and standard principles of rationality such as unambiguity, applicability, consistency. In the light of what we have seen in Sections 5 to 8 one is tempted to wonder whether psychology can extend its influence to the *normative* side of a model,

[20] Cognitive fallacies have been found in the conditional reasoning of human beings as well (see Wason, 1966, 1968; Evans, Newstead & Byrne, 1993; Manktelow, 1999; Politzer, 2003) but, as far as I know, this finding has not been exported yet to the economic sciences as it would perhaps deserve, and is confined to the field of psychology of reasoning.

[21] Heuristics-and-biases program is just one of several approaches offered by psychologists in the field of decision-making. Other ones are: social judgment theory (e.g. Cooksey, 1996), information integration theory (e.g. Phelps & Shanteau, 1978), image theory (e.g. Beach, 1990), fast and frugal heuristics (e.g. Gigerenzer, Todd & the ABC Research Group, 1999), naturalistic decision making (e.g. Klein et al., 1993), expert decision making (e.g. Krogstad, Ettenson & Shanteau, 1984; Stewart, Roebber & Bosart, 1997).

i.e. whether it is possible to add function *(iii)* for psychology, i.e. the study of normative-implied behaviors and the search for possible mismatch between such behaviors and rational prerequisites of consistency, applicability, non-ambiguity. The kind of falsification implied by this function has to do with the internal consistency of the model (I name it *falsification by internal inconsistency*): From an idea (a hypothesis, a theory) conclusions are drawn by means of logical deduction; such conclusions are then compared one another or with other relevant statements so as to find compatibility or incompatibility; that is, if two or more conclusions drawn from the assumptions are incompatible, then assumptions are to be rejected. In logical terms, *modus tollendo tollens* is implicated again: Letting C=C1 $\wedge$ C2 be the conjunction of two incompatible consequences of the assumptions (so that not-C is true), we have

$$((H \rightarrow C) \wedge \text{(not-C)}) \rightarrow \text{(not-H)}.$$

In words, if C1 and C2 are both derivable from H and C1 is incompatible with C2, then H is false. This paper fosters the idea that a decision-making model may be found to be *normatively* invalid (or at least *normatively* defective) on the grounds of a psychological perspective. In the first part of this paper we have actually seen that the very use of psychology have led us to find out freakish choice behaviors, distortions of the original decision process, logical fallacies, behavioral biases in the NPV+ER methodology. The features of ambiguity, inapplicability, inconsistency, frame-dependence we have discovered in this decision model may all be subsumed under the above described modus tollens,[22] so its normative validity is now challenged. This paper then reports an example of falsification by internal inconsistency obtained via a psychological analysis of a decision model. Inductively, a cautious generalization is here endorsed, since psychology may offer us a profound understanding of the psychology of the normative-minded decision maker, which formal optimization theory is not able to do, so that unexpected behaviors may be discovered even in the immaculate realm of optimization. If this challenging enterprise is undertaken, one should try to approach decision models as models of behavior rather than as models of mathematical optimization; only, one just has to shift from observation of ordinary people's behaviors to observation of behaviors of decision makers that normatively adhere to the decision model under examination. This epistemological strategy is equivalently rephrased by saying that the psychology's descriptive power of falsification is pointed toward normative-minded decision makers or, which is the same, falsification by internal inconsistency is realized by making use of the very falsification by empirical testing, but the data are in this case collected among normative-minded people. In this paper I have reoriented perspective toward NPV-minded people's behaviors and have searched in them deviations from requirements of consistency, applicability, non-ambiguity. I have relied on devices and principles taken from the psychologist's toolbox, testing decision makers and scrutinizing their implied behaviors. When observation of the NPV-minded decision makers is favored and the analysis of the behavioral content of the model is privileged, flaws and biases spring up; these fallacies cast doubts on the reliability of the NPV model as a *normative* paradigm.

To test normative-minded people, I have performed *thought experiments*. As known, to perform thought experiments means "to reason about an imaginary scenario with the aim of confirming or disconfirming some hypothesis or theory" (Gendler, 2002). They provide experiential understanding of an idea or concept with no real experiment and have "enormous influence and importance in the sciences [since they] can teach us something new about the world, even though we have no new data, by helping us to reconceptualize the world in a better way" (Brown, 2002). Thought experiments are able to "direct the reader's attention to inadequacies in her conceptual scheme that she herself recognizes immediately, as soon as they are pointed out to her" (Gendler, 1998, p.413) and for this fact they are formidable tools of arguments.[23] In our

[22] For example, as for the inapplicability, pick H="the NPV+ER methodology is followed", C1="the ER tenet is followed", C2="the ER tenet is not followed". H implies both C1 and C2 so H is to be rejected.

