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UNIVERSITÉ DE MONTRÉAL

A MULTIDISCIPLINARY PERSPECTIVE ABOUT DECISION MAKING UNDER UNCERTAIN AND RISKY SITUATIONS: AN APPLICATION TO ENTREPRENEURSHIP

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DEDICATION

To all of my own, family, cousins, childhood and adulthood friends

To all of my own, kind people I've met, people that know me well,

To all of my own, people I've lost sight of and touch with,

To all of my own, people that inhabit me

To you, as a reader (good luck!),

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It is momentous for me to mention my closest friends, my fellows from La Tour, spread all around the world but everyday supportive, inspiring, and heart-warming. I wound up by chance among them a decade ago, and since then everything I've lived and done has dwelt on their reliable and beneficial influence. Special note to Eléonore, Elida (often vising!). Benjamin, Paul and lately Boris, my neighbours in North America. In Montreal or Cambridge, dancing with the electronic Devil on the Old Port during winter, braving the waves at Cape Cod, warding off the

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Lucas & Clément, words fail me to say how wonderful a lot of my memories are thanks to you. My visits in France were always too short, but I cherished our little evenings trying to make up for lost time around food from Boccacio.

William was always orbiting around my entire stride in Montreal (or rather I was orbiting around the star), whether it be in Poly-Monde, PolyFinances or in CIRANO. Basically everywhere. It is staggering to think of what would have occurred if I had not crossed his path.

My epic journey in Polytechnique would not have been the same without my cherished family of Poly-Monde. I had to run to get a shirt for the interview, I missed the very first meeting, I was the sole "maudit français" of the crew, and navigating for an entire year from Montreal to Sydney harbour with such an outstanding company was the experience I sought and found in Polytechnique. Countless hours, words, reports, laughs, pictures, visits, not to mention celebrations... What a long and wonderful journey it has been!

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ponder sometimes how they managed to set that gigantic circular table at Moody's headquarters (among other things...).

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I'm very aware, humble and proud to have benefited from all the scientific knowledge I read over and over, inspiring and guiding my own path. Almost every day I encountered a new fascinating scientific story leaving me in awe, to the bane of my friends (I would tell them everything I found fascinating – basically everything). I conceived this work as an extensive production on the subject of risk and all its extensions. My desire was for this work to be very complete and accessible for anyone without a background on any of the subject it tackles. I delved into the early understanding of how the mind work, from Aristotle until neuro-imaging showing colourful kaleidoscopes of brain areas sparking as we make decisions facing risk. Today, entrepreneurship and financial risk-taking can be linked to genetic factors and psychological traits, and the list of cognitive bias impairing (or helping) our decision mechanisms is well documented. It is

flabbergasting how much there is to learn, and how much there is yet to discover. I think that all scientists crave for mystery and love not knowing. In that way I consider myself a very scientific person. This thesis is a product of all that I didn't know. I have done nothing but sitting on the shoulders of giants.

RÉSUMÉ

Ce projet est une étude exploratoire sur les comportements face au risque et la prise de décision dans des contextes d'incertitude. Nous souhaitons étudier plus particulièrement l'orientation entrepreneuriale d'étudiants provenant de différentes institutions académiques (principalement montréalaises) et utiliser différents outils de mesures existant dans la littérature et qui intègrent les multiples facettes de l'attitude face au risque.

Pour comprendre l'origine de l'attitude face au risque et ses variations, nous avons fait une revue de la littérature des différentes disciplines étudiant ce type de comportement (psychologie, neurologie, économie et finance) illustrée par des exemples relatifs à l'entrepreneuriat et la finance comportementale. Nous avons ensuite identifié plusieurs outils de mesure des comportements face au risque.

L'étude consiste à soumettre à une population d'étudiants et de jeunes diplômés un formulaire en ligne. Le formulaire est composé de questions avec des réponses à cocher sur une échelle de Likert et de questions à choix multiples de prise de décision dans un contexte de jeux d'économie expérimentale. L'originalité de ce projet est d'avoir consolidé plusieurs questionnaires existant dans la littérature et de les avoir intégrés dans un même formulaire pour pouvoir comparer les réponses, et donc la teneur des différents outils de mesure.

Nous mettons l'accent sur l'orientation entrepreneuriale des participants (que nous mesurons en utilisant un questionnaire établit dans la littérature), et nous cherchons à l'expliquer par le biais d'autres notions capturées par d'autres outils : le niveau d'optimisme, la recherche de nouveauté, la finance comportementale, etc.

Nous souhaitons analyser et comparer les différents outils dans le but de mettre en lumière ce qui pourrait expliquer la propension (ou non) à l'entrepreneuriat chez les étudiants.

C'est un sujet très important pour le Québec et pour les universités puisque l'entrepreneuriat joue plusieurs rôles [1], depuis l'incubation des innovations technologiques jusqu'aux développements économiques (performance et compétitivité, renouvellement de la structure industrielle) [3] et sociaux (création d'emploi, prospérité) [278]. Mieux comprendre permet de mieux mobiliser les efforts et diriger les solutions pour encourager et faciliter l'orientation entrepreneuriale.

L'étude menée auprès d'une population d'étudiants provenant de différentes institutions académiques (principalement montréalaises) (56 étudiants) suggère la présence de préférences au risque variant suivant les contextes (carrière, finance, santé). Les mesures de risque (ERG, risk-taking (EO), et FRT) sont corrélées à certains traits de caractères et ressources psychologiques mesurés par des outils expérimentaux provenant de différentes disciplines (psychologie, neurologie). Ces liens soulignent les accélérateurs et freins communs à l'attitude entrepreneuriale et l'attitude face au risque : recherche de variété, dynamisme, réserve-inhibition, pessimisme, et impulsivité. Les données récoltées au moyen du formulaire en ligne ne révèlent pas de différence remarquable dans l'attitude face au risque dépendamment du genre; en revanche les participants masculins se distinguent par un intérêt pour l'entrepreneuriat plus marqué, et ce sont aussi les sujets masculins qui auront tendance a déjà avoir une idée ou un projet qu'ils souhaitent développer dans un futur proche.

ABSTRACT

This project is an exploratory study on behaviour copying with risk and decision-making in uncertainty contexts. It notably tackles the question of entrepreneurship and entrepreneurial decision among students from different academic institutions (mainly from Montreal), and makes use of several different measurement tools stemming from a wide range of literature and describing the multiple aspects of behaviour when facing risk.

To understand the origin of behaviour facing risk and its variations, we investigated the literature in different disciplines studying this type of behaviour (psychology, neurology, economics and finance) and illustrated with examples relatives to entrepreneurship and behavioural finance. Then we elicited several tools measuring the extent and specificities of behaviours.

The study consists in subjecting a population of students and recent graduates an online survey of our design. The survey is mostly composed of easy questions and statements that have to be rated by the respondents using a Likert scale, as well as multiple-choice questionnaire following the concept of investment games (experimental economics). The originality of this project is that it amalgamates several questionnaires from an expanse literature, and by doing so mixes several conceptions, ideas, and points of view on risk behaviour. Assembling the different questionnaires into one survey allows comparing the answers and highlights the differences and similarities of the disciplines, giving a better complete picture.

We emphasise entrepreneurial orientation of the respondents (that we measure using a tool from the literature) and attempt to explain and intertwine it by way of the other notions and attitudes elicited with the other tools, namely: optimism level, novelty-seeking, risk aversion measured in behavioural finance, etc.

We aim at analysing and comparing the different proxies in order to highlight what could explain inclination or predisposition towards entrepreneurship.

Understanding the links between the numerous expressions of risky behaviour, as well as what could be the driving reasons behind entrepreneurial orientation is an essential subject for Québec and its universities. Indeed entrepreneurship has many important roles [1], from the incubation of technological innovation to economic developments (performance, competitively, renewal of the industrial environment) [3], as well as social developments (job creation, prosperity) [278]. A

better understanding allows directing the efforts and solutions to support and facilitate the entrepreneurial orientation.

The study conducted within a population of students from different academic institutions (mainly from Montreal) (56 students) suggests the presence of risk-preferences varying depending on the context (career, finance, health). The measures of risk (ERF, risk-taking (EO), and FRT) are correlated to particular personality traits and psychological resources measures via experimental tools stemming from several domains of science (psychology, neurology). Such links highlight the common catalysts and impediments to entrepreneurial attitude and risk-attitude: variety-seeking, pro-activeness, harm-avoidance, neuroticism, impulsiveness. The data elicited through the online survey do not indicate noteworthy differences of risk-preferences depending on gender; however male respondents stand out by expressing a higher interest for entrepreneurship, and they are also the one incline to already have an idea or a project in its inception in the short term.

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LIST OF ACRONYMS AND ABBREVIATIONS

5HT	Serotonin receptors
ACC	Anterior cingulate cortex
AI	Anterior insula
BF	Behavioural finance
BT	Balls and tables game
CAPM	Capital asset pricing model
CDS	Credit default swap
CE	Certain equivalent
DA	Dopamine
DAT	Dopamine active transporter
DRC	Daily risk compensation
DRD1-5	Dopamine receptor D1-5
EMH	Efficient market hypothesis
EO	Entrepreneurial orientation
EUT	Expected utility theory
FRC	Financial risk compensation
FRT	Financial risk-taking
GFC	Global financial crisis
HA	Harm-avoidance
HRC	Health risk compensation
IG	Investment game
IPIP	International Personality Item Pool
MPT	Modern portfolio theory
MRI	Magnetic resonance imaging
Nacc	Nucleus accumbens
NS	Novelty-seeking
OFC	Orbitofrontal cortex
OPT	Optimism
PFC	Prefrontal cortex
PRC	Pecuniary risk compensation
RA	Rational agent
RC	Risk compensation
RSP	Retirement savings plan game
SERT	Serotonin transporter
SME	Stock market entry game
SNP	Single-nucleotide polymorphism
TCI	Temperament and Character Inventory
TE	Triple envelope game

CHAPTER 1 INTRODUCTION & CONTEXTUALISATION

1.1 Preamble

In this project, we are interested in the domain of decision-making in risky situation (involving uncertainty), and especially in the domain of entrepreneurship which is a trait of character in some extent linked to risky behaviour [1]. We are also interested in the different measurement tools that are used as proxy for risky behaviour in various major disciplines (psychology, neurology, finance).

Indeed, each scientific discipline developed its own notion of risk, thus considering risk and responsive attitudes to risk differently, which resulted in diverse methods of evaluation. For instance, the relatively new field of study of behavioural finance borrows and develops multiple measurement tools, and often the lack of reproducibility, convergence or divergence of the results (because of the numerous different tools and notions of risk) is pointed at (refer to section 1.2.5). Are all those notions of risk helping to better define risky behaviour, refining analyses and building better models? Or is the picture scientists paint nothing but blurrier?

This is the problem we tackle. Also, we aim at exploring the different notions of risk and using the different tools associated to better understand the aspirations and traits of character leading to entrepreneurship paths.

In the 18th century, Cantillon defined the entrepreneur as a risk-taker, mobilising resources to explore opportunities and uncertainty, aiming at obtaining and maximising a financial gain. Since then, several definitions of entrepreneurs and entrepreneurship have evolved. Entrepreneurship is about taking risk, and an entrepreneur gambles its career and its financial security to take risk in the name of an idea [47] [261] [262] [263]. Schumpeter defined entrepreneurs as individuals who exploit market opportunity through technical and organisational innovation [264].

> Schumpeter's original theory develops the notion of the entrepreneur as a “lone hero” with exceptional creative ability, who overcomes all barriers to innovation in order to bring discontinuous “new combinations” to fruition. The Schumpeterian entrepreneur is a solitary figure endowed with pioneering vision, imaginative foresight and extraordinary leadership skills [265].

Thereafter, a rising focus on the opportunity side of the coin [266] [267] was developed. Then studies turned towards another impactful element of entrepreneurship, and an emphasis has been

set on the cultural factors that catalyse or on the contrary halt entrepreneurial ambition [268] [269] [270].

Consequently, measuring the participant's likeness with the entrepreneurial ways sounds a relevant proxy to evaluate its risk affinity. Moreover, insofar as our study is carried out within students this subsection of the questionnaire allow eliciting interesting information for the universities about their students' yearnings towards this career path (which is often seen as the key to the bliss of economy's health, a brashing or exemplary path). Entrepreneurship plays an important role in economic development by incubating technological innovations, increasing economic efficiency, and creating new jobs [1].

The extant literature shows that people who engage in entrepreneurial activity are not randomly determined. As introduced in section 4.3, there is a wide panel of factors related with a higher disposition to commit in entrepreneurial career, including psychological traits such as the need for achievement [112], overconfidence [113], locus of control [114], optimism [115] [116], risk-taking propensity [117], as well as demographic factors such as education [247], employment status [271] , age [247], marital status [114], income [272] and financing (for instance through social circles [273] or family capital [274]), career experience [114], social ties [275] [276], and social skills [277].

To put things into context, the future of entrepreneurship in Canada and Quebec is of concern and has been the subject of several studies. Indeed, according to a survey conducted by Réseau des ingénieurs du Québec in 2010, only 6% of engineers are their company's owners [2]. Moreover, according to the report *Le renouvelement de l'entrepreneuriat au Québec: un regard sur 2013 et 2018*, lead and published in 2010 by Ministère de l'Économie, de l'Innovation et des Exportations du Québec, until 2018 entrepreneurship will decrease by 13.9% in Quebec, versus a decrease of 1.3% in Ontario and an increase of 5,3% in Canada all together [3]. More recently, Fondation de l'entrepreneurship, Caisse de dépôt et placement du Québec and l'Institut d'entrepreneuriat Banque Nationale HEC Montréal have released a report entitled *Indice Entrepreneurial Québécois 2015* [278], which draws a slightly different picture: according to the study, entrepreneurial spirit in Quebec is strengthening and is steering towards a more reassuring horizon with entrepreneurial intentions increasing by 19.1% and entrepreneurial procedures increasing by 9.1% during 2014. The trend is foreseen to keep on this stride. Eventually, Centre

Entrepreneuriat Poly-UdeM lists 30 Polytechnique's companies that went through the centre's incubator and almost the double with 56 companies for HEC (and 31 companies for UdeM) [279]. Nota bene: it is not mentioned the period concerned by those numbers, and the centre mentions a total of 190 companies born and raised within its wall since 1996. Those numbers are interesting and raise many interrogations. Why would so few engineers decide to become entrepreneurs? Can we find signs and reasons behind that trend in Quebec? Are those trends explained by budget or structural policies, or can behavioural tools be used to better explain the discrepancies in entrepreneurial orientation?

Such report and studies vary in their results and conclusion because they vary on their methodology. Indeed, a report will deal either with entrepreneurial intention or entrepreneurial action [278]. Intention will be measured with tools such as the one used in this research project: questions about intention, ideas, aspirations, or general feelings about entrepreneurship or traits and attributes related to such activities. Action will be measured by data regarding the number of jobs and companies created. Only because 6% of Quebec engineers are entrepreneurs does not mean there is a low entrepreneurial intention in the province. The desire to venture into entrepreneurial activities does not corroborate with actual attempts, whether those attempts become failures or successes. Numbers vary and highlight a gap between action and intention. It is interesting to question the entrepreneurial orientation of students to look for explanations.

The review of literature traces the historic and scientific development of the notions of risk, rationality, and cognition, using the prism of behavioural finance as an illustration, and analysing when possible the case of entrepreneurship. In a nutshell, we use the innovative domain of behavioural finance to illustrate the most cutting edge research on the subject of risk, and take stock of the situation regarding the methods and tools of evaluation. Following the development of behavioural finance and the numerous scientific branches supplying it, we understand that risk and decision-making are complex notions intertwining manifold mechanisms.

In our study, we submitted students of several academic institutions of Montreal to a survey consisting of various risky behaviour evaluation tools taken from different disciplines, and compare them in order to lift the veil of their similarities, differences and complementarities (chapters 6 & 7). This analysis will help to better understand the nature of entrepreneurial

orientation among students. All the previous interrogations lead to the exploration of the dedicated literature, in order to better understand the subtleties and the complexity of the subject.

The thesis unfolds according to this outline:

- Chapter 2 introduces the notion of risk and the evolution of this notion, as well as the mean of calculating it and asserting the best option in a risky situation; then it tackles the psychology principles behind the notion of risk, and sheds light on the subjectivity and the cognitive biases impairing the decision-making mechanisms.
- Chapter 3 delves into the brain as throne of our thought and processes in order to draw a map of the regions committed in such mechanisms; then it explains the language of biochemistry taking place in the brain and reveals the role of particular molecules involved in decision and cognition especially related to risk; eventually it presents progress taking steps in the domain of genetics, considering genes as the blueprint on which the brain and its mechanisms are built.
- Chapter 4 is a synthesis of the review of literature, preceding the questions of research and statement of hypotheses.
- Chapter 5 describes in detail the design and modus operandi of the experiment.
- Chapter 6 is dedicated to data analysis, before the discussion and recommendations in chapter 7.

As a contextualisation, the next section tackles decision-making in finance and unveils the principles of behavioural finance and rationality.

1.2 Putting an emphasis on human irrational traits in decision-making: from Market Efficiency to Behavioural finance

This section aims at highlighting the significance of the behavioural aspect of decision-making through the example of the field of study of behavioural finance.

1.2.1 The dawn of homo economicus

As of today, neoclassical economics dominates microeconomics, the domain of the behaviour of individuals and firms in making decisions regarding the allocation of limited resources. Together with Keynesian economics, they constitute the neoclassical synthesis which dominates mainstream economics and finance [4].

1.2.1.1 Keynesian economics

Originating in the aftermaths the 1930s' Great Slump, *The General Theory of Employment, Interest and Money* was published in 1936. Keynes's theory overturned the standard thoughts of the time and brought about a greater awareness of structural inadequacies in economics: for instance, problems such as unemployment were viewed as a result of moral deficiencies (e.g. laziness), whereas according the Keynes they rather were resulting from imbalances in demand and whether the economy was expanding or contracting [5]. Keynes underpinned that since there is no guarantee that the goods produced by workers would be met with demand, unemployment is a natural and expected consequence (especially in the event of an economy undergoing contraction). Keynesian economics served as the standard economic model in the developed nations during the latter part of the Great Depression until the mid-1970s [6]. Although it lost influence following the oil shock and resulting stagflation of the 1970s, the advent of the financial crisis begun in 2007 caused resurgence of Keynesian thought, especially on the important ideas he put forth around the impact of behaviour, which were virtually entirely put aside (refer to section 1.2.4).

1.2.1.2 Neoclassical economics

Based on the works of Adam Smith and David Ricardo in the 18th and 19th centuries, classical economics dealt with value and distribution theories (e.g. the paradox of *value in use* versus *value*

in exchange). Following economists then included the notion of the *perceived* value of a good explained by the usefulness or utility of that good relative to the consumer (refer to section 2.1). The last step to neoclassical economics was the introduction of the notion of marginalism, the fact that economic decisions are made based on margins, which explains discrepancies in the values of goods and service.

Neoclassical economics rests on three assumptions: people have rational preferences between outcomes that can be identified and associated with values; individuals maximize utility and firms maximize profits; people act independently on the basis of full and relevant information [7]. Those three assumptions served as foundation for the development of a wide spectrum of principles, mechanisms, models and paradigms, which have ruled finance until today. Most notably are among them:

- Modern portfolio theory (MPT) -built on the mean-variance model developed by Markowitz which states the allocation of funds in a portfolio is based solely on expected return (means) and risk expressed as standard deviation (variance)- assisting the selection of securities in order to compose balanced portfolios [8];
- Asset pricing strictly follows the rules of risk-based mathematic models such as the capital asset pricing model (CAPM) [9], as well as other similar frameworks;
- General Equilibrium Theory (on the behaviour of prices, supply and demand) [10];
- The efficient market hypothesis (EMH), which avouches that financial markets are informationally efficient, i-e all products and assets prices fully reflect all available information [11];

At their very core, these financial concepts are all derived from the cornerstone notion of investor rationality, or one's capacity to make decisions assuring the highest benefits and satisfaction by following a logical and prudent thinking [12]. The evolution of economics and financial theories is derived from the grand assumption that all the actors, decision-makers and investors are rational: they will always make the right decision, which is the more advantageous to them, always maximising their gains and minimising their risk. From this subjective appreciation shared by numerous domains of decision-making stem the buds of a lot of problems and inaccuracies in decision-making and it inserts important factors allowing for dissonance.

1.2.2 Bias of rationality

Neoclassical economics is sometimes criticised for having a normative bias meaning it does not focus on explaining actual economies but instead on describing "ideal economies" [13], for instance in which *Pareto efficiency* applies (viz. it is impossible to make any one individual or entity better off without making at least one individual or entity worse off). The assumption that individuals act rationally may be viewed as ignoring important aspects of human behaviour: many economists consider the *homo economicus* to be quite different from real people and have criticised this model, sometimes caustically.