[23] It is debated whether a thought experiment is just a sound argument disguised in heuristically appealing garments (Norton, 1996) or enables us to go beyond the data and acquire *a priori* knowledge (Brown, 1991) or, rather, derives its justificatory power from "the way in which it invites the reader's constructive

normative-minded people behavior is perfectly predictable, and we know how they behave in each circumstance, so we do not need to test real people. Experiments 1, 2, and 3 previously presented are just experiments-in-thought (Gendler, 1998), i.e. "real experiments carried out in thinking" (Thomason, 1991, p.247).[24] Thence, they are *actual* experiments that mirror experiments performed with real-life participants. From these experiments fallacies of the model spring up easily. For example, take Experiment 2: Participants ask the experimenter which is the opportunity cost. The experimenters ask why such a piece of information is needed and participants evidently give an answer equivalent to the following one: "I am an NPV-minded investor so I *must* compare only alternatives which are equivalent in risk". It is straightforward from this answer and from the resulting choice behavior that fallacy *sub* f) arises. Experiment 3 is an even more striking example, as the contradiction is directly revealed by the answers.[25] However, we can indeed walk the usual route employed in experimental research, i.e. test *real* people. In this case, one takes a sample of previously selected normative-minded people, administers a task, collects results, discards the answers of false normative-minded people (i.e. answers of those who turn out to misapply the model), searches for biases in the remaining ones (the true normative-minded individuals). This classical way is just equivalent to performing thought experiments if the end is that of checking the normative validity of the decision model. While nothing prevents one from recruiting managers, financial analysts, MBA participants, business students, laymen and the like who are fervid normative-minded people, one has to cope with problems of: Choosing an appropriate sample, discarding false normative-minded decision makers, using statistical tools to corroborate hypotheses, avoiding misinterpretation of the task by participants and misinterpretation of the results by experimenters, solving debates about whether the experiment should be a between-subjects study or a within-subjects one, repeating experiments for further corroboration, and (possibly) spending money to recruit participants or to accomplish the tests. On the contrary, thought experiments of the kind used in this paper yield a significant methodological payoff: There is no concern about sample selection (since the sample coincide with the entire population); 100% of the participants report the same answer, so that no inferential statistics is needed; there is no need of rejecting answers of false normative-minded decision makers (there are only true normative-minded people); no misinterpretation is possible about people's asking for information and their consequent solving the task; no methodological problem whatsoever arises in the relationship between subject and experimenter; the experiments are costless; no theoretical issues about within- or between-subjects tests arise, no repetitions of experiments are needed; cases where experiments are technically difficult or even impossible (for whatever reason) are bypassed. We are then placed in a privileged position, as these thought experiments are just "limiting cases" of ordinary experiments: They achieve the same aim more easily and without being executed (Sorensen, 1992). Also, in our case, where normative analysis is at issue, thought experiments are more effective than real experiments and, in a certain sense, the former seem to be scientifically more "natural" than the latter.

To sum up, the use of psychology (via thought experiments on the psychological content of the model) has enabled us to come out with the *normative* invalidation of a classical decision model. This opens terrain for psychology to play a role in the philosophy of science as regards normative falsification of decision models and theories. If so, we will have to acknowledge a third epistemological function of psychology in addition to *(i)* and *(ii)* above: Normative falsification. A conclusive falsification of a decision model may therefore be realized, or some problems may be signaled that induce scholars to revisit or modify the model, or limit its scope of application. And if no biases are found, then this may be interpreted as an increase in the degree of corroboration of

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participation, depicts particulars in ways that make manifest practical knowledge, and describes an imaginary scenario wherein relevant features can be separated from those that are inessential to the question at issue." (Gendler, 1998, p.420).

[24] See Rescher (1991) and King (1991) for use of thought experiments in ancient and mediaeval times. For further reading, see Kuhn (1964), Horowitz and Massey (1991), Häggqvist (1996), McAllister (1996), Gendler (2000).