> The hedonistic conception of man is that of a lightning calculator of pleasures and pains, who oscillates like a homogenous globule of desire of happiness under the impulse of stimuli that shift him about the area, but leave him intact. He has neither antecedent nor consequence. He is an isolated, definitive human datum.... Self-imposed in elemental space, he spins symmetrically about his own spiritual axis.... The hedonistic man is not a prime mover. He is not the seat of a process of living. [14]

In general, allegedly overly unrealistic assumptions such as rationality or Equilibrium Theory are the most common criticisms towards neoclassical economics and models of decision-making. It is also often seen as relying too heavily on complex mathematical models without enough regard to whether they genuinely describe the real economy. The endeavours to explain modern finance and economy on the grounds of mathematical model (or models) are seen as unrealistic. A renowned reply to this criticism is Friedman's claim that "theories should be judged by their ability to predict events rather than by the realism of their assumptions" [15].

Along with the development and expansion of market finance and the overall satisfactory results of the developed and refined models, the hypothesis of the unbiased rationality of the actors was overall left outstanding and unresolved, and was not even reassessed when major crises happened [16]. Furthermore, even by putting aside the major economic crises (Dot-com bubble, GFC) the assumption of rationality in decision-making leaves some facts hollow of explanation.

1.2.3 The evidence of flaws in finance and the relevance of behavioural finance

Saunders documents that the NYSE stock market tends to earn positive returns on sunny days whereas returns are mediocre on cloudy days [17], and this result was confirmed across several

international markets [18]. This suggests that investor *mood*, ostensibly negative on cloudy days, significantly affects the stock market. Suggestive evidence that this effect is not due to the trading patterns of individual investors was later found, thus asserting the possibility that it rather arises from the mood of market makers [19]. On another topic, Kamstra et al. document that returns around the weekend of the switch to standard time from daylight saving time are very negative, and suggest that induced depression from the switch amongst investors spread with seasonal affective disorder causes the negative return [20]. Edmans et al. indicate that outcomes of sporting events involving the country as a whole impact the stock market of the country. It is hard to imagine what else but *mood* could cause this effect [21].

More impactful is the triggering of the financial crisis started in 2007, which mingles an ever-increasing complexity of the financial sphere, the ambiguous essence of CDS (credit default swaps), and the role of the irrational decision-makers [22]. Today economists point at the developments of financial markets as the source of instability that leaded to the crisis [23]. Derivatives markets were long described as a way to spread financial risk more efficiently, however, it appears that human "frailty" couldn't cope objectively and rationally with the toilsome entanglement of finance [24].

In a nutshell, those examples illustrate that markets are not rational, that markets are affected by mood, and that mood can be driven by all sorts of different parameters absent from traditional models. Moreover, finance revolves around models founded on the principle that economic agents are pristine effective and rational actors, whereas it appears they can be overcame by emotions impairing their decision mechanisms and overwhelmed by the system's and models' intricacies.

1.2.4 Nothing new under the sun: behavioural finance is an old and contemporary subject

Adam Smith is generally introduced as the author of *An Inquiry into the Nature and Causes of the Wealth of Nations* (1776), for which he earned the title of father of (modern) economics. Touted as the original free-market capitalist and proponent of liberal economic policies with the "laissez-faire", Smith was also a philosopher and the author of another seminal work, *The Theory*

of Moral Sentiments (1759) in which he was passionate with motivation, decision-making, interaction between humans, and especially paved the way to the notion of empathy:

> How selfish soever man may be supposed, there are evidently some principles in his nature, which interest him in the fortune of others, and render their happiness necessary to him, though he derives nothing from it except the pleasure of seeing it. And before sympathy, the capacity to suffer with, to commiserate and to want to relieve the pain from another, to want happiness for another; before sympathy there was probably empathy, the capacity to perceive and feel what another feels [25].

Ashraf et al. highlighted the behavioural underpinnings of Adam Smith relatively to economic theories: "In short, Adam Smith's world is not inhabited by dispassionate rational purely self-interested agents, but rather by multidimensional and realistic human beings" [26]. Similarly to Smith, Keynes offered psychological insights in his economic theories. However, although Keynes was very clear in describing specific behaviours, he often treated psychology in an ambiguous and vague manner which has probably contributed to the oversight of that side of his theories [26]. Keynes was deeply conscious about the necessity to incorporate realistic behavioural assumptions in economic theories that deal with judgment under uncertainty [27]. In *The General Theory*, Keynes explicitly emphasised the importance of psychological inclinations in analysing the economic consequences of human behaviour, and used them to support his departure from the neoclassical tradition. Ideas like wage rigidity, animal spirits, money illusion, conventions, and uncertainty (refer to section 2.2) all suggest that Keynes refused the pressure of rationality and obeying axioms of choice (such as the ones developed in chapter 3) as the decisive criterion of human behaviour. Controversies about Keynes' work have blossomed, still they are only related o the pure economic aspects of Keynes' ideas. Akerlof remarks that the current development in behavioural macroeconomics has its roots in and is, to a certain extent, a continuation of Keynes' project [28].

> That dream was the development of a behavioural macroeconomics in the original spirit of John Maynard Keynes' General Theory (1936). Macroeconomics would then no longer suffer from the "ad hockery" of the neoclassical synthesis, which had overridden the emphasis in The General Theory on the role of psychological and sociological factors, such as cognitive bias, reciprocity, fairness, herding, and social status. My dream was to strengthen macroeconomic theory by incorporating assumptions honed to the observation of such behaviour [29].

In their synthesis, Akerlof & Shiller reinforce the claim that macroeconomics can indeed be based on behavioural foundations, proposing a "behaviourally informed Keynesianism" [30].

Because today we sit on decades of psychology studies in decision-making, as well as on a decade of research in behavioural economics and finance, we consider obvious the idea that psychology and individual behaviour take an important part in risky decision-making. It is hard to understand why Keynesianism was not "behaviourally informed" since the very beginning, for Keynes expressed widely and deeply his concern for the psychological factors that might pull the strings [27]. However, historically economists did not have the tools to quantify behaviour and ascertain scientifically their intuition on the subject. It was simpler to use the economic concepts and put aside the behavioural factors, not to mention that this portion of the argument was not widely accepted as real science for a long time.

Nevertheless, it is also remarkable how immovable are the groundwork and all the pillars of neoclassical economics. The development of behavioural studies did not occur suddenly, but where never taken into consideration compared to the snowball nature of the heavy mathematical approach and models. In the concluding remarks of his Nobel Prize lecture, Stiglitz examined why the neoclassical paradigm (and models based on it) persists:

> One might ask, how can we explain the persistence of the [neoclassical] paradigm for so long? Partly, it must be because, in spite of its deficiencies, it did provide insights into many economic phenomena. ...But one cannot ignore the possibility that the survival of the paradigm was partly because the belief in that paradigm, and the policy prescriptions, has served certain interests [24].

Since the aftermath of the global economic meltdown initiated in 2007, the devotion to unrealistic models is increasingly being questioned and criticised [31]. For instance, a group of economists released a report decrying the unethical use of unrealistic models.

> The economics profession appears to have been unaware of the long build-up to the current worldwide financial crisis and to have significantly underestimated its dimensions once it started to unfold. In our view, this lack of understanding is due to a misallocation of research efforts in economics. We trace the deeper roots of this failure to the profession's focus on models that, by design, disregard key elements driving outcomes in real-world markets. The economics profession has failed in communicating the limitations, weaknesses, and even dangers of its preferred models to the public. This state of affairs makes clear the need for a major reorientation of focus in the research economists undertake, as well as for the establishment of an ethical code that would ask

> economists to understand and communicate the limitations and potential misuses of their models [16].

In the end, if the research prospects of the impact of psychology and human behaviour in economics were so far dampened, the relatively recent appearance and blossoming of behavioural and experimental economics created the possibility of overcoming the fetters imposed on economic analyses by the behavioural postulates of neoclassical economics. Nevertheless, traditional finance academics often offer a few common objections to behavioural finance.

1.2.5 Resilience to behavioural studies on decision-making

First, it is usually said that theoretical behavioural models are *ad hoc*, viz. designed to explain specific stylised reactions coped with in experiment room. Indeed such experiments are always dependant on the design, the time and place the experiment takes place in, the pool of respondents, the experiment length, or the fact that in laboratory people will not perfectly behave. Consequently, the researcher will not elicit the genuine reactions encountered in real and global situations, thus blighting the study which is rendered irrelevant. This is indeed a possible shortcoming that goes along the essence of this field of study. However, behavioural models are simply based on how people *actually* behave instead of how they *should* behave. As long as the limitations are understood, listed and accounted for, conclusions can be drawned and progress achieved. Plus, the studies are based on more and more extensive experimental material across different fields of studies (neurology, psychology, and experimental economics) applied to several domains (risk, finance, entrepreneurship, decision-making, dependence, cognition). Such behavioural models explain the evidence elicited, as well as the shortcomings of the classic models, better than the classic models themselves. The bottom line being: people do behave differently from the optimal, rational and often expected way that classic and somehow dusty models dictate. This new approach in economics and decision-making echoes the unquestioned stance that scientific theories should be able to cope with real-world situations and should not force the facts to conform to theoretical assumptions. In the end there is a conceptual opposition rising between the highly mathematic methods from neoclassical theories and the more down-to-earth approach of behavioural economics pointed at for its *ad hockery*.

Another common objection is that the empirical work is plagued by data-mining. For instance, if the researchers set out to find deviations from rational pricing by running numerous regressions,

ultimately they will be successful. Moreover, by aiming at eliciting particular behaviours and statistical pieces of evidence, researchers will unconsciously drive not only the design but also the conduct of their studies and experiments towards their goal (refer to section A.10). Another problem lurking in research is p-hacking. Once again, one way to bolster the results and the pertinence of behavioural studies finance, economics and decision-making is quite simply to acknowledge the relevance of those domains full of fruitful promises, multiply the works, enhance and corroborate the experimental methodologies, as well as harvesting more and more data. One problem though is the globally lack of commitment towards reproducibility studies.

1.2.6 Conclusion & transition

For decades in economics and finance the relevance of the behavioural preferences of agents were ignored. To help with decision-making, strong mathematical models were built, refined and enhanced to cope with the reality of the economy. However, those models relied and still rely on hypotheses such as rationality, and are incompatible with not only the empirical data and observations, but also with the progress of other fields of science such a psychology (see chapter 2), neurology, biochemistry and genetics (see chapter 3). Many effects impacting economy, finance and decision-making escape the grasp of those ‘normative’ models.

Concerning the domain of behavioural finance, it is sometimes claimed it doesn’t present a unified theory similar to the principle of expected utility maximisation using rational belief. Some behavioural study aim at answering one question and eventually raise a dozen more, thus not providing “clear” bounds or solutions. Some behavioural studies also have ambivalent conclusion(s) or sometimes can’t be pristinely reproduced (not to mention reproducibility is seldom an area of interest) This critique may well be true at this point, but not only the seminal hypothesis of rationality of classical models is false by nature, it appears that traditional risk-based theories do not appear to be strongly supported by the data. Consequently, there is a strong case to build upon some new theories that are consistent with evidence, rather than theories based on rational economics and decision-making which empirical support unfolds as quite limited, not to say questionable. Normative theories relying on the backbone of rational utility maximisers cannot be construed as a superior alternative to behavioural approaches, merely because they discuss how people *should* behave. If people do not actually behave in this way, such an

approach has limitations in helping to understand decision involving risk and uncertainty, such a financial phenomena or entrepreneurship.

Through the prism of the development of behavioural economics, we understand that the mechanisms supporting decision-making involving risk and uncertainty display several strata, offering much to explore.

In decision-making, the definition of risk and the relationship of the agent to risk are the central clutch of the mechanisms, the essential item of focus at the nexus of everything. The following chapters aim at understanding risk and its impact on decision-making from every angle, and resorting to examples of studies tackling the domain of entrepreneurship.

CHAPTER 2 REVIEW OF LITERATURE (1/2) - EXPRESSING RISK VIA MATHEMATICS AND PSYCHOLOGY

2.1 The expression of risk with mathematics and economics models

In the domains of economics, finance or entrepreneurship, agents have to manage risk and make decision often irrevocable. Understanding what risk is, how it was conceptualised and analysed is an important step in effectively managing it. As we will see, models are rules of thumbs with limitations, and models have evolved on the rhythm of the understanding and the overtaking of those limitations. Every model is good as long as we understand them. This chapter follows chronologically the evolution of the expression of risk, and introduces all the notions and concepts involved in decision-making when comparing options, as well as in every game of experimental economics. Refer to section A.1 in appendix A for some cultural context on the concept of risk.

2.1.1 From expected value to expected utility

2.1.1.1 The mathematic expected value criterion

The mathematic expected value criterion is the most ancient of the criteria used to evaluate a risky situation. It is used in problems where the probabilities of the possible outcomes are known, or at least weighted with numbers. The basis of probabilities calculus is first elaborated in the 1650s by Pascal who uses the term of *The Geometry of Fate*. Then, in 1657 Huygens defines in *On Reasoning in Games of Chance* the mathematic expected value as the right price to which an individual would accept to yield its place in a game. It is quite basically a weighted arithmetic mean. The following formula is used:

$$\mathrm{E} = \sum_{\mathrm{i}=1}^{\mathrm{n}} p_i * c_i$$

Where p_i is the probability of the status i to occur, and c_i the associated outcome.

Example: Boris plays a dice-rolling game. To enter the game and roll the dice, Boris has to pay \$10. To each possible roll, a prize is associated. By adding up the \$10 price to play the game and

the earnings, the overall value of each roll is obtained. Assuming the dice is not loaded, each roll has $\frac{1}{6}$ chance to appear.

Table 2.1: Products of overall value and occurrence in the dice-rolling game

The dice rolls	Boris wins	Overall value	Occurrence	Overall value * Occurrence
1	\$0	-\$10	1/6	-\$1.67
2	\$1	-\$9	1/7	-\$1.5
3	\$2	-\$8	1/8	-\$1.33
4	\$5	-\$5	1/9	-\$0.83
5	\$10	\$0	1/10	\$0
6	\$30	+\$20	1/11	\$3.33

Eventually, the expected value of this game is obtained by adding up each line of the last column (value*probability).

$$E = \frac{1}{6} * (-1.67) + \frac{1}{6} * (-1.5) + \frac{1}{6} * (-1.33) + \frac{1}{6} * (-0.83) + \frac{1}{6} * 0 + \frac{1}{6} * 3.33 = -2.00$$

In this example, the expected value of the dice rolling game is -\$2. By the criterion of the expected value, it is not wise for Boris to play because when playing the game over and over, he can expect to be \$2 poorer.

When using the expected value, one can compare different situations: the optimal decision is the one with the highest expected value. However, this sole and simple criterion is not sufficient. Indeed, swiftly, paradoxes linked to the human nature are put into light.

2.1.1.2 The St. Petersburg paradox

The most famous paradox and textbook case formulated is the story of the mendicant and the wealthy trader, stated by Nicolaus II Bernouilli in early 1713, and from which stemmed the work of his brother Daniel Bernouilli towards the "Bernouilli criterion".

Wording of the problem leading to the paradox: a mendicant possesses a lottery ticket exposing him to a fifty percent (50%) chance to win 20,000 ducats, and a fifty percent chance to win nothing. A wealthy trader offers to buy the ticket for 9,000 ducats.

$$E = \sum_{i=1}^{n} p_i * c_i = \frac{1}{2} * (20{,}000) + \frac{1}{2} * (0) = 10{,}000$$

By using the formula of the mathematic expected value criterion, the mendicant should refuse the proposition (loosing 1,000 ducats compared to the expected value of the lottery ticket). However, the mendicant accepts to trade, as most mendicant would in that situation.

2.1.1.3 Limitations to the mathematic expected value

Daniel Bernouilli illustrates limits of the mathematic expected value as criterion in another thought experiment. Here the game consists in tossing a coin. The coin is flipped until heads appears. If heads appears on the umpteenth flip (ranked n), the player earns a gain of $\$2^n$. As soon as heads appear, the game ends and the earning are paid. How much one is willing to pay to be allowed to play this game?

Using simply the mathematic expected value criterion:

$$E = \left(\frac{1}{2}\right)^1 * 2^1 + \left(\frac{1}{2}\right)^2 * 2^2 + \cdots + \left(\frac{1}{2}\right)^n * 2^n = 1 + 1 + \cdots + 1 = +\infty$$

The mathematic expected value of this game is infinite. It is mathematically profitable for someone to pay a gigantic fortune in order to play this game since the gains are possibly infinite (the mathematic expected value is infinite). This behaviour seems obviously counterintuitive, for as soon as the first rank (n=1) – the first coin flip – it is highly possible (50%) to be deprived of the bet by winning "only" $\$2^n$=\$2. Nobody would risk to pay a gigantic fortune to play this game, although the return prospect given by the calculus should talk anyone into doing do.

2.1.1.4 Solution to the paradox: the utility function of gains & expected utility theory

Daniel Bernouilli published in 1738 the essay *Theory of the measure of risk*, in which he formulates and formalises the resolution of the St. Petersburg paradox by introducing the Bernouilli criterion (or the utility criterion). This important step is often considered today by economists as the cornerstone of the economic and financial theories on risk and decision-making, because it introduced the notions of risk aversion, risk premium and utility, even though Bernouilli did not tackle these questions directly.

The St. Petersburg paradox is an example of a situation where an artless criterion which takes only the expected value into account predicts a course of action that presumably no actual person would be willing to take. The resolution of St. Petersburg paradox is made via the introduction of the notion of utility function (utility function of gain) which measures the price one is ready to

pay in order to play, in other words, the price one is willing to pay to expose oneself to risk. By definition it is also the price one is ready to be paid in order to concede its right to play. The notion of a utility function, relative and unique to every player, leads to the expression of an expected utility.

> The value of an item must not be based upon its price, but rather on the utility it yields. The price of the item is dependent only on the thing itself and is equal for everyone; the utility, however, is dependent on the particular circumstances of the person making the estimate [32].

Let X be the maximal amount an individual is willing to pay in order to play the coin tossing game. X is not the expected outcome, but corresponds to the expected *value* of a function of gain. This function, unique to every individual, is a proxy that embodies risk aversion. It is usually written U and named utility function of gains. Then, by combining the utility and probability of each situation, expected utility is calculated:

$$EU(G) = \left(\frac{1}{2}\right)^1 * U(2^1) + \left(\frac{1}{2}\right)^2 * U(2^2) + \cdots + \ + \left(\frac{1}{2}\right)^n * U(2^n) = X$$

X is the expected utility of the coin toss game. It depends on the utility function of gains U of the individual playing the coin toss game. This individual would not pay an amount superior or equal to X to play this game.

It takes art to determinate the right function U verifying that one's willing to bet at most X to play the game. Depending on the choice of the function U or its design, the calculated value of X will be different. In the previous example, the St. Petersburg paradox, if the mendicant accepts the deal with the wealthy trader it is because the utility provided by the certain 9,000 ducats is superior to the utility of the gain of 20,000 ducats with a probability of fifty percent (50%). U is a proxy measure of the preferences of an individual regarding risk.

2.1.1.5 Bernouilli criterion

Based on the establishment of one's utility function of gain, it is possible to organise different situations depending on their probability and their calculated utility. The best situation is thus the one providing the highest utility. The value attached to a gamble varies across individuals, some individuals are willing to pay more than others and the difference is a function of their risk aversion.

2.1.1.6 Shape of the utility function of gains

For Daniel Bernouilli, in general the satisfaction of individuals increases with the wealth (thus, the utility function U is increasing): the more you earn money, the better you feel on the whole. Earning money is on the whole a better feeling than losing money or staying at the same level of money.

However, the satisfaction of individuals increases gradually less and less as the individuals get richer and richer. For Bernoulli, the utility from gaining an additional dollar decreases with wealth: "One thousand ducats are more significant to a pauper than to a rich man though both gain the same amount". This is the principle of the decreasing marginal utility, or diminishing marginal utility.

$$\frac{d^2U}{d^2x} \leq 0$$

Thus, utility functions verifying these hypotheses have to be increasing and concave (curving inwards) and are usually illustrated with logarithmic function as below:

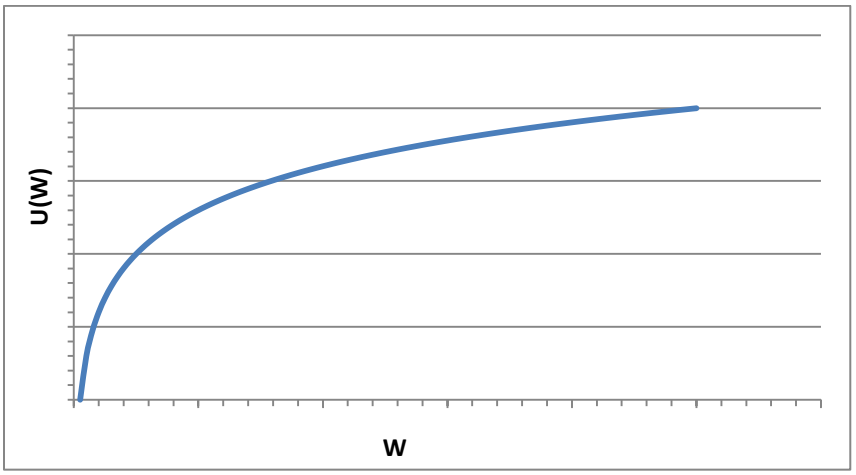

Figure 2.1: An increasing and concave utility function U of wealth W

The marginal utility corresponds to the satisfaction level provided by the last unit consumed or obtained of a good. The principle of diminishing marginal utility asserts that an agent's utility will decrease more with a loss of $1 in wealth than it would increase with a symmetric gain of $1.This principle illustrates risk aversion. As Marshall explained, any rational human being with a diminishing marginal utility will reject a fair bet (50% chance to win $100, 50% chance to lose

$100) because the loss of utility when losing the bet is more important than the gain of utility when winning the bet [33].

As formulated in 1854 by Gossen, “the intensity of a good, the pleasure that draws out, decreases and finishes by disappearing when one’s reaches satiety or repletion” [34]. The neoclassical school adheres to the hypothesis according to which the marginal utility provided by each additional quantity of a consumed or obtained good decreases and becomes zero when crossing a certain threshold called *satiety point*. Beyond this point, the marginal utility of additional quantity may even become negative, viz. each additional quantity yields *disutility*.

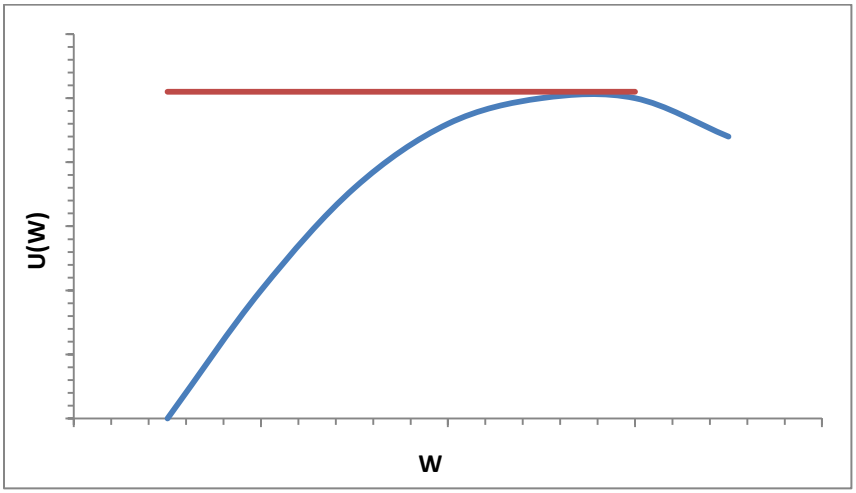

Figure 2.2: Satiety threshold of an increasing and concave utility function *U* of wealth W

2.1.1.7 Criticism of Bernouilli criterion and diminishing marginal utility

The simple and concise solution elaborated by Daniel Bernoulli was first globally retained, but eventually greatly discussed and criticised by other economists such as Wicksell, Edgeworth, Pareto and Marshall. The most striking criticism was formulated by Marshall in 1890 in *Principles of Economics*. According to Marshall, individuals making their decision based on the expected utility (their utility function of gains) while having a decreasing marginal utility will, in fact, simply never expose themselves to any risk [33]. Indeed, when assuming decreasing marginal utility, no rational individual would play the coin-tossing game since losses would be greater than gains, in the way that losses cost more utility than equivalent monetary gains provide. Yet, people do gamble. And thus, in its essence Bernoulli’s solution does not

corroborate the behaviour of risk-takers. The practice of games of chance and gambles slips from Bernoulli's solution, which makes the model neither representative nor good enough.

Expected utility theory will be rejuvenated later by the work of Von Neumann & Morgenstern in *Theory of Games and Economic Behaviour* (1944), where the expected utility is preserved but revised and enhanced, for the principle of a solely decreasing marginal utility is dropped.

Although it was as such left on the side by the evolution of economic thought, Bernoulli's solution has contributed to put into perspective an important hypothesis, the absolute rationality of decision-makers, highlighting individuals' preferences in the form of the utility function. This is on Bernoulli's shoulders that new models and new thoughts were born and have grown.

2.1.1.8 Von Neumann & Morgenstern generalise the utility theory [35]

Von Neumann & Morgenstern support the same idea as Bernoulli: in a risky situation, the decision-maker's behaviour is entirely determined by their preferences regarding the probability distributions in view of the consequences of their actions.

They attempted to axiomatise this hypothesis in terms of agent's preferences over different ventures with random prospects, i-e preferences over what can be called lotteries. Moreover, the law of diminishing marginal utility is given up as general explanation for individuals' choices, still the concept of expected utility is preserved to illustrate such choices [35].

Von Neumann & Morgenstern enrich the approach with 4 axioms:

- Comparability : the decision-maker is able to rank the situations;
- Transitivity : there is consistency in the ranking;
- Independence (linearity) : a convex combination do not modify the preferences;
- Continuity.

There exists a continuous utility function, strictly increasing and unique, such as: with X, X' two situations belonging to the set of the possible situations, $X > X'$ is equivalent to $U(X) > U(X')$where U(X) is the decision-maker's utility for situation X such as:

$$U(X) = \sum_{i=1}^{n} p_i U(c_i(X))$$

Where p_i are the probabilities associated with the outcomes c_i in the situation X.

This utility function may take many different forms, nonetheless it must convey at best the behaviour of the decision-makers and reflect their attitude vis-à-vis the risk. With this new representation backed by stronger hypothesis and axioms, Von Neumann & Morgenstern start the ball rolling of the field of study digging in the decision-maker's behaviour and define several risk attitudes: from risk-averse to risk-loving and risk-neutral. To help this approach, the concept of certainty equivalent (CE) is introduced.

2.1.1.8.1 The notion of certainty equivalent (CE)

The certainty equivalent (CE) appoints the threshold that will make the choice between a certain outcome and an uncertain outcome irrelevant in the eyes of the decision-maker.

For instance, the certainty equivalent of a lottery ticket is the maximal amount a player is ready to pay to acquire this ticket. The player is indifferent between possessing the ticket and keeping the money value of the certainty equivalent. In finance, the value invested in a risky asset is the certainty equivalent of the possible return of this asset.

Example: A financial equity F may return \$1000 with a probability of 0.25, or return \$100 with a probability of 0.75. Let us use a logarithmic utility function to calculate the expected utility of the financial equity.

$EU\ (F) = \frac{1}{4}U(1000) + \frac{3}{4}\ U\ (100) =\ 5{,}18$ where $U(x) = ln(x)$

The certainty equivalent (CE) of the financial equity F is such as U(CE) = EU(F) = 5,18. To calculate the certainty equivalent, we use the inverse function of the utility function *U*, in this case the exponential function. Hence:

$CE\ = e^{5{,}18} = 178$. For an investor, holding the financial equity F is equivalent to possess \$178.

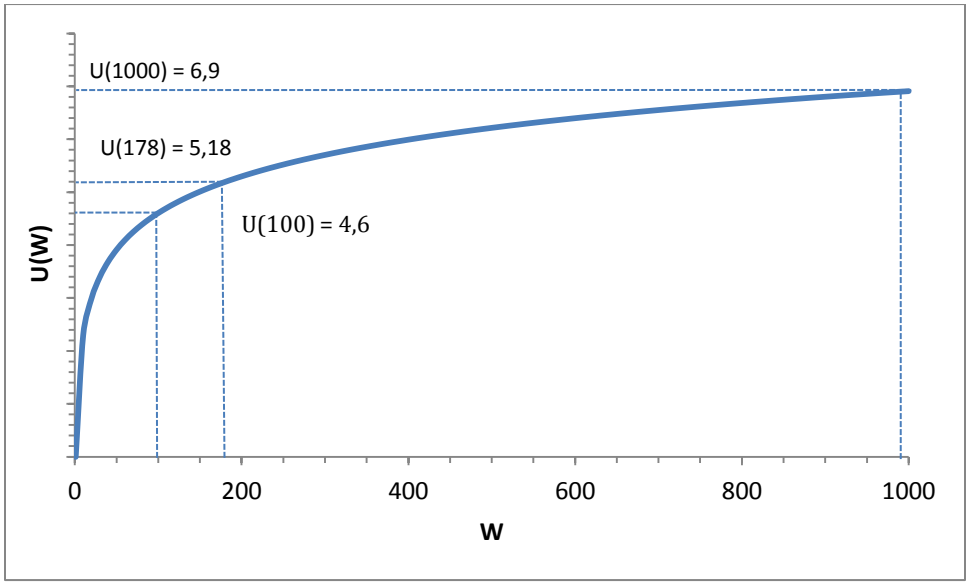

Figure 2.3: Illustration of the certainty equivalent

The notion of certainty equivalent gives the possibility to compare different risky situations by calculus and classification. Moreover, by eliciting multiple certainty equivalents of a decision-maker, it is possible to characterise their global utility function, therefore to convey their attitude facing risk and to reflect their behaviour.

2.1.1.8.2 Different behaviours to cope with risk

Let be the following game of chance:

- *Win +X with a probability of 0.5;*
- *Win –X (lose +X) with a probability of 0.5;*
- *The final wealth of the player is W+?, id-est $W + X$ with a probability of 0.5 and $W - X$ with a probability of 0.5.*

The player can choose to play (and thus, having a random final wealth of W+?), or choose not to play and having a certain average gain of $\frac{1}{2}(W + X) + \frac{1}{2}(W - X) = W$.

- To Play: $E\big(U\ (W+?)\big) = \frac{1}{2}U(W + X) + \frac{1}{2}U(W - X)$
- Or not to play: $E\left(U\ \left(\frac{1}{2}(W + X) + \frac{1}{2}(W - X)\right)\right) = U\ (W)$

- **Risk premium**

The risk premium (RP) is a calculated value that gives the amount the decision-maker is ready to pay, or ready to be willingly deprived of, not to expose themselves to the risk of a lottery L.

It is the difference of the mathematic expected value $E(L)$ minus the certainty equivalent CE of that lottery.

$$RP = E(L) - CE$$

The risk premium is a measure of risk preference, expressed in a monetary value. This gauge allows comparing behaviours.

- **Risk-aversion**

A player that will prefer the certain amount (average gain W) to the random outcome is considered risk-averse, or risk-phobic.

$$U(W) > E\big(U\,(W+?)\big) \leftrightarrow U(W) > U(CE)$$

The certainty equivalent of the lottery (playing, uncertain outcome) is inferior to its average gain W (not playing, certain outcome). The player prefers a certain situation to a situation that may expose them to lose. In a graphic where wealth is on the abscissa axis and wealth's utility on the ordinate axis, utility function is concave. It embodies the theory of decreasing marginal utility, hence it is the spirit of the solution developed by Bernouilli in 1738.

$$\frac{d^2U}{d^2x} \leq 0$$

Moreover, the risk premium is positive.

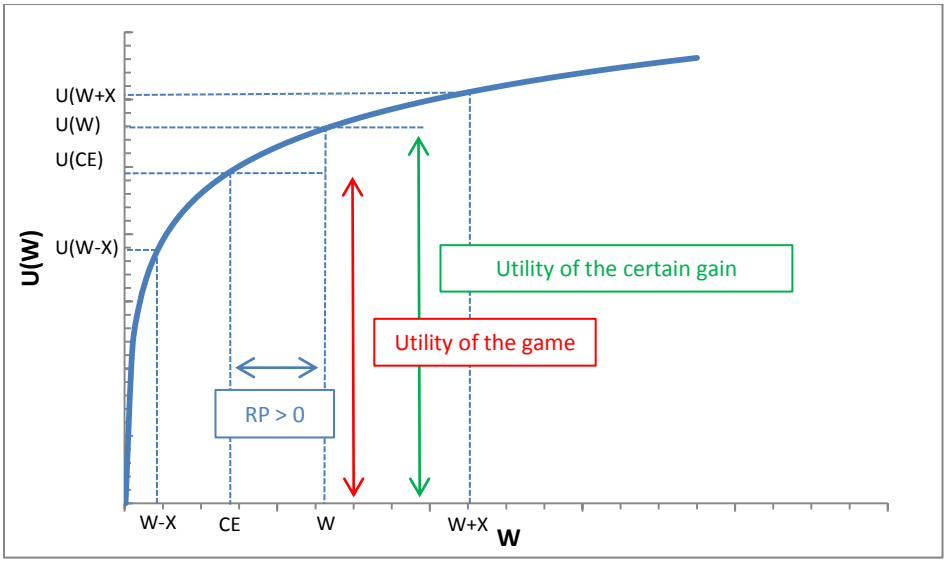

Figure 2.4: Illustration of a risk-averse behaviour

- **Risk-neutrality**

The player is indifferent to picking the lottery (and thus exposing them to risk) or opting for the certain average gain.

$$U(W) = E\big(U\,(W+?)\big)$$

The utility function is linear and represented by a straight line. The risk premium is zero. The marginal utility of the player is steady: for every additional unit received, the utility increases as much. The player is risk-neutral; still a certain event is less risky than a lottery. The player turns their nose up at this parameter and does only considerate the expected gain of both choices.

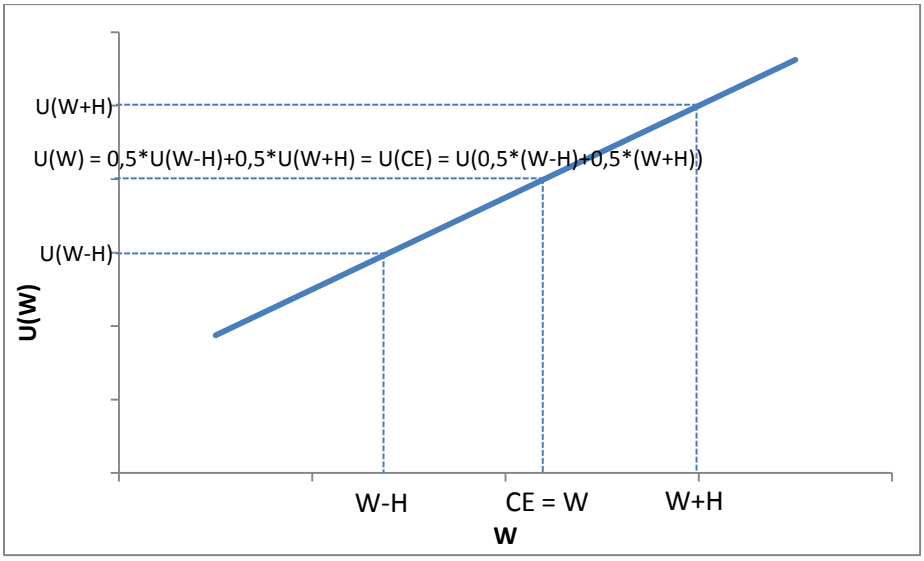

Figure 2.5: Illustration of a risk-neutral behaviour

- **Risk-propensity**

For a player having a fondness for risk, the risk premium is negative; id-est the certainty equivalent CE is superior to the average gain W.

The utility function is convex, which depicts an increasing marginal utility.

$$\frac{d^2U}{d^2x} \geq 0$$

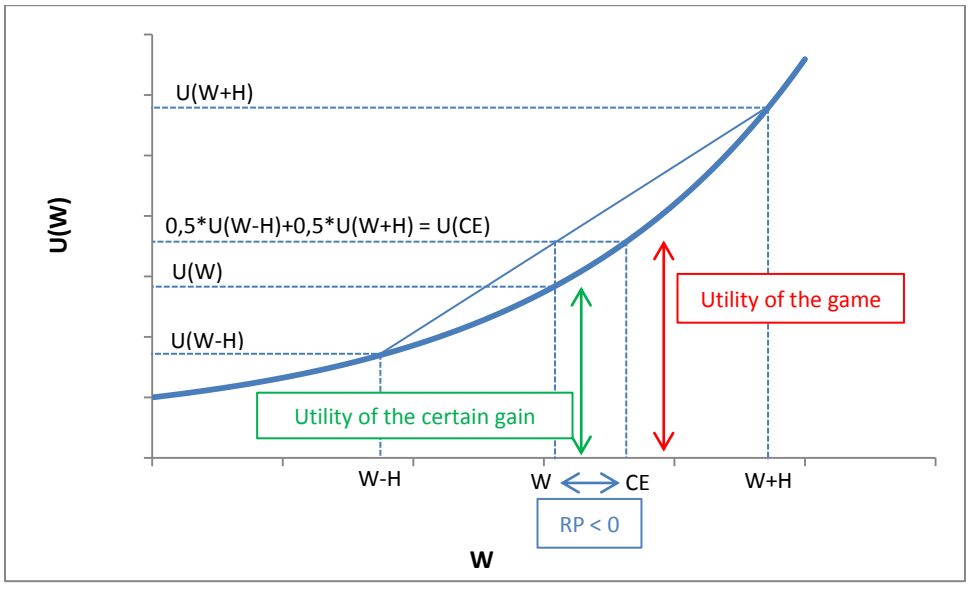

Figure 2.6: Illustration of a risk-loving behaviour

2.1.1.8.3 EUT's legacy

Since the formulation of expected utility theory (EUT) by Neumann & Morgenstern in 1944, EUT-based models were foundations that dominated the study of risk in economics and decision theory. Given a choice between multiple options, people will choose the option that maximises their own expected utility. EUT thus shows in stark clarity that which decision the agent prefers depends on a personal utility function, namely the attractiveness of a risky opportunity as perceived by them. However there has been extensive research, progress and documentation of evidence displaying that people's behaviour deviates from the normative models, often in predictive ways [36].

2.1.2 Criticism of the generalised EUT

2.1.2.1 Deeper roots of subjectivity

The expected utility model relies on a postulate which implies that the decision criterion, the player's system of preferences, is the one of utility's expected value. This intertwines the price of risk, the shape of the utility function as well as the amplitude of the possible gains and losses. The specificities of the utility function elicit on one hand the marginal evaluation of the consequences by the player, on the other hand their own behaviour regarding risk.

The expected utility developed by Von Neumann & Morgenstern in 1944 was the milestone to the birth of a new thought that shambled the basic criterion of (mathematic) expected value. Experiencing and exploring deeper into the agent's reactions, soon was introduced the notion of subjective probability, adding another layer of biased, personal and sometimes irrational relationship with a component of risk. All along the second half of the 19th century, several shinning works delving into the decision-maker's mind served as flagships for behavioural studies and paved the way to an early understanding of the psychological factors involved with uncertainty.

According to the historian Hacking, the notion of probability appeared in the middle of the 17th century and encompassed a twofold meaning: firstly, the relative frequency of a random outcome in repeated trials (which is objective); secondly, the measure of a decision-maker's degree of trust in the truth of propositions, or the credible realisation of events (which is subjective) [37].

> Probability has two aspects. It is connected with the degree of belief warranted by evidence, and it is connected with the tendency, displayed by chance devices, to produce stable relative frequencies. Neither of these aspects was self-consciously and deliberately apprehended by any substantial body of thinkers before the time of Pascal [37].

As we have seen, from Bernoulli's early solutions to von Neumann & Morgenstern's more refined axiomatic characterisation of expected utility-maximising agents, it was assumed that probabilities only existed in the sense of relative frequencies.

In *The Foundations of Statistics (1954)*, Savage honed a theory of decision-making under uncertainty and defined *choice-based subjective probabilities*. He intended these probabilities to express the decision maker's beliefs, thereby furnishing Bayesian statistics with a behavioural basis (refer to section A.2 in appendix A for an introduction to Bayesian statistics).

2.1.2.2 Savage's subjective probabilities (1954)

Summoning the non-objective notion of probability, Ramsey (1931) and de Finetti (1937) formalised the concept of choice-based subjective probability assuming that individual seek to maximise expected utility when betting on the truth of propositions (rather than betting on the relative frequency of random outcomes). The basic idea behind subjective probabilities with a choice-based approach is that a person's degree of belief about the truth of a proposition, or the likelihood of events, is manifested and can be inferred from his willingness to bet on the truth of the proposition, or the realisation of events [38].

Savage synthesised the ideas of Ramsey, de Finetti, and von Neumann & Morgenstern: the analysis of a decision involving uncertainty is related to the decision maker's taste for the possible consequences and their beliefs regarding their likely realisation. Then, the preferences of the decision-maker associate two subjective notions: a subjective probability distribution with a subjective utility function [39].

The probabilities are not considered an objective parameter the agent takes into account anymore, but on the contrary express inherently a feeling of the agent for the possibility of the outcome. Every agent has a self representation, or appreciation, for a fixed probability. The probability depends on the agent's perception of the parameters relative to the decision [40]. This belief is formed in the decision-maker's mind and takes into account a personal evaluation of the situation forged by risk preferences, previous experiences but also possibly other notions like morals. As

with previous models, which decision the agent prefers depends on which subjective expected utility is higher. Here different agents may make different decisions not only because they may have different utility functions, but also because of different beliefs about the probabilities of the different outcomes.