[25] It is perhaps worth noting that my thought experiments are just experiments of the same kind as those conceived in the heuristics-and-biases tradition; only, they are carried out in thinking.

the model. Furthermore, it is far too obvious that a psychological analysis of the normative content of a model may offer new insights and inspiration for a deeper understanding of the model and of the relations between normative-minded behavior and human behavior.

Concluding Remarks

Since "the classical theory does not tolerate the incomparability of oranges and apples [and] requires a complete ordering of pay-offs" (Simon, 1955, p.108) the NPV under uncertainty, as a maximizing model, "breaks down for lack of a complete ordering of the pay-offs" (p.109). To salvage it, the *equivalent-risk* tenet is introduced, but the decision maker is trapped in a cognitive illusion since the NPV model cannot avoid heterogeneous comparisons between oranges and apples, though the introduction of this tenet is just supposed to rule them out. This paper then shows that the normative NPV paradigm is biased and the NPV maximization rule breaks down just because of its self-inconsistency. We have encountered several fallacies and ambiguities, plus the RBIS bias and a framing bias, none of which is currently recognized in the literature. All these fallacies imply a distortion of the decision process, a solution based on a bizarre (to say the least) representation of the problem, and different behaviors depending on the way the problem is depicted. To unmask these biases, the psychologist's toolbox is necessarily retrieved: Experiments, analyses of behaviors, study of decision makers' lines of reasoning. It is just the recourse to the cognitive/behavioral implications of the model that enables one to show that the formal restriction in the set of alternatives is illegitimate and illusory. If the formalized versions (##)-(###)-(####) of the NPV maximization are retained with no further inquiry, neither ambiguities nor biases appear in the decision process. But to a deeper inspection of the psychological implications of that optimization processes biases and behavioral absurdities arise, as well as the factual and logical contradictions deriving from the artificial restriction of the set of alternatives: It is avowed that the set must be restricted (with no other justification than the inadequacy of the NPV when used under uncertainty) but in fact the set is not restricted at all. As a result, the equivalent-risk tenet is inapplicable.

This brings about the second aim of the paper, which is to intimate that psychology may play a role in the normative side of an optimization model designed for decision-making. To this end, one should reverse the usual practice in research, according to which the subjects of experiments are ordinary people. Replacing them with *normatively-optimizing* people boils down to shifting from the descriptive side of the model to the normative side. While a natural focus for research in decision-making consists in answering the question: "How well do ordinary people size up against well-defined normative benchmarks of rationality ...?" (Tetlock, 2002, p.452), in this work roles are inverted and the question is changed: How well do normatively-optimizing people size up against well-defined normative benchmarks of rationality (such as consistency, applicability, non-ambiguity)? The biases found in the NPV model should attract interest of economists and psychologists (as well as philosophers of science and mathematicians). As for psychologists, the significant roles they currently play in economic sciences may be enhanced and extended to normative falsification, which is quite a new perspective in the philosophy of science: At the very least, behavioral analyses of the normative content of decision models may play a distinctive role in capturing their practical, theoretical, and methodological features. As for economists, both advocates and critics of the model should find reasons for welcoming these results. The former are now able to see that the behavior of their NPV-minded agents is cumbersome and freakish, and that they fall prey to self-inconsistency (self-deception) and framing effects. This should lead them to reconsider the model, either for emending it, or to limit its scope, or to definitely abandon it in favor of other models. The belittlers, who criticize the model by replacing it with their preferred ones, should find a more powerful reason for rejecting the NPV model, in the following sense: The objections here raised are not coming from outside the model (as it is done, for example, by upholders of options pricing models), but from the very inside. In actual fact, assumptions and consequences of the model are here accepted with no external criticism. A Trojan horse is used, since I respectfully comply with the behavioral (and logical) consequences of the NPV paradigm: "Internal criticism as a strategic weapon is more powerful when successful that external criticism, since it takes the theoretical aims and situational constraints

of an adversary as given … internal criticism is the most powerful (since it takes a program on its own terms) and is often the most fruitful (since critics must fully understand the program being criticized). As such, internal criticism is the preferred form of criticism" (Caldwell, 1982, pp.249-50). Internal criticism is here put to use alongside thought experiments, which let us have unequivocal results. Nevertheless, should one prefer real participants and real experiments, one is free to perform them, *necessarily* finding the same results but with the addition of some problems regarding the interpretation of the task (by subjects) and of the results (by experimenters), as well as the selection of the sample and the possible presence of false normative-minded people.