Savage bolstered this preference structure with seven axioms or principles indicating how *rational* individuals *ought to* behave. The axioms were not describing how individuals really behave in the face of uncertainty, and thus were immediately questioned. It was rapidly repeatedly been shown in experiments that the theory fails systematically to predict individuals' choice. The most severe and remarkable criticisms in this regard were due to Allais (1953) and Ellsberg (1961).

For Allais' paradox, refer to appendix A. Allais' paradox dealt with the axiom of independence and presented objective lotteries. Ellsberg's tackled other lotteries involving ambiguity, which is an aspect of decision-making present in the games that are used in this project.

2.1.2.3 Ellsberg's ambiguity (1961) [46]

Ellsberg's basic idea was that people overwhelmingly prefer taking on risk in situations where they know specific odds rather than an alternative risk scenario in which the probabilities are completely or in part ambiguous. They will always choose a known probability of winning over an unknown probability of winning even if the known probability is low and the unknown probability could be a guarantee of winning. As Allais proved earlier, Ellsberg tackles the axioms defining EUT and demonstrate people actually behave differently from these utopian rules of decision-making.

Ellsberg proposed several thought experiment to entice ambiguity aversion and prove that people violate the axiom of independence. We will illustrate the 3-colour/1-urn quandary.

2.1.2.3.1 Choice problem

An urn contains 90 balls of different colours.

- 30 red balls;
- 60 other balls which can be either black or white.

It is unknown how many black or how many white balls there are. The balls are thoroughly mixed; consequently each of the 90 balls is as prone to be picked as any other ball. Every ball as one in 90 chances to be picked. The experiment is a two-round choice between two gambles, the comparison of which sparks the paradox.

First the respondents have to choose between the gambles 1A and 1B.

Table 2.2: Gambles 1A and 1B, first round of Ellsberg' experiment

Situation 1	Winning condition and gains
1A	• Draw a ball and receive $100 if the ball is red
1B	• Draw a ball and receive $100 if the ball is black

Then the respondents have to choose between the gambles 2C and 2D (it is explained that whatever ball they will draw in the first round, they put it back in the urn and all the balls are again perfectly mingled before they will draw again).

Table 2.3: Gambles 2C and 2D, second round of Ellsberg' experiment

Situation 2	Winning condition and gains
2C	• Draw a ball and receive $100 if the ball is red or white
2D	• Draw a ball and receive $100 if the ball is black or white

When determining which gamble to choose, respondents consider the probabilities of the balls that aren't red to be either black or white and based their decision on the expected utility they infer from these probabilities.

Considering the payoffs are equals, the possible decisions are as follow:

- Respondents prefer 1A over 1B if they think picking a red ball is more likely than picking a black ball.

- Respondents opt equally for 1A or 1B if they think picking a red ball is equally likely as picking a black ball.
- Respondents prefer 2C over 2D if they think picking a red or white ball is more likely than picking a black or white ball.

If a respondent thinks they are more likely to pick a red ball rather than a black ball, it is inherent that they think they are more likely to pick a red or white ball rather than a black or white ball. The opposite is also true. Meaning choosing 1A over 1B shall lead the respondent to choose 2C over 2D (and the opposite is also true). Nevertheless, Ellsberg's findings are the majority of the respondents prefer 1A over 1B, and 2D over 2C [46].

Let be the following notations:

- R is the probability of picking a red ball from the urn;
- B is the probability of picking a black ball from the urn;
- W is the probability of picking a white ball from the urn.

Ellsberg's general result that most people would choose 1A over 1B, and 2D over 2C is incoherent and violates the independence axiom of EUT.

Participant considers A over B
↔ A > B
↔ U(A) > U(B)
*↔ R*U(100) + (1-R)*U(0) > B*U(100) + (1-B)*U(0)*
U(0) = 0
*↔ R*U(100) > B*U(100)*
↔ R > B
↔ Participant evaluates R higher than B

and

Participant considers D over C
↔ A > B
↔ U(A) > U(B)
*↔ B*U(100) + Y*U(100) + R*U(0) > R*U(100) + Y*U(100) + B*U(0)*
U(0) = 0
*↔ B*U(100) + Y*U(100) > R*U(100) + Y*U(100)*
*↔ B*U(100) > R*U(100)*
↔ B > R
↔ Participant evaluates B higher than R, which is a contradiction with the first choice of A over B.

The result of the paradox holds regardless of the player's risk preferences and utility function. The four gambles involve risk. Nevertheless, the exact chances of winning and losing are known

only for the gambles 1A and 2D which highlights the source of the paradox regarding EUT: ambiguity aversion. Ellsberg demonstrated that this phenomenon occurs only when the choice set permits comparison of an ambiguous proposition with a less vague proposition.

2.1.2.3.2 Explanation of Ellsberg's paradox

- Uncertainty and ambiguity aversion [44]

Since the probabilistic information available to the decision-maker is incomplete, the paradox embodies the Knightian uncertainty the agent has to cope with when making the decision. The seed of the clear differences between risk and uncertainty was first enounced by Frank Knight in *Risk, Uncertainty, and Profit* (1921).

> Uncertainty must be taken in a sense radically distinct from the familiar notion of Risk, from which it has never been properly separated.... The essential fact is that 'risk' means in some cases a quantity susceptible of measurement, while at other times it is something distinctly not of this character; and there are far-reaching and crucial differences in the bearings of the phenomena depending on which of the two is really present and operating.... It will appear that a measurable uncertainty, or 'risk' proper, as we shall use the term, is so far different from an unmeasurable one that it is not in effect an uncertainty at all [47].

In this scheme, the agent formulates subjective probabilities for the possible outcomes of the gambles and tends to over-evaluate certainty versus uncertainty.

- Information gap [48]

Ellsberg's experiment sheds light on the inability for the agent to elicit practical sense from the incomplete probabilities they are given. It's not the sole impact of the subjective interpretation of the probability information that are provided, but the very unclear impression rising from uncertainty. The decision based on the rule of maximising expected utility is impossible for an agent unable to assess correctly the probabilities of the problem. The agent then computes self-probabilities to fulfil their expected utility function.

- Deceit aversion [49]

People naturally assume that if they are not provided with the full information of the problem, they are to be swindled. In the experiment room, participants will act as the experimenter has interest to be a deceiver. In the context of Ellsberg's experiment (the first choice between 1A and

1B), respondents may assume there are fewer black balls than white balls since in a real life situation it would be unfavourable to them when offering such a choice rewarding payoffs. Participants either assume the experimenter is deceitful, or forget the experimenter has either no way to modify the content of the urn or that there isn't any interest for Science to act as such (not mentioning experiments precisely about deceit, cheating and trust). The behaviour of having trust issues about the experimenter has to be mentioned if not taken into account when designing experiments.

- Kahneman & Tversky's certainty effect (1986) [50]

An additional explanation behind this paradox is formulated by Kahneman and Tversky in 1986 and their certainty effect. This effect refers to the idea that people have a tendency to over-evaluate outcomes that are certain regarding outcomes that are only likely. Contrary to the postulate developed in EUT (section 3.1.8.2.2), this effect implies that people believe the probabilities are not neutral and behave in consideration. People tend to be enticed by the lure of certainty, and tend to willingly diminish their expected gain to reach certainty by modifying their appreciation of the probabilities.

- Competence hypothesis [51]

Heath & Tversky (1991) postulated that players prefer betting on their own judgment over an equally likely event when they consider themselves knowledgeable, but not otherwise. People would even pay a significant premium to bet on their judgments and to prove them right This explanation takes a divergent path from aversion to ambiguity, because judgmental probabilities are more ambiguous than chance events.

- Comparative ignorance [52]

Fox & Tversky (1995) postulated that ambiguity aversion is produced by a comparison with less ambiguous events or with more knowledgeable individuals. The effect of ambiguity aversion seems to disappear in a non-comparative context in which a person evaluates only one of these prospects in isolation.

2.1.3 Kahneman and Tversky's Prospect Theory (1979) [44]

To cope with the flaunting of EUT by empirical data, at first economists stayed within the normative confines of the axioms of rational choice and only attempted to hone and tweak the existing models to make them conform more closely to the reality.

The real revolution occurred when two psychologists, Kahneman & Tversky, studied the mechanisms of decision-making through the more sentient prism of social sciences and human biases. They developed a new theory based solely on the observed and documented deviations from rationality of the human mind, which were now foundations of the theory rather than divergences that had to be "patched". Kahneman & Tversky suggested that the problem with EUT was not with one axiom or another but with its view of human behaviour.

In *Prospect Theory: An Analysis of Decision under Risk* (1979), they forged a psychologically more accurate description of decision making. This work is considered a seminal paper in behavioural economics for which they were awarded the Nobel Prize in Economics in 2002.

Prospect Theory dwells on several quirks, or deviations, from rationality:

- Framing effect

As mentioned in Allais' paradox, the framing effect materialises when identical outcomes result in different choices if they are differently explained, or framed, to the decision-maker. For instance, people are more susceptible to buy a product when it is labelled off priced rather than when it sold not labelled off priced but with the same discount applied. Refer to the framing effect sections (3.1.4 and A.9).

- Source of the information

For identical products or services, the mechanism through which information is delivered matters. The classical example is the influence of packaging of a good, even though packaging is immediately discarded once the purchase is made. Another example is the effect a brand has on a product, and people may value more a branded item than a better one from an unknown brand.

- Loss aversion

Individuals feel more pain from losses than they feel joy from an equivalent gain.

- Non-linear preferences

Individuals may display behaviour violating the axiom of transitivity: preferring A over B, B over C, and eventually preferring C over A.

- Risk-aversion and risk-seeking

Individuals often simultaneously exhibit risk aversion in some of their actions while seeking out risk in others. Consequently, in prospect theory how individuals behave depends upon how a problem is framed, with the decision being different if the outcome is framed relative to a reference point to make it look like a gain as opposed to a different reference point to convert it into a loss.

2.1.3.1 Kahneman & Tversky's experiment

This experiment is a two-round choice between two gambles.

First the respondents have to choose between the gambles 1A and 1B.

Table 2.4: Gambles 1A and 1B, first round of Kahneman & Tversky's experiment

Situation 1	Gains and probabilities
1A	• A gain of 3000 with a probability of 0,002
1B	• A gain of 6000 with a probability of 0,001

Then the respondents have to choose between the gambles 2C and 2D.

Table 2.5: Gambles 2C and 2D, second round of Kahneman & Tversky's experiment

Situation 2	Losses and probabilities
2C	• A loss of 3000 with a probability of 0,002
2D	• A loss of 6000 with a probability of 0,001

In this experiment the majority of the respondents preferred situation 1B over situation 1A, and situation 2C over situation 2D. However, in respect of EUT an individual valuing 1B over 1A should value 2D over 2C. This experiment illustrates that people do not evaluate potential losses and gains in the deliberative rational manner of an expected utility maximising agent: there is a subjective value for each gamble.

2.1.3.2 Formulation of prospect theory

In prospect theory, subjective value is modelled by a value function v concave for gains, convex for losses, and steeper for losses than for gains. The influence of probabilities is characterised by a weighting function w overweighting low probabilities and underweighting moderate to high probabilities. Thus, the value V of a simple prospect that pays x with probability p is calculated as follows:

$$V(x,p) = v(x) * w(p)$$

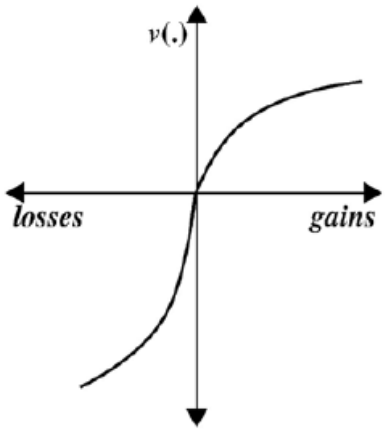

Figure 2.7: Representation of value function as a function of gains and losses

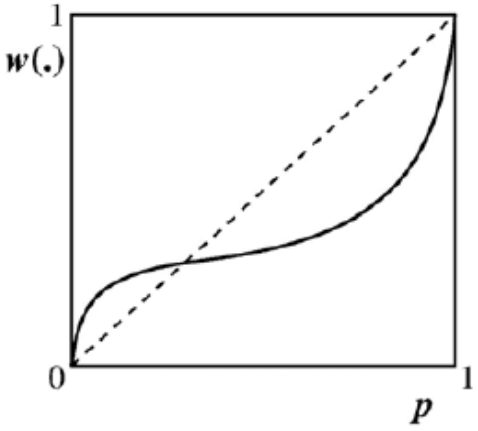

Figure 2.8: Representation of weighting function as a function of the probability p of an event

The utility function U varying upon states of wealth W is replaced by a value function v dependent on gains and losses relatively to a reference point (often an equilibrium), where $v(0)=0$. A decision-maker may believe that the probability of a fair coin landing heads or tails is fifty percent but assign those events a weight lower or higher than fifty percent in the *evaluation*

of the prospect. Last but not least, on the contrary to EUT here are specifically included principles of framing and editing of the problem that allow for different descriptions of the same choice to lead to different decisions.

2.1.3.3 Explanation and legacy of prospect theory

The general assessment of Kahneman & Tversky is that individuals are subject to various cognitive limitations that for instance lead people to be risk averse when it comes to gains but risk seeking when it comes to losses [44]. This is the first mention of cognitive biases as underlying causes of risk preferences.

The two psychologists summon the phenomenon of overweighting low probabilities, a tendency to subjectively transform probabilities. This phenomenon arouses an appealing effect regarding gains, and the opposite regarding losses. For instance in another late experiment by Tversky (1995), individuals will choose a certain 85k dollars instead of a gamble with an 85% chance of winning 100k and 15% chance of winning nothing, but will take a gamble with an 85% chance of losing 100k and 15% chance of losing nothing rather than taking a certain loss of 85k [53]. In extensio, their research leads to the reflection effect: observed preferences with gains invert with losses (however, there is no genuine symmetry, as in some case it is no perfect).

Support for Prospect Theory can be found in a wide variety of disciplines, including sociology, psychology, and many areas within economics. Nowadays, studies in neurology and genetics (heritability of traits) points towards cognitive biases Kahneman & Tversky alluded to (refer to sections 3.1 and 3.3). Much of the empirical support comes from studies in which people make hypothetical or real choices between gambles and such gamble studies are ideal because they allow researchers to clearly specify the value and probabilities associated with of each gamble, and provide an analogy to many if not all risky decisions made in daily life.

Substantial empirical support exists for the major tenets of prospect theory: the importance of reference points in decision-making, the asymmetry between gains and losses of equivalent magnitudes, and the weighting function that overweighs low-probability events and underweighs high-probability events. Recent advances in Prospect Theory involved demonstrations in field settings (such as with New York Taxi drivers [54]), and the more complicated treatment of decisions with a very large number of possible outcomes (called cumulative prospect theory [55]). None of these recent advances challenged the major tenets of the original formulation.

2.1.4 Conclusion and transition

Individuals have always had to deal with risk, and as soon as the 17th century models to express attitudes copying with risk have emerged. Human beings can either be risk-averse, risk-neutral, risk-seeker, and these risk preferences can sometimes stir together or evolve as the situations, or the individuals, change. Mathematics and economics models of risk built themselves on axioms, boundaries within which a paradigm will be verified. However axioms were in some cases boundaries for the models beyond which they were not working properly, and actually did not cope with the reality. Those axioms have been put to the test by multiple experiments highlighting the irrational behaviour of the agents and the consequent violability of the axioms [41] [46]. The true revolution occurred when psychology peeked in and helped building a new model of decision-making under risk, prospect theory, founded on deviations of the human mind and experimental documentations. 300 years after the initial work by the Bernoulli brothers, Kahneman & Tversky explained divergences from the optimal utility-maximisation behaviour chanted by EUT as so many cognitive biases and psychological effect that have to be taken into account in any discipline dealing with decision-making: framing effect, common consequence effect, loss aversion, ambiguity aversion, and certainty effect are the first entries in a dictionary of human flaws exerting control on cognitive mechanisms involved in decision-making and have consequences in the fields of economy, finance, and entrepreneurial decision-making.

However, it is unclear as to what makes some individuals sensible to certain biases and effects, and some less sensible. It is unclear what generates differences in risk preferences across individuals. As the discipline analysing the behaviour and the mind, psychology is a pivotal stone to pave the way to a better understanding of the underlying mechanisms of decision-making. But it is not the only one. Indeed, it has been claimed numerous times that Science has paid insufficient attention to the role of biological factors in the production of human behaviour [59], and the eternal “nature vs. nurture” debate has been vivacious ever since. At an increasing pace, scholars have begun to examine the biological factors contributing to human behaviour. To better understand risk preferences, scientists took a step further and delved deeper into the human blueprints, venturing down many different paths that always cross each other at some point. Focus on psychology allowed to understand more and more the origins and implications of cognitive biases, situations and threshold triggering them, and helped to draw the borders between situational factors, education, and more “mechanical” flaws of the human mind (the

blueprints of the inner machinery). Indeed, technological advances allowed the study of our brain's mechanisms on multiple levels: neurology and imagery mapping our brain, hormones and neurotransmitters produced, transferred and received being both the message and the carrier. Eventually the very unique and intimate decipherer, DNA, is the apex of this search for answer.

The following chapter and sections explore the progression and latest developments on these subjects that are new interesting areas of investigation for the understanding of risk preferences and behavioural decision-making (through the examples of entrepreneurship and finance). Section 2.2 gathers topics around psychology. Then section 3.1 tackles the brain and neurology. Section 3.2 refines and deals with hormones and biochemistry. Eventually, section 3.3 accounts for the genetic factors holding sway over those mechanisms and risk preferences.

2.2 Psychology of risk and cognitive biases

In a world where people sky dive for pleasure, where gambling industry is a multi-billion dollar business, where people throw themselves in the entrepreneurial arena with all their money and energy, where people buy insurance, and where financial markets are seen are gigantic casinos, it is clear that human beings can be either attracted to or repelled by risk, and that some are more susceptible to its attraction than others. Psychology studies are the first layers to a better understanding of the distribution of risk preferences among the population as well as their underlying causes, not to mention the flaws and biases influencing the decision-making process.

2.2.1 Internal-dispositional factors and external-situational factors

Dispositional attribution is the explanation of individual behaviour as a result caused by internal factors and characteristics that reside within the individual. It is opposed to situational influences that stem from the environment or culture in which that individual is found. This concept is an echo to the "nature vs. nurture" concept. Risk preferences may have dispositional factors as well as situational factors.

> Having gained an overview of the kinds of relationships that dispositions toward risk and conservatism exhibit with other kinds of differences among individuals as well as with information on the kinds of situation characteristics that can be expected to influence the riskiness of a person's decisions it is necessary to perform some kind of psychological weighing of these two classes of determinants [60].

Risk preferences are central to any model of human decision making, and a number of studies have documented from substantial to considerable heterogeneity in individual attitudes towards risks [61] [62], expressed as the willingness to trade off increasing variance of returns against greater expected returns.

Some individual variation in preferences can be explained by dispositional factors such as demographic variables, for instance gender [61] [63], age [61] [62], race [61] [62] [64], and socioeconomic status [65] [66]. Moreover, loss aversion and other factors relevant to risky decision-making have been shown to be related to various personality dimensions, such as surgency (a trait aspect of emotional reactivity in which a person tends towards high levels of

positive affect), shyness, and impulsivity [67], novelty-seeking or harm-avoidance (refer to section 5.3.5).

On the other hand, studies by Weber and Hsee (1998) showed that perceptions of risk and risk preferences might vary across cultures, suggesting that there might be factors that influence risk preferences not only in individuals but also in groups [68]. In their study, Chinese respondents were significantly less risk-averse in their pricing of risky financial options than Americans. However these apparent differences in risk preferences were associated primarily with cultural differences in the perception of the risk of the financial option rather than in attitude towards the perceived risk. Whether Chinese or American, the majority of the respondents was willing to pay more for options perceived as less risky, id-est were perceived-risk averse. Another study by Hsee & Weber compared Americans' and Chinese risk preferences in investment, medical and academic decisions, and found that Chinese were more risk seeking than Americans only in the investment domain and not in the other domains. The explanation given suggested people in collectivist societies, such as China, are more likely to receive financial help if they are in need and consequently they are less risk-averse than those in an individualistic society such as the USA. These results not only enlighten on the complex underlying causes of risk preferences, they also have practical implications for cross-cultural negotiations and commerce.

Other situational factors have been investigated, such as religion [61] and education [62] [65] [66]. Levin et al. (2007) found correlations between several dispositional factors and preferences in risky decision-making [69]. Eventually, there is some evidence that suggests that these preferences evolve in response to environmental influences [70] [71], notably time.

Investigating carefully the laws and mechanisms pulling the strings of perceptions of risk and attitudes towards risk help to better understand and cope with real life decision-making in our topics of interest: economics and entrepreneurship.

2.2.2 Cognitive biases and effects influencing decision-making

A cognitive bias is a tendency or pattern characterising a deviation in judgment, by means of which comprehension and reasoning about situations or people are drawn in an illogical or irrational manner [72]. Individuals create their own subjective social reality from their perception of the input. An individual's construction of social reality, not the objective input, may dictate

their behaviour in the social world. Thus, cognitive biases may sometimes lead to perceptual distortion, inaccurate judgment, illogical interpretation, or what is broadly called irrationality. Some cognitive biases are presumably adaptive [73] [74]. Cognitive biases may lead to more effective actions in a given context. Furthermore, cognitive biases enable faster decisions when timeliness is more valuable than accuracy, as illustrated in heuristics (use of rules of thumb). Other cognitive biases are by-product of human processing limitations, resulting from a lack of appropriate mental mechanisms (bounded rationality), or simply from a limited capacity for information processing.

A continually evolving list of cognitive biases has been identified over the last six decades of research on human judgment and decision-making in cognitive science, social psychology, and behavioural economics. Cognitive biases are important to study because systematic errors highlight the psychological processes that underlie perception and judgement [75] [76].

It is important to understand that cognitive biases are very common and have a wide range of application, situation, nature, amplitude, and of course consequences. They influence our appreciations of information and situations in common decision in daily life, routinely behaviours as well as more important and decisive steps that we take. In a nutshell, they are an important and very common aspect of the human mind that can be accounted for in everyone, everyday, and one aspect so commonly shared and involved we don’t notice it.

Cognitive biases are often summoned in behavioural economics, and classified in three groups . First group of cognitive biases and effect concerns heuristics, which is the tendency of people to make decisions based on approximate rules of thumb, and not strict logic. As we explained, heuristics may have several causes: adaptive mechanism, limitations from the processing capabilities of the brain and/or limitations inherent to the nature of the situation (e.g. decisions have to be made quickly). The second group of cognitive biases and effects concerns the wide notion of framing and assembles a collection of anecdotes and stereotypes composing the mental and emotional filters individuals rely on to understand and respond to events. As for heuristics, these framing effects are the fruit of several mechanisms. The third group is more specific to the domain of behavioural economics and concerns market inefficiencies such as mispricing and the broad notion of non-rational decision-making.

The following sections offer a wide panel of cognitive biases and effects directly related to risk, the assertion of a situation based on information, decision-making in economics or entrepreneurial world. The boundaries between these effects are not always rigorous, in the sense that some are declensions of others, particular illustrations or applications. For complementary cognitive biases, refer to appendix A.

2.3 Conclusion and transition

In entrepreneurship, finance or daily life, decision-making relies on information gathering, analysis, comparison, evaluation, recording, contextualisation, objective parameters and personal views. Human mind is subject to a long list of cognitive biases, making the decision-making process far from a pristine objective and rational mechanism. Some of those processes have been carefully elaborated along evolution to respond in an optimised way to the concerns of the human species (they are adaptive), other are plain flaws and limitations that have to be accounted for. However nowadays, such mechanisms can lead to misconception and mistakes.

An extant literature shows that people who engage in entrepreneurial activity are not randomly determined. Indeed, a variety of factors are associated with the tendency of people to engage in entrepreneurial activities including psychological attributes such as the need for achievement [112], overconfidence [113], locus of control [114], optimism [115] [116], risk-taking propensity [117], and several additional demographic factors (see 1.1).

Understanding cognitive biases affecting decision-making and shaping one’s behaviour in face of risk and uncertainty is unveiling research prospects for the future. Studies could target precise biases and tackle the conditions triggering them as well as the extent of their consequences in different situations.

As the throne of our thought and the playground of psychology, the brain has naturally been another subject of high attention to delve one step deeper into mental processes and understand them. The progress of neurology maps the many mechanisms of cognition and their dedicated areas in the brain: the next chapter deals with the neurology aspect of decision-making and risk.

CHAPTER 3 REVIEW OF LITERATURE (2/2) - UNDERLYING CAUSES OF RISK PREFERENCES THROUGH THE PRISMS OF NEUROLOGY, BIOCHEMISTRY AND GENES

3.1 Neurology of risk and cognitive biases

From Vesalius' drawings to Clarity's colourful kaleidoscopes (refer to appendix B for the scientific journey of the brain research), studying the brain has greatly benefited from innovations. Technologies allowed delving deeper into the human mind and reveal the visible (the structure, the continents) and the invisible (the electrochemical interactions, the brain functioning).

In this section reveals the concealed machinery and lists several significant brain studies shedding light on the brain functions and regions implicated in decision-making and risk. For additional studies and a further understanding of the structure and all the regions involved in such processes, refer to appendix B.

3.1.1 Neural activation and decision-making in the brain

The study of decision-making in the human brain is relatively still in its infancy. To this day the majority of the works studying the functions of the brain have used mammal subjects, however decisive and enlightening steps have already been realised. Brain-imaging studies with human have confirmed the involvement of cortico-limbic circuitry (refer to appendix B) in cognitive function related to decision-making between competing choices associated with uncertain outcomes (rewards or punishments) [118] [119] [120]. The limbic circuitry (or limbic system) and its components deal with emotion regulation, whereas the cortex (and especially the orbito-frontal cortex (OFC)) realise functions of planning, memory processing, rational thinking and projection. Emotion processing and response are crucial component involved in the decision-making mechanisms, for instance the amygdala and the ventral prefrontal cortex are two major nodes of the cortico-limbic circuitry involved in processing and regulating responses to emotional stimuli.

Studying neural activation of the decision-making processes at work is an inextricable task because regions and sub-regions of the brain are wired, entangled altogether and often

communicate in loops. Area A receives input from area B, computes it and then delivers signals called projections to several other regions, among them is often the “initial” region A, which creates a manifold feedback mechanism.

The effect of stress on decision-making is also being extensively documented. Response to stress is a refined mechanism designed to optimise the survival. Dealing efficiently with fear, making the most adequate decision in a snap, or planning ahead are the inherited traits human share. Risk-averse or risk-seeking behaviour are thoroughly fashioned to balance each other or prevail depending on the situations. Activation of the stress-system is an adaptive physiological response allowing the organism to deal with challenges, such as being able to respond immediately, meeting current or upcoming psychological and metabolic demands, being able to store relevant environmental information and adapt to it [121].

3.1.2 Prefrontal cortex

In another experiment dealing with a management simulation of a business, patients with DLPFC lesions were able to accurately assess the quality of financial advices they were provided with, yet they were unable to actually use the advice in making decisions [126].

3.1.3 Amygdala

In decision-making, neuro-imaging studies reveal that the amygdala is active during the anticipation of losses [134]. In a classic repetitive gambling task, patients with amygdala lesions displayed learning impairments (namely they did not learn to choose the less risky options with a positive expected value) [135]. Such results have been repeated [136] and hint at the key role of the amygdala in processing the losses and in the representation of negative outcomes (the experience utility of losses).

3.1.4 Framing effect and neural activation

As aforementioned, prospect theory takes a particular interest in the representation aspects of decision-making, viz. how the representations of the prospects (the outcomes, the chances) affect the agent’s utility and how these representations can be manipulated by the decision giver or altered by the decision maker. Through the prism of neuro-imaging, researchers have also

explored the path of the different tricks and cognitive biases involved in decision-making such as framing effect.

There is suggestive evidence that the degree to which an outcome is viewed as a *relative* gain or loss affects the neural processing of the outcome. Indeed, Deppe et al. lead an experiment focusing on judgment and the framing effect. Results showed that significant changes in the neural activity of the prefrontal cortex (ventro-medial) were correlated with the participant's susceptibility to the framing information provided [139]. These results were supported in another experiment by De Martino et al. who found that orbital and medial prefrontal cortex activity predicted a reduced susceptibility to the framing effect [140]. Additionally, the framing effect appeared to be specifically associated with amygdala activity, which vouches for the importance of the emotional system in mediating decision biases [140]. Moreover, the response to the same outcome in the ventral striatum is greater when the outcome is viewed as a gain than a loss [134]. The response also differs when the reward occurs in the context of a winning streak, hinting at the expectation and desirability of the outcome.

These findings vouch for a print of some cognitive biases down to the level of neurology, and highlight the importance of incorporating emotional processes within models of human choice. They suggest how the brain may modulate the effect of these biasing influences to approximate rationality.

3.1.5 Conclusion and transition

Risk fundamentally involves weighing potential gains against potential losses, and the idea that distinct neural mechanisms govern such functions and anticipate gain versus loss implies new considerations for understanding risk-taking. Above and beyond contributing to rational choice, anticipatory neural activation may also induce irrational choice. Thus, decision-making mechanisms involve and require a delicate balance, and the activation of distinct circuits seems necessary for taking or avoiding risks. However, excessive activation of one mechanism or the other may lead to mistakes. The study of brain structure, functions and activity of neural mechanisms may add predictive power to the rational actor model of decision-making in economy, finance and entrepreneurship.

Specific regions of the brain are designed and involved in the multitude of mechanisms used to make a decision, process the information, weigh the pros and cons, estimate risk and act in consequence trying to predict the outcome. All of the steps that are crucial in financial and entrepreneurial activities. The following chapter investigates one level deeper into the brain and deals with the cryptic alchemy governing those brain regions: which strings are pulled and what are those strings made of.

3.2 Hormones, neurotransmitters and biochemistry in the brain

At the dusk of the 19th century, the neuroanatomist Santiago Ramon y Cajal used Golgi's method (a chemical solution composed of silver nitrate) to visualise nervous tissue with unprecedented details. A few more years after the first drawing of a neuron, Charles Scott Sherrington proposed the concept of synapse: located on the small spots where the extensions of nerve cells join in an area both splitting and binding the link, the synapse is the locus where the pursuit or interruption of electric impulse that journeys through nerve cells takes place. The nerve impulse propagates as electric current along a nerve cell and its extensions (the axon and the dendrites), however in the synapses that cut off one cell from the others, it is not electricity that relays the nerve impulse but the release of chemical molecules, the neurotransmitters. As of today, scientists have identified several different neurotransmitters for an inventory of more than twenty distinct types: it is thanks to that expansive alphabet, as well as the series of precise matching receptor sites, that the nervous system communicates like clockwork. In the previous section (and appendix B) are introduced regions playing a decisive role in decision-making and risk-preferences; this section introduces specific molecules swaying the communication in those regions. Refer to appendix B for more explanation on communication in the brain, neurotransmitters and hormones, as well as additional examples of specific molecules involved in decision-making.

3.2.1 Specific molecules and their implication in decision-making mechanisms

3.2.1.1 Dopamine (DA)

Dopamine is a modulatory neurotransmitter that has been associated with the cortico-limbic reward circuitry (or pleasure system) in the brain. Dopamine, when released, provides feelings of

joy that become associated with the triggering thoughts or acts. As such, dopamine provides reinforcement for certain behaviours, particularly those associated with the expectation of reward.

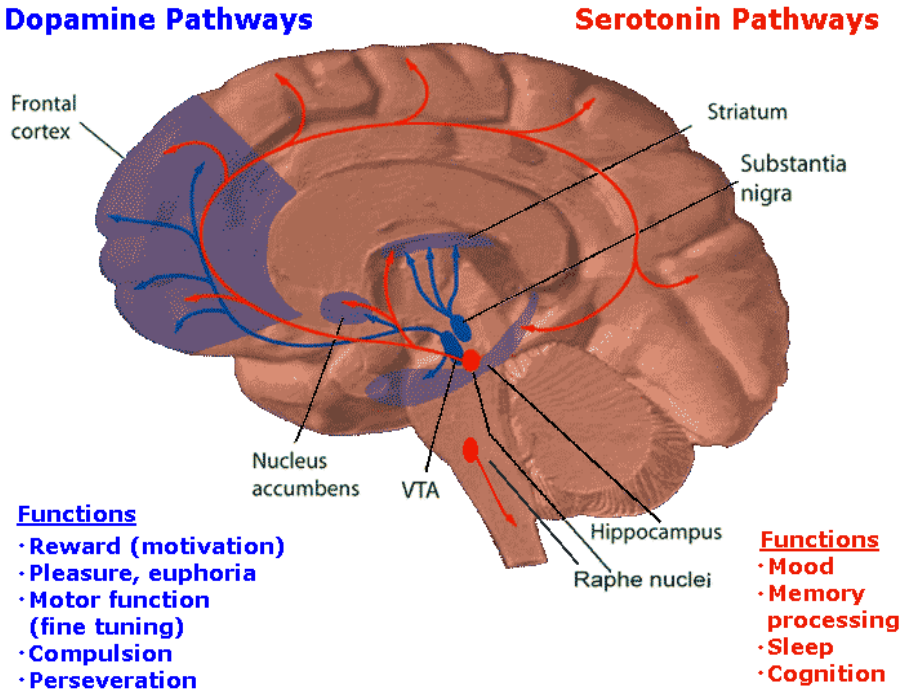

Figure 3.1: Dopamine and Serotonin pathways

The dopaminergic system appears to be a primary substrate for the representation of decision utility. Indeed, a number of studies have shown that dopamine neurons increase their firing for unexpected rewards and for stimuli that predict future rewards [141].

Then, it is suggested that dopamine illustrates and conveys the notion of the incentive value of stimuli, which in turn leads to the action (selection, decision) [143].

3.2.1.2 Serotonin (5-HT)

In the manner of dopamine, serotonin is a neuro-modulator implicated in the reward circuitry and functions such as mood, memory processing and cognition.

A complex interaction between serotonin and the dopaminergic system modulates the incentive-motivational processes [145] involved in decision-making. Rogers et al suggested that serotonin undermines decision-making through altering the representation of reward within the orbito-frontal cortex [146].

3.2.1.3 Androgens, estrogens, testosterones: sex hormones

Robust gender differences exist regarding risk preferences: men tend to be less risk-averse than women [153] [154] [155]. One possible mechanism for these differences may be the regulation of testosterone. Indeed, testosterone influences male behaviour [156] [157] [158] and has been especially implicated in a wide range of reflexes and conditions entailing some degree of risk, such as increased aggression [159], sensation-seeking [160], hostility [161], mate-seeking [162], food acquisition [163], dominance [164]. The underlying explanation for such behaviours is an adaptive explanation, putting forth the potentially increased payoffs resulting from the increased risk taken (in the context of evolution and inherited traits from our ancestors, reproductive payoffs).

Dreber & Hoffman found that financial risk aversion is positively correlated with 2D:4D ratio (second to fourth digit ratio, a proxy for prenatal testosterone exposure) in a Swedish sample of Caucasian men and women, yet not in a heterogeneous sample of American men and women in Chicago [165]. Coates et al. detected that the 2D:4D ratio predicts performance among high frequency financial traders based in London [166]. If the question of risk aversion is not directly tackled, the study seals the relevance of androgen exposure to financial decision-making, the success being a proxy of risk aversion. Plus, the study demonstrated that when participants' testosterone level is above average, they made greater profits comparatively to the days when the testosterone level was below. Although they did not examine risk taking directly, the authors attribute this higher profitability as being partly mediated by testosterone effects on the brain. It is worth mentioning however that the study did not provide the performance of the market for the days of the study, one can wonder if these traders' performances might be explained by a healthy and growing market. A rising tide lifts all boats.

3.2.1.4 Environmental influences

If natural molecules operate and modulate the functioning of the brain, one can ponder what is the impact of foreign chemicals and particles present in the environment. In the brain, the blood-brain barrier (BBB) makes sure the central nervous system is protected from perturbations and performs complex tasks. However, some particles and especially pollutants are small enough to permeate the barrier and reach the CNS. A work in progress by Heyes et al. tackles the question of air pollution and the efficiency of the financial sector with data elicited in the NYSE. Indeed,

small particle such as the fine particles labelled PM2.5 (particle matter 2.5 (1/30th of a human hair), designing particles smaller than 2.5 micrometers in diameter and believed to pose the greatest health risks) [168]) are not only present outside in the city, but their concentration does not drop when measured inside of the buildings, which means every individual is exposed to such particles. After several months conducting the study and measuring weather parameters, PM2.5 concentrations, and performance of the NYSE, Heyes et al. found a robust and negative relationship between PM2.5 and stock market returns [169]. The modus operandi was reproduced in another location and the same effect was found. Similar results are documenting the existence of an air pollution effect in another study by Lepori within a trading floor in Italy [170].

Such studies spark another path for future research, especially focusing on the environment around the decision-maker.

3.3 Decision-making down to the genes

Development of sciences made genetics the next field of investigation: with recent advances in understanding the neuroscience of risk-taking, attention then turned to genetic factors that may contribute to individual heterogeneity in risk attitudes, simply because the genetic “blueprint” shapes and hews the utmost level of our human nature.

Still a very “niche” domain of study, the question of how genetic factors may sway decision-making and risk-preferences (especially economic) is more and more prolific and of interest. Moreover if a genetic basis for differences in economic risk preferences could be determined, this would provide more support, an ultimate proof for the proposition that risk preferences are indeed a dispositional effect, meaning that an overall tendency to respond to situations in stable and predictable ways could be determined.

This section introduces a flourishing field of studies at the nexus of economics, psychology, and neurology, putting an emphasis on the genetic factors contributing to individual heterogeneity in risk attitudes. Refer to appendix B for more information regarding heredity of risk-preferences (from twin study to genetic loci), and the notions of polymorphism and phenotype.

3.3.1 General influence of genes on risk and entrepreneurship

Genes might have direct effects on chemical mechanisms in the brain that predispose people with that genetic composition to engage in risky behaviour or entrepreneurial activity. Indeed, not only genes are the blueprint of the architecture of the brain, they also provide instructions for the creation of proteins out of amino acids. For instance, if a gene that codes for the creation of a particular protein is missing, then the chemical reaction that it is designed to facilitate will not occur as efficiently. Presence or absence clearly affects such processes, but so do variation of genes (different versions of the same gene). If that chemical reaction controls brain activity, it can influence behaviour. For example, an allele of the DRD2 gene has been shown to be more prevalent among excessive gamblers than the general population because the gene affects sensations of pleasure in response to risk taking [171]. Because entrepreneurship involves risk taking, it is possible that people with this variant of the DRD2 gene are more likely to engage in entrepreneurial activity than other people because the gene increases the pleasure that they obtain from taking risks.

Genes might predispose people to develop individual attributes that affect the tendency of people to engage in entrepreneurship [172] or other risky activities such as finance. For example, extraversion is a personality trait that incorporates several attributes, including sociability, gregariousness, talkativeness, and exhibitionism [173]. Extraversion increases the likelihood that people will engage in entrepreneurship because it facilitates many skills, such as selling, that are crucial in this domain [174]. Moreover, extraversion is heritable [175] [176] [177] [178] and is related to the long alleles of the DRD4 exon III repeat gene [179]. Thus, genes might affect the tendency of people to engage in entrepreneurial activity by influencing their level of extraversion.

Genes might affect the tendency of people to select into environments more favourable to entrepreneurial activity, a phenomenon called gene-environment correlation [180] [181]. Because genes lead people to select their environments [182], environmental factors are non-randomly distributed among people of different genetic make-up. For example, gene-environment correlations might influence the tendency of people to engage in entrepreneurial activity by affecting their educational choices [183] [184] [185] [186]. People are more likely to engage in entrepreneurial activity if they are more highly educated because education provides the background knowledge necessary to notice new business opportunities [187], and information

and skills that increase the expected returns to entrepreneurial activity [188]. Genes affect the level of education that people obtain [186] [185]. Thus, genes might affect the tendency of people to engage in entrepreneurship by influencing their level of education.

On another ground, genes might make some people more sensitive than others to environmental stimuli that increase the likelihood of engaging in entrepreneurial activity. This tendency, called gene-environment interaction, means that a person with the relevant gene displays a greater reaction to the environmental stimulus than a person without that gene [180] [189] [190]. For example: the dopamine D4 receptor gene which regulates the level of dopamine in the brain [191] [179] has been shown to increase the salience of information [142] [192], and the prowess of identifying new business ideas is conditioned by the prominence of information relative to the individual gathering it [187] [193]. Consequently, people with a particular version of the DRD4 gene might be more sensitive than others to the stimulus of information about potential business opportunities. In a nutshell, the DRD4 gene might interact with information about opportunities to the extent of increasing the chances an individual will distinguish a new business idea, and therefore increase the probability the individual venture in entrepreneurship.

3.3.2 Genetic studies targeting specific molecules

For additional studies tackling the influence of genes on dopamine, serotonin, and nicotinic receptors regarding risk preferences, refer to appendix B.

3.3.2.1 Dopamine & Serotonin

Novelty-seeking (NS) and harm-avoidance (HA), two measures of risk-taking coming from psychology (refer to 5.3.5), were originally hypothesised to be driven by variation in the dopamine and serotonin systems, respectively [194]. Several studies have shown associations in NS and HA with polymorphisms thought to affect dopamine and serotonin receptors and transporters

3.3.2.2 Nicotinic Receptors

In 2009, Roe et al. identified two SNPs in the gene encoding the alpha 4 nicotine receptor, CHRNA4, that are significantly associated with harm avoidance, a risk attitude measurement drawn from the psychology literature [207] [208].