Further research may be addressed to explaining the biases the NPV-minded decision makers incur. As a first attempt, it seems that such decision makers show a sort of *focussing effect* of the same type described by Legrenzi, Girotto & Johnson-Laird (1993). The subjects obeying the NPV paradigm neglect consideration of the available alternatives. They do focus on *one* alternative (an equal-risk one), but they overlook the fact that there are other alternatives at work in the decision process, some of which cannot be neglected without deviating from the model's prescriptions (it is worth noting that Experiment 1 in this paper mirrors the movie task of Legrenzi, Girotto & Johnson-Laird , 1993, p.54). While it is interesting to know whether the opportunity cost principle is ignored by *ordinary* people (Friedman & Neumann, 1980), it is also important to ascertain whether *NPV-minded* people ignore the opportunity cost principle. Or, to be more precise, to ascertain whether NPV-minded people ignore the opportunity *costs* principle: There are always more than one opportunity, more than one norm, more than one reference point, in financial decisions as well as in every-day life; and they are non-equivalent, whatever the meaning one attaches to 'non-equivalent'. Experiments could be carried out to fathom out whether NPV-minded people may be defocused (and therefore debiased) by a context where other alternatives are more visible (e.g. in Experiment 1 one may point out that the money received may alternatively be invested in one's own business or current investment). To this end, *real* experiments are indeed necessary and may fruitfully tell us whether NPV-biased people will be debiased (and so freed from the chains of the NPV model) or rather they will stick at their model, thus giving us insights about the degree of conventionalization (Poincaré, 1902) reached by the NPV paradigm in the (scientific and non-scientific) community.

Also, this paper aims at intimating that decision processes should not be distorted: If the decision process is, literally, "do the project or not" then one should not compel decision makers to turn to "do the project or do the best-equivalent-risk alternative", since the decision maker has discarded the latter a priori (otherwise it would not be a to-do-or-not-to-do decision process) for reasons that the NPV is evidently not able to manage (e.g. the decision maker has accomplished a prescreening of alternatives, based on: Consistency with corporate strategy, need of managerial or financial flexibility, use of multicriteria decision-making tools, of personal values and beliefs, of cultural and emotional variables etc.). Decision makers may be helped in solving the decision process, but they should be left free to decide what the decision alternatives are. In contrast, the NPV model does not aim at solving decision problems as decision makers *have actually* defined them, but at solving decision problems as decision makers *should have "rationally"* defined them.

Whether the NPV may be somehow healed from this point of view (by changing interpretation or by making use of it in conjunction with other different measures) remains a question that may in future be answered. Other questions also arise. Leaving aside violation of the ER tenet, the normative-minded decision makers show behaviors that one could define freakish, awkward, bizarre, unreasonable, so to say (e.g. see the Guido box). How should one consider such behaviors? What is their status in terms of rationality? Could we reject NPV only on the basis of these cumbersome behaviors? Moreover, there are questions dealing with the relations normative-minded people bear to ordinary decision makers. As seen, ordinary decision makers seem to be biased against NPV-minded decision makers, but, likewise, NPV-minded decision makers are biased against requirements of applicability, consistency, non-ambiguity. Does this imply that hurdle-rate-minded decision makers are *a fortiori* biased? What biases do they show? Or, rather, do they somehow offset the NPV's biases? And if so, how can they?

In all this, the usefulness of a psychological perspective should now be evident. It may be the case that the NPV must be abandoned in favor of other models, or that it should be reinterpreted

in some other sense, or that it needs to be applied along with other models, or that its scope of application should be confined to particular situations. Whatever the path one is willing to follow, a psychological perspective throws a new light on the model and on its implied behavior, as well as on its implied cognitive content.

Psychology has undermined the classical NPV rule. Although a single instance is presented, this work encourages a generalization and suggests a methodology: Using internal criticism and thought experiments (among other tools) psychology may play a significant role in the normative side of decision models. Cosmides and Tooby (1994a) complain that "psychologists are called in only to provide second-order corrections to economic theory" (p.327). Hopefully, this paper indicates that psychologists may be called in to provide first-order corrections as well, to the benefit of economics and its (and our) decision makers.

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