CHAPTER 4 PURPOSE OF THE RESEARCH

4.1 Synthesis and conclusion of the review of literature

We investigated the development of the theories around which decision-making and rationality orbit, illustrating the contradictions of human's behaviour when dealing with risk in finance, economic, and entrepreneurial contexts. Indeed, the relatively new field of research of behavioural finance tackles the foundations of paradigms not only ruling as kings in finance and economics, such as EMH and RA, but also serving as canvas upon which new models are based, enhanced, refined [209]. Always in this area, impressive work has been undertaken to build extensions of models as well as new designs to account for unveiled anomalies and unchecked abnormalities (e.g. [210] [211]), whereas on the other hand new theories of decision-making (especially through the prism of behavioural finance) are inquiring the same questions via another path and are focused on the elementary clutch, the crucial link of the system: the Human [212] [211]. Notably, as soon as the 70s, Shiller wrote extensively on excess volatility which ignited a school of thought inferring EMT [211] and sparking new paths of study. From that moment on, the paradigm shifted from inflexible theoretical models to developing models on human psychology and its relationship with financial markets [213] [12] [214] [215] [216] [217] [218]. Nonetheless, extreme volatility has scourged financial markets worldwide especially since the 2007 GFC [219] and until today. Since then, investors' sensibility has been all the more one of the key determinants of market behaviours, as well as a centre of focus for the booming fields of research about decision-making and behavioural finance.

More generally, the seminal and early works of Allais [41], Ellsberg [46], or Kahneman & Tversky [44] put the finger on the contradictions of Human mind in decision-making, introducing sensibility and subjectivity in every choice. Then, an important and ever growing list of cognitive biases has arisen, explaining the inner layers of those misconceptions, errors, or incapacities to cope with a decision rationally [220]: the previous chapters of the review of literature explore the wherefores of the noteworthy ambiguity effect, confirmation bias, gambler's fallacy, loss-aversion, optimism bias, overconfidence, selection bias, ambiguity aversion, or framing effect (chapters 3 & 4 and appendix B).

The field of psychology explores the ways of the mind and shed some light on the underlying mechanisms of those biases, explaining how and why they take place [221]. Then a further step can be taken, delving into the shell of the human body, mapping and charting its inner design: just as the movement of continents and earthquakes are manifestations explained by the invisible machinery of plate tectonics, the nervous system and most notably the brain are the throne of our thoughts, our sensibilities, the operating centre for the information we harvest, the storage and processing of our memory, and it accordingly designs the reaction patterns of the decisions we make [222] [223]. In 2000 years of scientific exploration, we jumped from animal spirits in our heart, dictating our behaviour, to the regionalisation of cognitive functions the brain (e.g. [224] [225]) and the countless nodes and interactions of our neurons (refer to chapter 3 and appendix B). Precise areas in the brain are summoned depending on the presented scenario, and brain activation can be linked to errors.

While neurons are the elementary unit of the brain, electricity and chemistry are the fuel, the underlying operators piloting it. A nebula of 100 billion neurons, each of them connected to roughly a thousand other neurons, and through which travels an electric impulse translated into a complex molecular language of neuro-modulators and hormones [226]. After studies where non-invasive technologies allow visualising in real time specific zones of our brain while making decision [227], neurochemistry studies reveal that specific neurotransmitters are linked to certain behaviours and emotions [228]. For instance, oxytocin is linked to optimism [229]; serotonin and dopamine are ruling the reward circuitry, memory processing and cognition (e.g. [230] [207] [231]); and testosterone levels are predictive of a trader’s daily earnings [167] [232].

In parallel, heritability studies are conducted and reveal that although the nature vs. nurture debate will never be really closed [233], patterns of risk preferences echo from one generation to another [183] [234] [235] [236]. The scouting takes the next step by exploring a little bit deeper and studying the program code in which Humans are written: heredity is no more and no less the transmission of genetic information from one generation to the following, and genes are the molecular unit of heredity. Nowadays, variations of specific genes are studied and correlated to certain behaviour. For instance, people who carry the 7-repeat DRD4 allele (as opposed to the 4-repeat allele), which is the gene coding for a specific dopamine receptor in the brain, are more likely to increase the amount of risk they incur in certain conditions [230] [237] [238]. On the biological level, the variation in the gene variably modulates the binding of the neurotransmitter

in the brain, and therefore regulates the intensity of the experienced sensation [239]. Just like the ratio of a solar cell that accounts for the ratio of solar energy converted into electrical energy.

This bottom-down approach, from factual anomalies and anecdotes, then psychology and cognitive biases, to brain regionalisation, neuro-modulators and eventually, heredity & genetics, opens a tremendously vast area of investigation and a real adventure of multiple branches for the scientists. Moreover, this exhibit enquires us on the multiples facets and components of our risk preferences. Thanks to time, science developments and technological innovations, researchers have drawn a complex combination, a blend sewn from several disciplines that lift some mist and enlighten us (while also raising many more questions) on the ins and outs of decision-making. Each of these disciplines explores a very specific area, and brings only one piece of the answer: in spite of being at the cutting edge of the bottom-down approach, the estimate of genetic influences on risk aversion is 0.16 [240], meaning it's only one piece of the puzzle and not the ultimate inception of risk preferences.

This paper is aligned with this approach and draws its inspiration from all of the literature we mentioned. Using the tools developed and used notably in all the ramifications of behavioural finance, it brings a new milestone into the study of the factors that affect decision-making under uncertainty. We reviewed a great number of studies dealing in their own way with the subject, whether it is about the specific field of study (neurology, psychology, behavioural economics, behavioural finance...), or about the tool(s) used, in particular how to measure risk. Frequently, a lack of possibility to reproduce the studies or to compare the results with other scientific productions in pointed out: psychologists, neuroscientists, behavioural economists have their own ways to consider the nature of risk, which are often distinct, however not antagonistic. In this paper, we postulate that risk in all those disciplines is not different by nature, but by degree, meaning that there is a strong interest and advance to use the different measures all at once and enquire for a pattern and congruous links, which would help to better understand risk preferences on the whole. The essence of our subject is to compare these measurement tools to each other, see how they supplement themselves, see if they overlap, and see if the whole is more than the sum of its parts and the lines drawn between the different papers and their field of study are separating or can be bonding.

The subject brings another contribution by exploring the topic of risk-attitude in the particular context of our sample. Students are the decision-makers of tomorrow, this statement being all the more true since graduates from our sample will play key roles in leading corporations, governmental institutions or build their own companies from the scratch of a pioneering idea [241] [242]. This is the reason why we explore the domain of entrepreneurship, another range of risky behaviour, among students. Of fundamental importance for our subject, entrepreneurship among students is also of concern for the universities which tend to foster the maturing of technical ideas into practical benefits and businesses for society.

At the end of our investigation through the literature, the early questions we raised in the introduction become better-rounded, and we coined the following research questions.

4.2 Research questions and hypotheses

4.2.1 Research questions

Our research question is the following:

QR: How can we understand the reasons behind entrepreneurial orientation in students?

This interrogation brings along two sub-questions:

SQ1: How sundry concepts of risky behaviour drawn from multiple fields of study and their respective measurement methods are intertwined?

SQ2: How to combine and arrange those proxies to better depict the subtle variations of rationality, risky behaviour and decision-making capacities?

4.2.2 Hypothesis

- H: Respondents who will score positive in optimism, in novelty-seeking, and negative in harm-avoidance will score positive in entrepreneurial orientation and financial risk-taking (on the contrary, respondents who will score negative in optimism, in novelty-seeking, and positive in harm-avoidance will score negative in entrepreneurial orientation and financial risk-taking).

4.2.3 Assumptions

In this research project, several tools from different disciplines are used to build the experiment. This construct has been designed under several assumptions:

- There are differences of nature and amplitude of risky behaviour in every individual;
- Experimental tools developed in various fields of studies (psychology, neurology, behavioural economics and finance) and measuring different aspects of risk attitudes help highlighting those differences and are complementary, altogether refining a global picture of multiple shades of risky behaviour and decision-making skills;
- Such differences are ardent and strong through gender differences, as well as academic program differences.

4.2.4 Transition

The following section introduces and develops in details our methodology: what we measure, how we measure it, what is our sample, how we deal with the data, our different levels of analysis and how it will allow us to answer our research question.

CHAPTER 5 DETAILED METHODOLOGY

As the review of literature shows, in order to understand the strings pulling students towards the path of entrepreneurship it is necessary to consider decision-making as a whole, its multiple sides and aspects. This is the reason why this project borrows notions and tools from all the disciplines tackling this subject and amply discussed in the review of literature.

There are several strategies to measure entrepreneurship affinity, for instance using statistics about the number of company and entrepreneurial projects students ignite and steer after leaving school. However considering the other tools adopted and the demeanour of our interrogations, our methodology followed another structure.

5.1 Architecture of the experiment

Every respondent to the study was invited to complete an online survey consisting of two sets of questions. The first set of questions has the purpose of gathering data about different aspects of risk-taking via numerous methods borrowed from several fields of study (refer to 5.3) while the second set of questions is dedicated specifically to elicit data about financial risk-preferences through mini-games (refer to 5.4).

As aforementioned, by compiling the literature review it is notable that all of the studies dealing with decision-making behaviour differ in terms of how risk preferences are defined and measured. For instance, risk preferences proxies such as harm-avoidance (HA) and novelty-seeking (NS) are commonly applied risk measurements. These two measures originate from the psychology literature [243] and are used broadly by behavioural neuroscientists [227] and geneticists [244] [245]. On the other hand, the vast majority of behavioural finance and experimental economics studies focusing on decision-making and risk preferences use the magnifying glass of various mini-games that involve choices under uncertainty and investment decisions. Although converging and tackling down the same subject, these different methods speak the same idea in different languages and sensibilities.

The experiment is divided in two main sections: questionnaires and games. Both of them offer a range of risk preferences measures from literature expressing multiple nuances.

There are eight questionnaires and five games. See Figure 5.1, and sections 5.3 & 5.4.

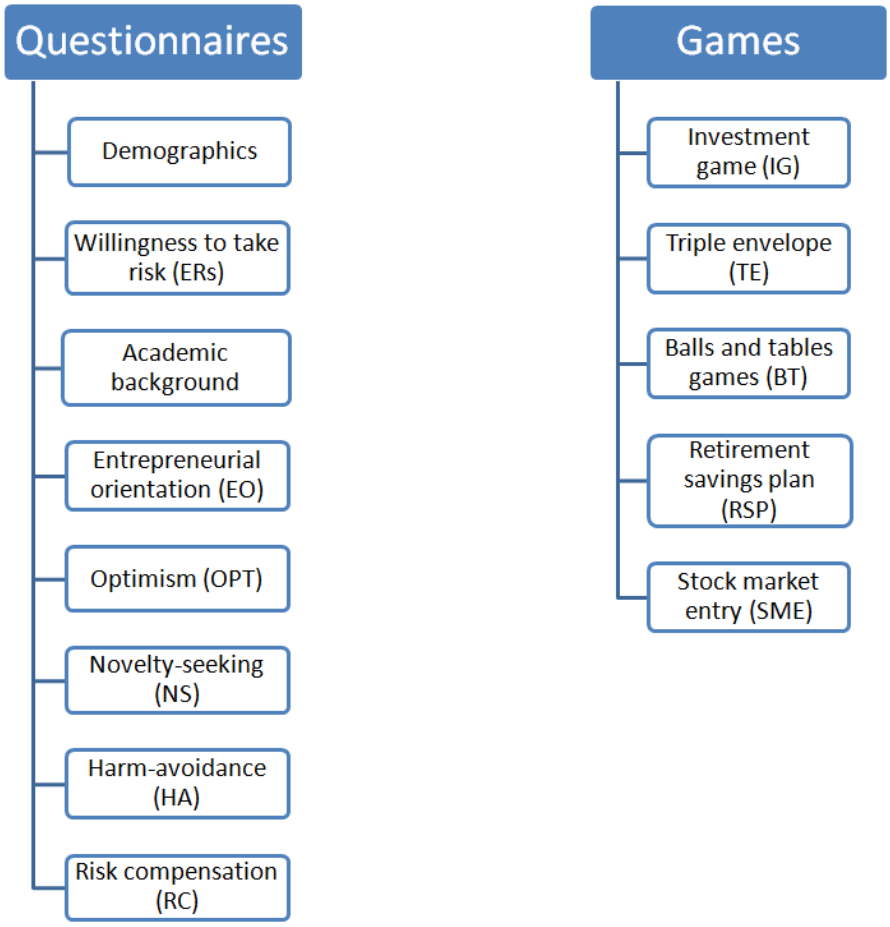

Figure 5.1: Framework of the experiment (8 questionnaires and 5 games)

5.2 Data Analysis

The goal of this research project is to shed light on links and interactions between the different conceptions of risk-preferences found in distinct areas of the behavioural decision-making literature. That is, seeking a Rosetta stone for those sundry languages that same idea is expressed in. The other object of focus of our research is to better understand entrepreneurial orientation and its components using the different tools at our disposal, as different filters to reveal deeper invisible layers explaining the visible. Targeting specifically a student (an engineering student) population, the research project also aims at underlining a particular risk profile (if it exists) as well as entrepreneurial profile for this population. Consequently, the essence of the methodology is to compare the data elicited thanks to different measurement tools (from sections and subsections) to one another. The analysis is organised around several "levels".

5.2.1 Level 1 analysis

Compare to one another the data and scores of the questionnaires (for instance: is the score of optimism measured by LOT-R [249] correlated to novelty-seeking measured by TCI/IPIP [251] ?). Tools directly borrowed from literature (the majority of the tools used during the study) are of particular interest and set apart from the measurement proxies developed for the study (inspired by literature – refer to chapter 6). As the item of utmost interest, the data of entrepreneurial orientation (EO) will be at the centre of intention.

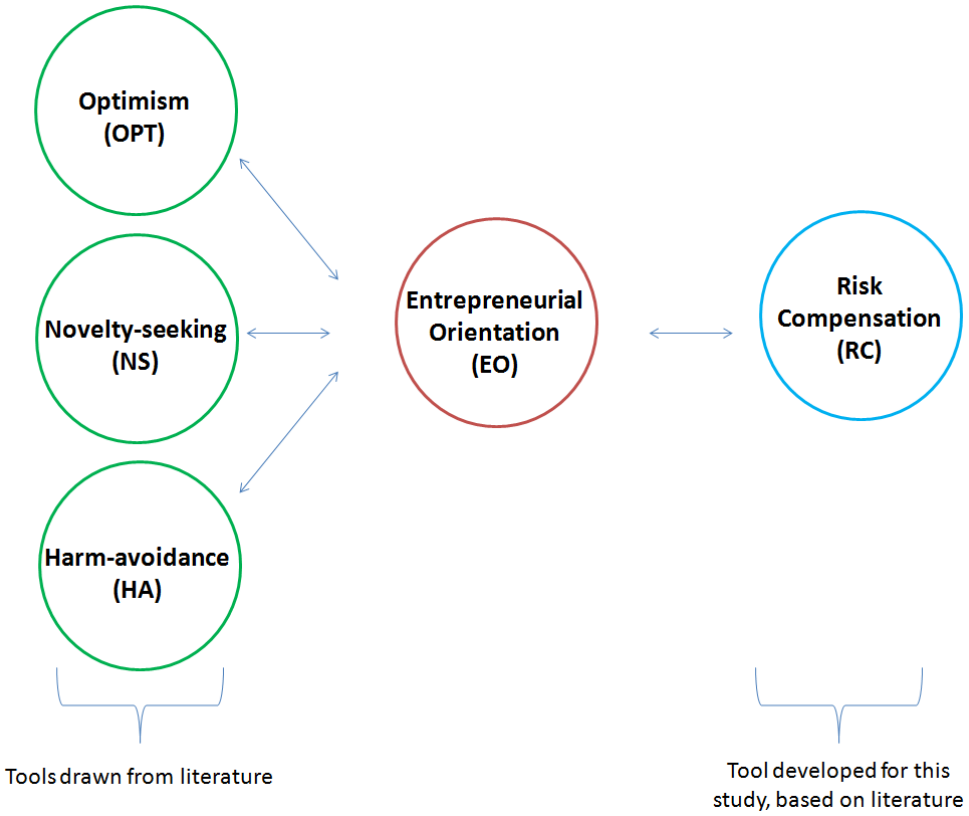

Figure 5.2: Comparing proxies measuring risk-preferences to the measurement of entrepreneurial orientation (EO)

5.2.2 Level 2 analysis

Compare the data from the questionnaires to the results of the games (for instance: is the score of optimism measured by LOT-R correlated with the choice made in the investment game?). Additionally, answers from the games will be pooled together in a calculated financial risk-taking (FRT) score engineered for this study defined as a behavioural finance score summarising risk-

attitude elicited from the games (refer to 5.5). FRT will be compared to the data of the questionnaires (for instance: is the score of optimism measured by LOT-R correlated with the FRT score?).

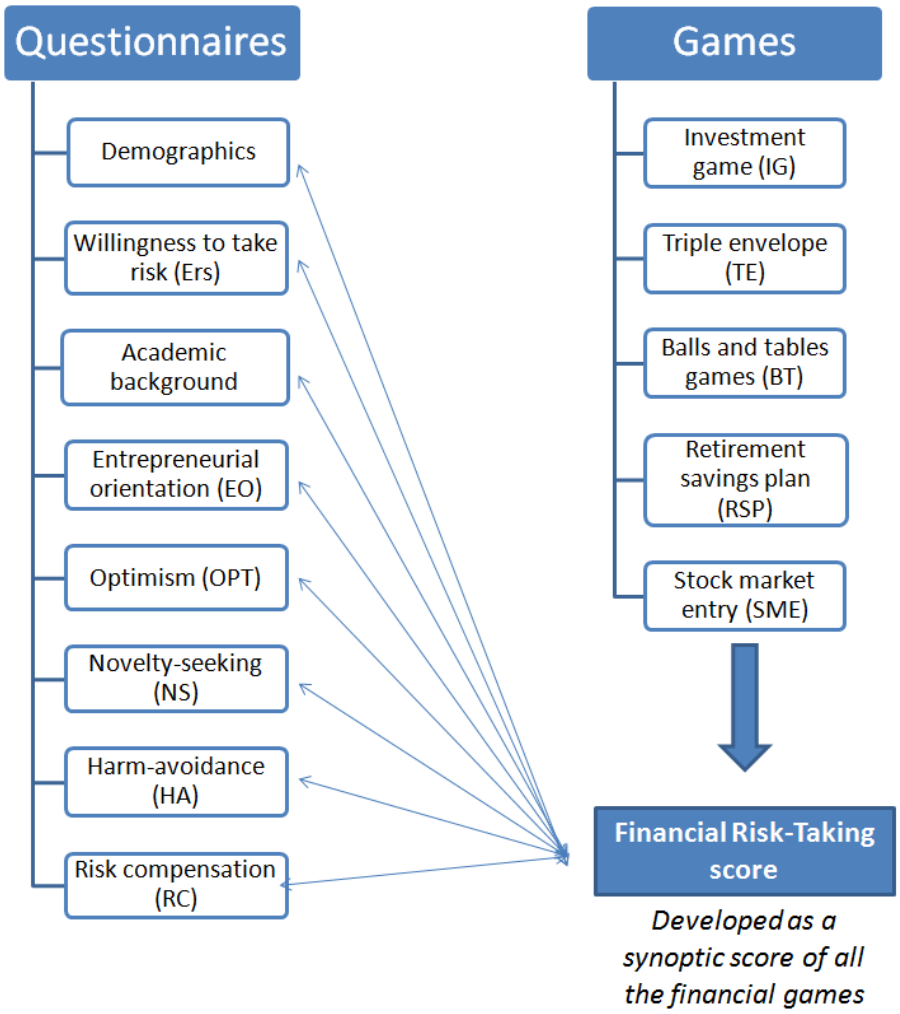

Figure 5.3: Comparing risk-preferences proxies to experimental economics data

5.2.3 Level 3 analysis

The third level of analysis will be a synthesis consisting in the definition of a risk profile for the population of respondents, as well as the entrepreneurial profile according to the other notions and proxies of risk-preferences.

5.2.4 Adjustments to the measurement tools

Those three levels of analysis between distinct measures of risk preferences allow focusing on very specific links and also investigate a more global picture. Sections 5.3 and 5.4 explain in details each element composing the questionnaires and games, providing the sources of the tools used, their instruction book in order to obtain measures and calculated scores, as well as the reasons why they are providing relevant data for the project.

In the tools taken from the literature, a couple of adjustments and tweaks were realised in order to achieve simplification and standardisation of the questions asked not only for the participants, but also for a standardisation of the data elicited (namely, the range of the Likert scales used). Indeed the majority of the tools taken from literature, participants have to rate a statement following a specific scale, and in some cases the amplitude of the scale had to be changed. Moreover, in rare occurrences the wording of the statements was tempered to avoid too extreme answers and grant the participant more subtlety.

In the questionnaire assessing EO, respondents had to use a Likert scale scoring from 0 (= not like me at all) to 5 (=very much like me) to assert their position regarding each statement, thus having a range of six possible nuances towards the statement. The choice between odd and even scale comes down to offer to the respondent, or not, a “neutral” position. With an odd scale, there is a balanced answer (equilibrium) that does not convey a real opinion or commitment towards an attitude, whereas on the contrary an even scale is referred to as *forced choice*, for the respondent has to topple over one side or the other of the attitude in the statement.

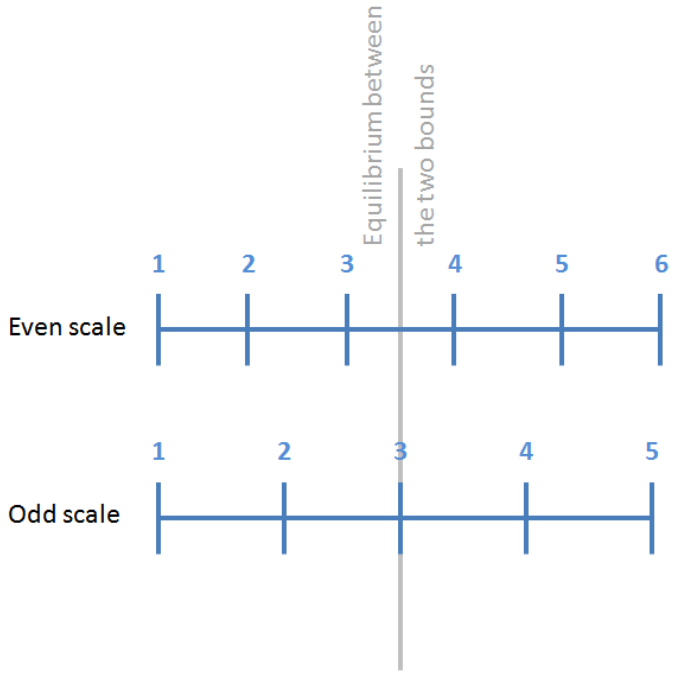

Figure 5.4: Representation of even and odd Likert scales, and the neutral position

As an odd scale is used in the models of LOT-R and IPIP, respectively used in questionnaires OPT, NS, and HA, it strongly suggested turning the originally even Likert scale in EO model into an odd scale in order to unify the whole questionnaire as much as possible (whether it be for the participants' understanding, or the unity of the questionnaires').

The whole survey was available in both English and French to open for more respondents. The same cautious approach was applied to the translation from English to French when no occurrence of a French version of the measurement tool we use was found in the literature. The majority of the questions has been translated from English to French, with the exception of the optimism survey (LOT-R) which has a review version in both languages. The translation was cautiously undertaken by the student in charge of the research project. The statements of the survey once translated in French have been examined by Carl St-Pierre, and eventually both versions –French and English- of the survey have been tested by several French-speaking and English-speaking volunteers for misunderstandings and nuances.

Eventually, it is noteworthy that the whole survey, questionnaires and games, has been the subject to several review sessions and enhancements following the expertise of Carl St-Pierre. Carl St-Pierre is a statistician, research associate at Polytechnique Montreal. He has been

involved in numerous projects lead collectively at Polytechnique Montreal and at CIRANO. His savoir-faire and his expertise were crucial to produce several meticulous amendments at multiple steps of the experiment.

5.3 Questionnaires

Our research aims at capturing the respondent's risk attitude in different domains and situations. For that purpose, several tools were drawn from the literature and others were elaborated in order to elicit certain facets of behaviour towards risk. Together, and in addition to the data collected via the financial mini-games, a wider picture is obtained to illustrate every aspect of risk-preferences, a sweeping and more detailed picture to highlight subtleties and potential links. Each of the following subsections dissects in details the tool used and gives examples of studies in which it was applied. Demographic information

This section gathers plain data concerning profile of the respondent (gender, age, occupation). Refer to the section C.1 for the questions as they were presented to the respondents.

Such socio-economic variables are quite obviously interesting, and are very orthodox and conventional in this type of study for they are easy to gather and analyse. Moreover, they have already been of focus for previous research which vouches for our point and provide a foundation to relate to. For instance, it is of knowledge that robust gender differences exist, with men being less risk averse than women [153] [154] [155] [257]. Age is also key component of decision-making, whether it be regarding information search pattern, information processing and decision rules (e.g. [258]); accumulation of decision making experiences (Taylor, 1976); or on a more biological ground the plasticity and development of particular brain regions [259]. As our sample of participants will not offer a wide spectrum of age differences, we do not expect to see heterogeneity in that area, however we expect to see trends corresponding to previous studies (id-est, above average willingness to take risk [260]).

5.3.1 Willingness to take risk (ERs) [246] [260]

Eventually, we ask the participant to assess its willingness to take risk, following the model of Dohmen et al. [246] [260]. In their wide range study, they found that such assessments are a

qualitative survey measure generating a meaningful proxy for risk attitudes. They also offer relevant data to explore and compare to further parts of our experiment.

First and foremost, the respondent has to perform a self evaluation of their willingness to take risk in general (ERG). Then, five additional evaluations concerns precise situations or domains: in health matters (ERH), in financial matters (ERF), in sports and hobbies (ERS), in their professional career (ERC), and while driving (ERD).

It is interesting to compare the values of the different domains to the ERG in order to elicit context specific risk-preferences.

5.3.2 Academic background [247]

Since our study tackles the entrepreneurship among students, it is of interest to gather as much information as possible on the respondents' background. And since it is not seldom that a student earns multiple degrees in different institutions while forging their orientation, every participant can fill in three different triplets of information. The three facets being: institution, degree type, and program. Refer to section C.3.

Information on the academic profile is relevant and was exploited along with the data from the measure of the entrepreneurial orientation (5.3.3).

5.3.3 Measure of the entrepreneurial orientation (EO) [248]

In our study, the evaluation method of the entrepreneurial profile is taken from a tool developed in 2012 by Matlay et al. [248], based on the work by Covin & Slevin [280]. The tool provides an evaluation of the entrepreneurial orientation (EO), which is a score calculated via a questionnaire listing statements to be assessed via a Likert scale. Refer to the appendix C.4 .

Nota bene: the original test used in Matlay et al. offers 24 statements to be rated by the participant. In the present research project were added statements 25 to 31. Indeed, based on related literature [281] [282] [283] [284] we tailored six supplementary questions in order to elicit data specifically in regards to the students' respective institutions and the role of entrepreneurship education [285] [286]. We coined simple statements to be assessed by the participants using the same model than the EO and the same 1-5 scale aforementioned. Refer to the appendix C.

The 24 original statements agglomerate in sub-dimensions expressing various aspects of entrepreneurial orientation: innovation, pro-activeness, confrontational tolerance, entrepreneurship desire, risk-taking, and networking. While asserting the robustness of the data of our experiment (see 6.2.3.1.1), the same sub-dimensions were found. The additional statements were designed to put forth two sub-dimensions: EO_edu (vouching for the effect of the academic institution on the respondent's entrepreneurial orientation) and EO_proj (vouching for the existing desire and project to become an entrepreneur).

After several discussions, cultural differences were not accounted for. Indeed, asking the participants a question to elicit data about their culture wasn't an element in Matlay et al., and also asking about nationality or country of origin did not sound relevant, for several other more meaningful bias apply to international students (a certain profile, a social background). Moreover, asking questions about cultural background such as nationality or religion could potentially ward off either the respondents or the ethic committee. Eventually, it was foreseen that the majority of the respondent would be from the undergrad population which sees fewer international students, and it appeared that a small sample of non-Canadian/Quebec/French-speaking respondents wouldn't be subject to analysis.

5.3.4 Optimism (OPT) score [249] [250]

Eliciting a measure of optimism is gathering relevant data for our study. Indeed, optimists tend to process information in a different way than the considered average person, and make decision accordingly [249] [287]. Their expectations for the future tend to be higher too. This personality trait has an influence in daily situations, mood, as well as more stressful situation and important decisions. Our revue of literature specifically points out the impacts of mood in finance [17] [288], and more broadly the numerous underlying links with reward, motivation, memory processing, and cognitive biases such as selection bias, apophenia (tendency to perceive signs or meaningful patterns within random data), confirmation bias. This is the reason why this lead is often followed in research domains tackling decision-making in psychology [287], neurobiology [289] [290], behavioural finance [291] and behavioural genetics [292].

In our study, optimism was measured using the Life Orientation Test – Revised (LOT-R) [249], a ten-item measure of dispositional optimism. The revised scale was constructed in order to eliminate two items from the original scale [293] , which dealt more with coping style than with

positive expectations for future outcomes [249]. The LOT-R is broadly adopted in the multiple aforementioned fields of study (e.g. in behavioural finance [294], in neurology [295]), and is very easily used by both the participant and the researcher: it lists 10 simple statements the participant has to score using a Likert scale, viz. expressing its degree of agreement. Refer to appendix C.

Based on the participant's answers, a score is calculated following these instructions:

- Reverse code items 3, 7 and 9 prior to scoring (0 => 4) (1 => 3) (2 = 2) (3 => 1) (4 => 0). The items to be reversed are marked as (-) keyed in the table below, whereas the items that do not change are marked as (+) keyed;
- Sum items 1, 3, 4, 7, 9 and 10 to obtain the overall score;
- Items 2, 5, 6, and 8 are filler items only. They are not scored as part of the revised scale.

Table 5.1: Illustration of the LOT-R scoring method to calculate the OPT score

Statement #	Key	Score	Adjusted Score
1	+	3	3
2	+	4	4
3	-	1	3
4	+	4	4
5	+	4	4
6	+	2	2
7	-	1	3
8	+	4	4
9	-	1	3
10	+	4	4
		Total	17/30
		OPT score	2,833

Items #1, 3, 4, 9, and 10 are involved in the score. Others are fillers items.

Recently, this tool was translated from English and evaluated specifically for a use within the French-Canadian population, to facilitate its use and assure its results [250]. This translation was used in the French version of the survey, whereas the English version uses the original English test [249].

5.3.5 Novelty-seeking (NS) and harm-avoidance (HA) [251] [252]

Novelty-seeking captures a subject's tendency toward exploratory activity and exhilaration in response to novel stimuli, as well as impulsive decision-making, desire for novelty and the unknown [243]. Harm-avoidance captures the intensity of a subject's response to aversive stimuli

and eagerness to avoid such stimuli. It is often associated with anxiety, pessimism and shyness [243].

Numeric scores for NS and HA are based on subjects' ratings of 34 and 39 statements, respectively. Those statements are drawn from the International Personality Inventory Pool (IPIP), a public-domain instrument shown to correlate to major personality inventories including the Temperament and Character Inventory (TCI) of Cloninger et al. [296] [252]. There are many instances of the IPIP scale used in recent research tackling down behaviour, notably: psychological factors and trading performances [297], measuring risk attitudes compared to personality traits [298], or risk perception relative to personality facets [299]. Regarding NS and HA, these notions are also used extensively and broadly, for instance from prediction of drinking [300] to genetics determinants of financial and psychological risk attitudes [245] [207].

Just like the LOT-R, this tool is a list of simple statements the participants have to score using a Likert scale (34 statements for NS, 39 for HA). Refer to appendix C.

In the literature, those measurements tools provide indication on several sub-dimensions expressing specific aspects of NS and HA. Indeed, novelty-seeking is composed of four sub-dimensions (variety-seeking, impulsiveness, extravagance, and rebelliousness – refer to 6.2.3.2), and so is harm-avoidance (neuroticism, harm-avoidance, social discomfort, and low self-efficacy – refer to 6.2.3.3).

The sub-dimensions are defined as follows:

- Variety-seeking: also known as exploratory excitability, qualifies the tendency of arising boredom when there is a status quo, the desire to change and switch to alternative even if the current state is satisfactory;
- Impulsiveness: the tendency to act on a whim, displaying behaviour characterised by little or no forethought or consideration of the consequences;
- Extravagance: the tendency to wander outside the norm, and behave with excess, eccentricity;
- Rebelliousness: also known as disorderliness, qualifies an undisciplined, rebellious, unruly or disturbing behaviour, trait of an individual lacking regular or logical order;

- Neuroticism: personality trait opposite of optimism, characterised by anxiety, fear, moodiness, worry, envy, frustration, jealousy, shyness, and loneliness.
- Social discomfort: also known as social anxiety, the fear of interaction with other people that brings on self-consciousness, feelings of being negatively judged and evaluated, resulting in avoidance;
- Low self-efficacy: self-efficacy is one's belief in one's ability to succeed in specific situations or accomplish a task, and this sense may play an important role in how an individual approaches goals, tasks, and challenges.

5.3.6 Risky behaviour in real situations

This score is original to this study. It has been conceived following the models of LOT-R, IPIP and EO, and aims for picking up aspects of risky behaviour focusing on real life situations everyone can experience every day. The situations we use to build this test are whether generally accepted as risky, or backed up by literature. They belong to the domain of risk compensation and risk homeostasis which concern many and varied environments, and which leads are studied in decision-making and behavioural finance since they do bring participants face to face with plain rational decisions. More broadly, risk compensation is the formulation of a cognitive bias asserting people typically adjust their behaviour in response to the perceived level of risk, becoming more careful where they sense greater risk and less careful if they feel more protected. It is in cahoots with other biases we largely cover in the literature review, such as confirmation bias and selection bias.

5.3.6.1 Statements 1 to 6: Daily risk compensation (DRC)

We formulated those statements on several readings, taken from psychology articles mentioning certain attitudes to specific reports tackling a niche subject in another field of study. For instance, we found that regarding the non-use of the seat belts, those most commonly reported individuals are of male gender, passenger status, high risk takers/drinkers, of younger age, and rural living [301]. As for the cycling, helmets have the potential to reduce head injuries according to several cross-sectional case-control studies [302], however those who use helmets routinely perceive reduced risk when wearing a helmet, and compensate by cycling faster [303] [304].

5.3.6.2 Statements 7 to 14: Pecuniary risk compensation (PRC)

Those statements tackle the risk compensation in the narrower field of money management. They do not involve any investment decision, or risk taking in situation of uncertainty, but address the subject of daily management of money, habits, and real life situations. To this extent it differs from the mini-games tackling the subject of financial risk-taking (10.4).

The statements and method we use are not stemming from a model or measurement tool developed and published in the manner of LOT-R, IPIP or EO. However they are mentioned in several studies, such as the behavioural article by Carpenter involving DRD4 receptor gene and risk-taking [238]. We borrowed some statements and tweaked some others.

5.3.6.3 Statements 15 & 16: Health risk compensation (HRC)

In a study conducted by Institut de la Statistique du Québec [305], light is shed on several behaviours qualified as risky and their link with socio-demographic data. The four behaviours under the spotlight in this study are: tobacco consumption, drug consumption, pathological gambling, and alcohol consumption.

We took on tobacco consumption and alcohol consumption and included them into the risk compensation section of the questionnaires. We avoided the drug consumption aspect for ethical and sensible reasons, and the pathological gambling aspect is dealt with in a previous statement. The respondents are asked to assess their consumption frequency. Refer to appendix C.

5.4 Games: Measure of financial risk preferences (Experimental economics)

The second type of risk attitude measurement comes from the experimental economics literature. Economists commonly measure risk attitudes by recording subjects' decisions among competing financial gambles or investment opportunities. Economic risk attitudes often show a limited correlation to psychologically based measurements of risk attitude [207], suggesting that risk attitudes may be domain specific [306] and not captured precisely by more general risk attitude measures stemming from others fields such as the one we used in the questionnaires: OPT, HA and NS.

In our study we measure variations of economic risk attitudes by means of multiple mini-games that put the respondents into situation similar to reality.

5.4.1 Investment game (IG) [253]

In this first game we measured the participants' risk preferences using an investment game with real monetary payoffs adapted from Gneezy & Potters [253] and used recently by Apicella et al. [167].

Respondents begin with an endowment of $250 and are asked to choose an amount, X, between 0 and 250 that they wished to allocate to a risky investment. The rest, $250−X, is kept by the respondent. The participants are told that the result of the risky investment is determined by a coin flip, the outcome being that in case of failure, the money invested is lost, and thus the player earns $250−X. If successful, the money invested is multiplied by 2.5 and the player earns $250+1.5*X. Since investing is risky but offers higher returns, subjects must weigh a higher expected return compared to the risk they feel regarding the investment. This means that a risk-averse individual can choose to invest $0, and would thus get $250 with certainty. On the contrary, a risk-seeking individual can invest all $250 into the risky investment, and is then equally likely to receive $0 or $625 (the expectation being $625*0.5=$312.5).

The respondents were submitted the previous explanation, as well as the diagram below:

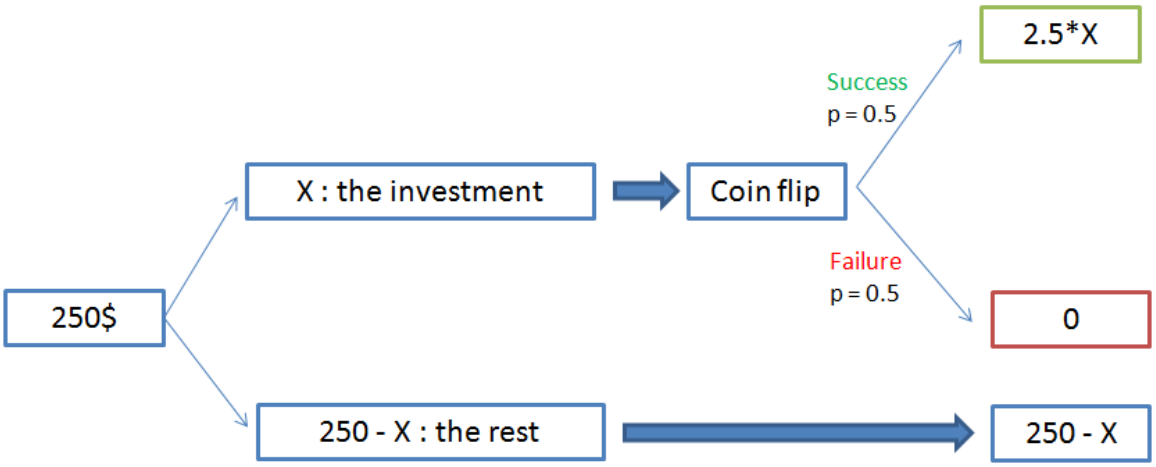

Figure 5.5: Investment Game - Diagram displaying the process of the first mini-game

In this subsection, it is *X*, the fraction invested by the respondent, that is our measure of risk-taking.

5.4.2 Triple envelope (TE) [254]

As our second measure, we use another simple investment game presenting a different situation coined by Hube [254]. In this mini-game, each participant is given the choice between 3 different envelopes:

- First envelope has inside 2000 dollars with a 100% probability 0;
- Second envelope has inside 5000 dollars with a 50% probability, 0 dollars with a 50% probability;
- Third envelope has inside 15000 dollars with a 20% probability, 0 dollar with a 80% probability.

The difference in expected payoffs across these lotteries mirrors real world investment decisions, where the three lotteries have successively higher expected payoffs and risks (see Murnighan, Alvin & Francoise, 1988). The respondents were submitted the previous explanation, as well as the diagram below:

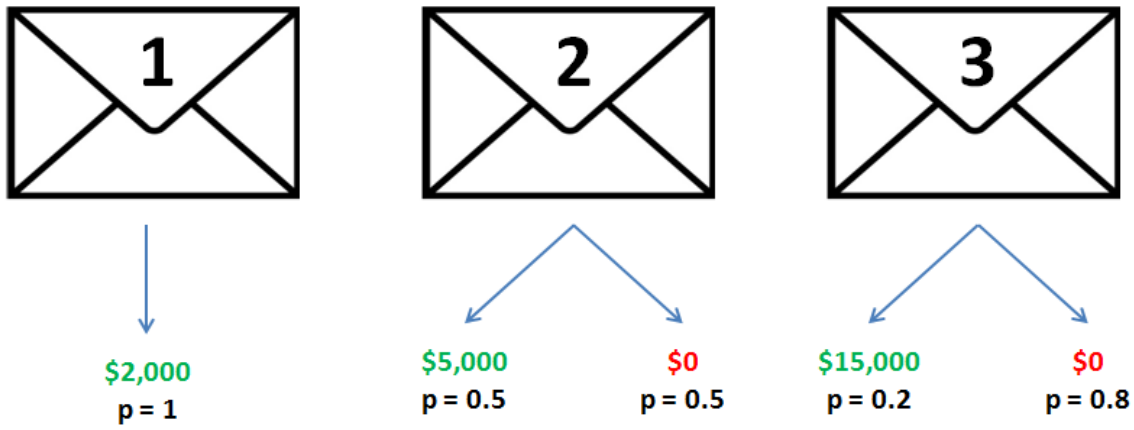

Figure 5.6: Diagram illustrating the first round of the Triple Envelope game

We then propose the same choice to the respondent, however this time we also display the calculated expected value of each lottery. With this additional information and the relatively low delta in expected earnings versus the greater risk, we want to observe if a change in the decision happens.

Table 5.2: Expected earnings for each envelope of the Triple envelope game

Envelope number	Outcomes ($)	Probabilities	Expected earnings ($)
1	2000	1	2000
2	5000	0.5	2500
	0	0.5	
3	15000	0.2	3000
	0	0.8	

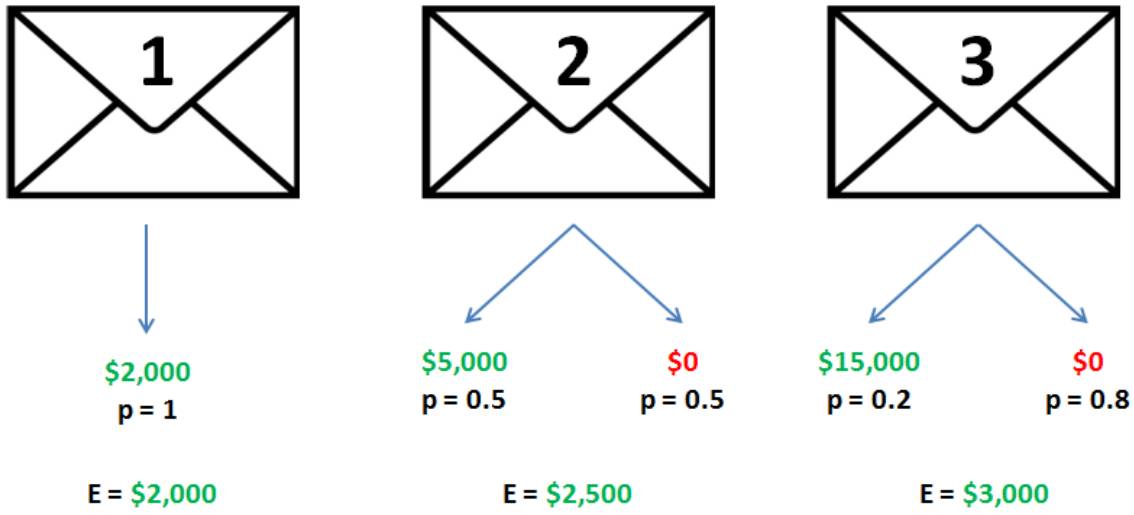

Figure 5.7: Diagram illustrating the second round of the Triple Envelope game

This game gives three pieces of information: choice of first envelope, choice of second envelope, and change of choice between the two rounds of the game.

5.4.3 Balls and tables game (BT) [154] [307]

Again we use an experimental economics grand classic: a modified version of the structure introduced in Eckel & Grossman [154] [307] and used more recently in 2011 by Garbarino et al. [255] and Carpenter et al [238].

Each participant plays four rounds, thus makes four risky choices in the same order. For each choice, participants consider the situation where there is a table on top of which six boxes are set. Those boxes represent a lottery: in every box lie 10 balls that can be either black or white. The colour indicates the outcome of a lottery: picking a white ball gives the high outcome of the box, whereas picking a black ball gives the low outcome of the box. The six boxes display different couples of high and low outcomes. Now, the respondent can't see the balls inside the boxes, thus

even if the choice is made regarding the box from which a ball is picked, the ball will is actually picked randomly.

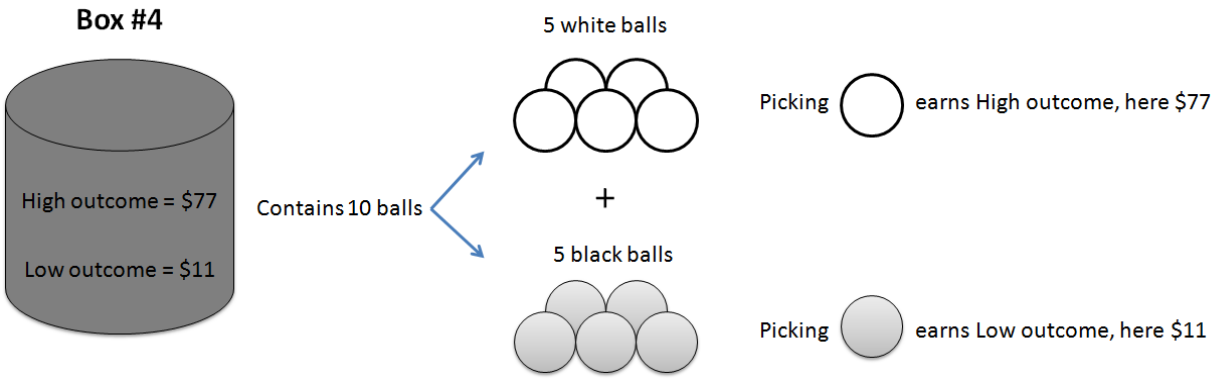

Figure 5.8: Diagram illustrating the concept of the third game, balls and tables game

While designing the balls and tables game, there was a long discussion regarding the form of it and the implications that variations of designs would have in the results. This would raise more questions regarding the rationality of the participants, as the trustworthiness of the researcher, the difference of result if the respondent is presented four actual tables with boxes and balls in them or playing on a computer, the delta between the amount of each set of balls, etc. This is an amazing as well as a mazing topic.

5.4.3.1 First table: simple choice table

To minimize any problems that the participants might have with assessing probabilities [77], the likelihood of good and bad outcomes were equalized for the first table. The Figure below displays the first table (the first round of the game), which was designed to gather baseline risk attitudes. Here the payoffs for each 50–50 lottery were chosen so that both the expected payoff and the variance in payoffs increase from left to right.

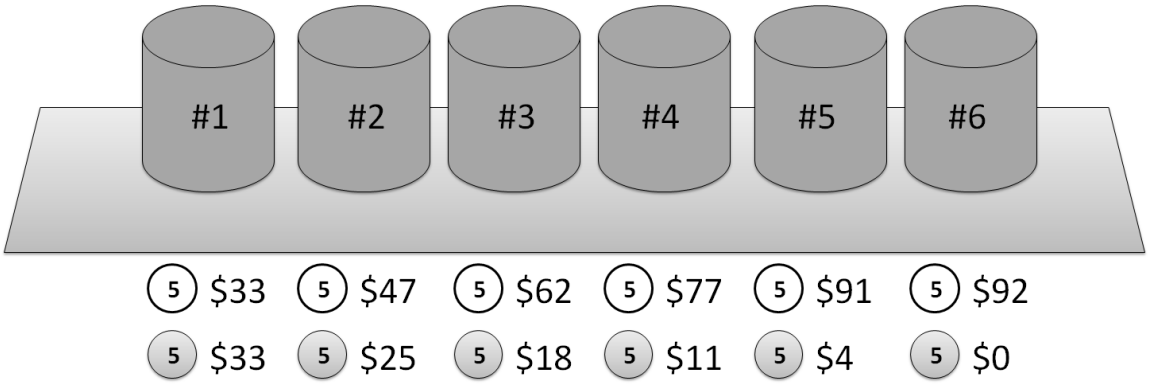

Figure 5.9: Simple choice table, first round of the third game

It's important to design an experiment that is understandable for the participant to capture its true behaviour and measure its risk preferences. After choosing one of the boxes to pick one ball from during the first round, participants played 3 more rounds where the setup was slightly altered.

5.4.3.2 Second table: ambiguous choice table

In the second, ambiguity, task displayed in the Figure below, the possible outcomes of the lotteries were the same but the chances of either the good or bad outcome were uncertain.

Instead of six boxes with five high and low value balls for sure, participants were told to think of each box as having two high value balls and two low value balls for sure, but they were told the distribution of the remaining six balls is unknown and random. This meant that the probability of the good outcome was uncertain; it was somewhere between 2/10 and 8/10. The ambiguity task was designed to see if probability uncertainty would cause a shift in the behaviour compared to the first round, which served as benchmark.

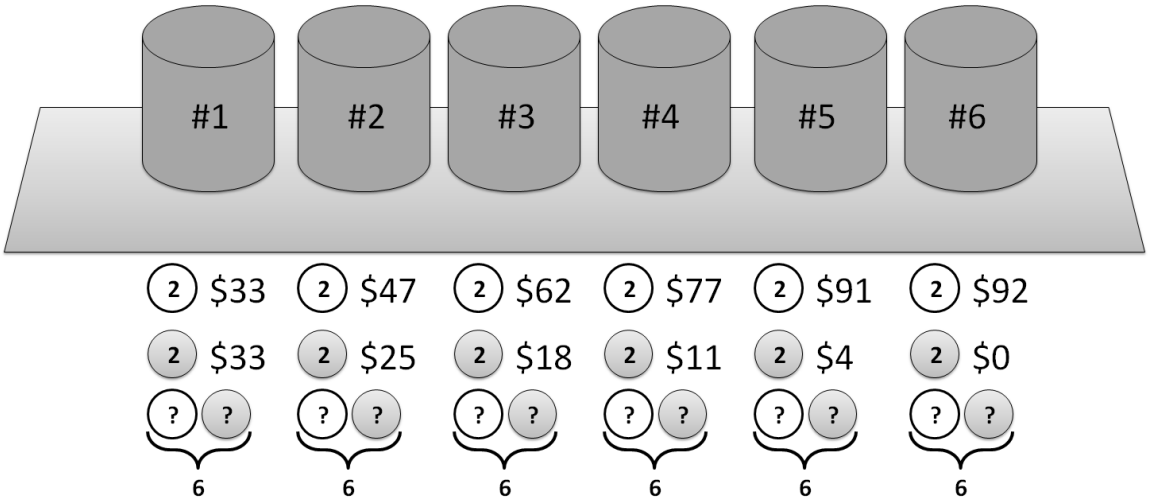

Figure 5.10: Ambiguous choice table, second round of the third game

5.4.3.3 Third table: potential loss table

In the third, loss task motivated by prospect theory [44] [55], players are given $50 to "play with" and then chose from the six boxes in Figure below. Quite simply, if you add $50 to each payoff, you get back to the benchmark of Figure 10.9. Therefore the only change is the framing of the decision problem. The purpose of the loss task was to investigate whether participants would react differently compared to the first round when losses are considered and possible.

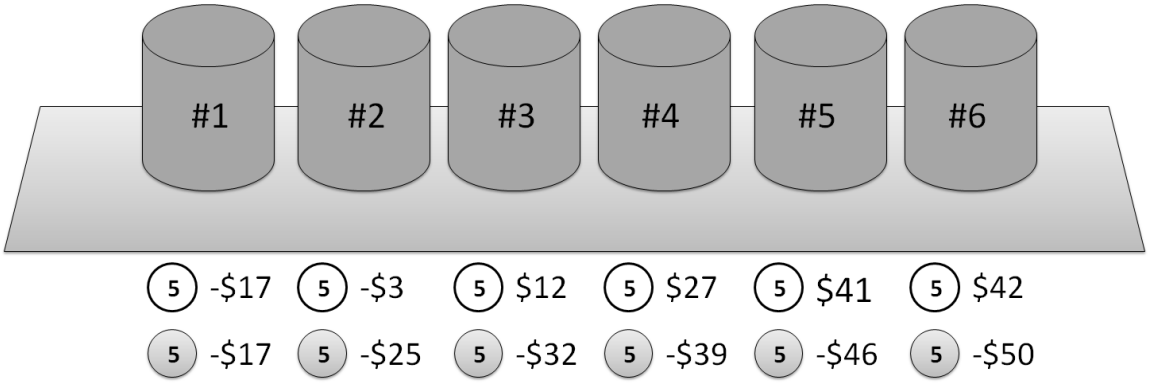

Figure 5.11: Potential loss table, third round of the third game

5.4.3.4 Fourth table: ambiguous choice & potential loss table

Eventually, in the fourth round, ambiguity and potential loss designed of table#2 and table#3 are combined. Players are "given" a new $50 endowment to play with and are faced with the same

numerical value than the potential loss table, however with the uncertainty of the probabilities regarding the good and bad outcomes of each box.

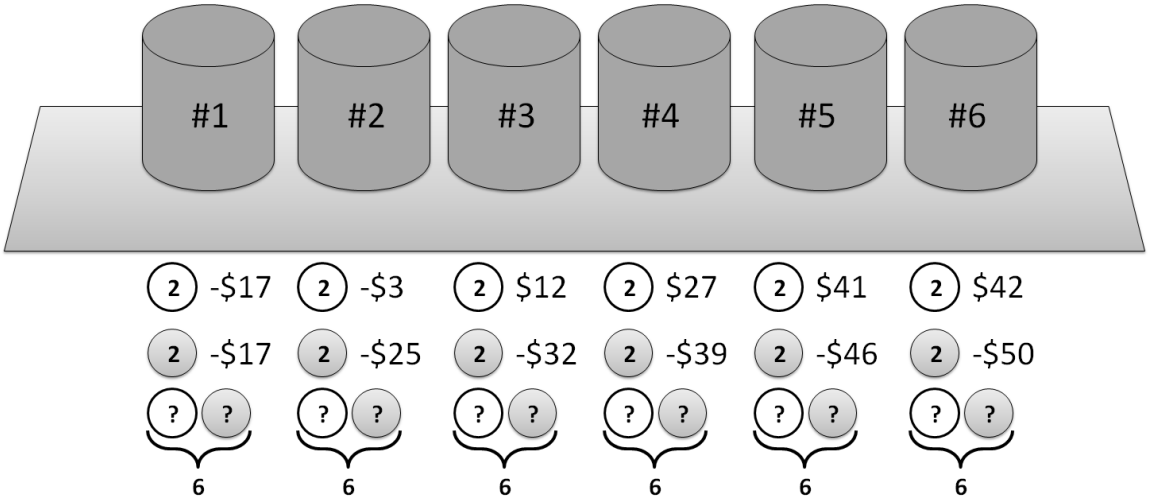

Figure 5.12: Ambiguous choice and potential loss table, fourth round of the third game

This game gives seven pieces of information: first choice (simple choice table), second choice (ambiguous table), third choice (potential loss table), fourth choice (ambiguous potential loss table), change of choice between table#1 and table#2, change of choice between table#1 and table#3, change of choice between table#3 and table#4.

5.4.4 Retirement savings plan (RSP) [256]

The respondent is asked to consider the situation where he/she has to choose a plan for his retirement savings 15 years away from now. The three propositions are formulated as follow:

- Plan A: A money market fund or guaranteed investment contract, giving up the possibility of major gains but virtually assuring the safety of your principal;
- Plan B: A 50-50 mix of bond finds and stock finds, in hopes of getting some growth but also giving yourself some protection in the form of steady income;
- Plan C: Aggressive growth mutual funds whose value will probably fluctuate significantly during the years but have potential for impressive gains in the long term.

In this game, we elicit one measure of risk-taking which is the choice of plan.

5.4.5 Stock market entry (SME) [256]

The respondent is asked to consider the situation where he/she works for a company that is going public in 3 years. Every employee is offered the opportunity to buy stock now, knowing that it is impossible to sell it until it is going public, nor it will benefit from dividends until then. This situation offers possibly quite large profit; however additional investment implies additional risk, but more potential profits. The respondent chooses to invest between 3 amounts equivalent to months of pay:

- Invest 0 month of pay;
- Invest 2 months pay;
- Invest 4 months pay.

In this game, we elicit one measure of risk-taking which is the choice of investment (number of months).

5.5 Financial Risk-Taking (FRT) score

We develop another score which serves as a synoptic measure of the behaviour towards risk in financial situations, based on the games the respondents play. Indeed, so far we can analyse the decisions made during the five financial games, pursuing the presence or absence of link between those decisions and the data (e.g. optimism score, entrepreneurial orientation...) elicited from the questionnaires., still it is also interesting to forge a global score for comparison purposes.

5.5.1 Concept

So far, we are able to pinpoint games that stand out by themselves or if particular profiles of respondents distinguish themselves in certain games. The FRT score gives a global picture of a respondent's behaviour towards risk in financial situations, thus could shed some light on links that can be less detectable at the level of analysis of the games (namely, an average behaviour). Not only the FRT score can provide another level of analysis, but also could assert the necessity of using many different games, or vouch for the uselessness of multiplying their number.

5.5.2 Method to calculate the FRT score

As aforementioned, the FRT score aims at illustrating the games section of the survey. This section consists of five games, within which nine risky decisions are made (one per game, except for the tables and balls games during which four rounds of one decision take place). Consequently, we give the same weight to every decision made.

FRT score is defined as follows: the higher its value is, the higher the respondent is ready and willing to take risk. Consequently is established a correspondence table where the respondent is awarded the maximum points when they opt for the riskiest choice. Eventually, for every decision made during the financial games, a minimum of 0 and a maximum of 5 points are awarded, the FRT is then the average score of all the financial games. The scale is [0;5] for comparison purpose with the risk scores calculated based on a [0;5] Likert scale in the questionnaires.

This method does not take into account the difficulty of the games, or the particular situation of the decisions made in the tables and balls games. Decisions made are considered independent. Below is a table displaying how much points are granted depending on the decision made in each financial game (column Matching points). The third and fourth columns illustrates with random choices how this scale works, and how is calculate the final FRT score.

Table 5.3: Method of attribution of points to calculate the FRT score

Game	Matching points	Answer	Score
G1 IG			
Simple investment	(X/250)*5	210	4.2
G2 TE			
Triple envelope first round	Envelope 1 = 0		
	Envelope 2 = 2.5		
	Envelope 3 = 5	x	5
Triple envelope, second round	Envelope 1 = 0		
	Envelope 2 = 2.5		
	Envelope 3 = 5	x	5
G3 BT			
Simple choice table	Box#1 = 0		
	Box#2 = 1		
	Box#3 = 2	x	2
	Box#4 = 3		
	Box#5 = 4		
	Box#6 = 5		
Ambiguous choice table	Box#2 = 1	x	2
Potential loss table	Box#4 = 3	x	3
Ambiguous and potential loss table	Box#4 = 3	x	3
G4 RSP			
Retirement savings plan	Plan A = 0	x	0
	Plan B = 2.5		
	Plan C = 5		
G5 SME			
Stock market entry	0 month = 0		
	2 months = 2.5		
	4 months = 5	x	5
Total			29.2
FRT score			**3.244**

CHAPTER 6 EXPERIMENT AND DATA ANALYSIS

6.1 Setting of the experiment

6.1.1 Ethic committee

This exploratory project has been approved by the Research Ethics Board of Polytechnique Montréal and HEC Montréal. Refer to appendices D and E for the documents relative to ethic approval of the research project.

The board was provided with a summarised review of literature introducing the research purposes and objectives, as well as all the measurement tools borrowed from scientific publications. Other documents such as the information and consent form, or the final version of the survey (questionnaires and games) were provided as well.

After a long period and several exchanges to tweak the documents and meet all the considerations of the board, this project labelled *CER 1516-22* was eventually granted for conformity and approved for launch on February, 22nd 2016. The survey went online the same day.

6.1.2 Online survey

The experiment was designed as an online survey to be completed anonymously by the respondents. Depending on their focus and ease to answer the questions, from 15 to 25 minutes were needed to complete the whole survey.

The survey was put online through the software LimeSurvey, installed on the server of the CIRANO research center (Center for Interuniversity Research and Analysis of Organizations).

The survey was available in both French and English (English was particularly considered for graduate respondents who are not always perfectly at ease with French, even though the survey was also available for students from English-speaking academic institutions).

6.1.3 Respondent pool

The online survey was made public, meaning that anyone with the link was able to access and complete it.

The main target audience for the research project were engineering students from Montréal academic institutions. Ideally data of students from business/economics students was interesting too (for comparison purposes), however very few answered the call. A model email was sent and broadcasted through several channels, from professors to departments communication staff, as well as several relevant committees of those institutions, for instance such as PolyFinances (student investment fund), Poly-Monde (industrial and economics mission), CCGP (Comité de consultation en gestion de Polytechnique) and Poly-E (entrepreneurship committee) in Polytechnique Montréal, Association étudiante de l'école de sciences de la gestion in UQAM, RÉTS (Réseau d'entrepreneuriat technique et stratégique) in ETS, Centre d'entrepreneuriat Poly-UdeM, CCM (Club de Consultation en Management) in H.E.C. Montréal. Also, a short presentation of the research project was conducted in several classrooms at Polytechnique Montréal to kindle participation.

In the end most of the respondents are from an engineering background.

6.2 Data processing

6.2.1 Respondent population

Despite a relatively "heavy" campaign to recruit respondents ongoing for four weeks, a total of 122 responses were collected, composed of only 56 complete answers and 67 partial answers (which were as such unexploitable). Among the 56 complete answers were 26 women and 30 men, aged between 21 and 58 (averaging 27.55-year old). Most of the 56 complete respondents were engineering students: 44 studied within the walls of academic institutions providing an engineering education. Moreover, 31 studied exclusively in engineering programs ("*OES*"), whereas 25 respondents had another academic background (either they have never studied in engineering or they also studied in another program, notably business or management programs). 15 respondents reported one diploma (bachelor degree), 29 reported two diplomas (master's degree research or course, D.E.S.S. or advanced graduate diploma), and 11 reported three diplomas (either Ph.D. level or cumulating two of the previous diplomas).

Precision on the “OES” status:

- OES (Only Engineering Student): respondent who has studied exclusively in engineering;
- NOES (not - Only Engineering Student): respondent who has maybe studied in engineering, but has also studied in another domain (or has only studied in a domain different from engineering).

For instance:

- A respondent with a bachelor degree and a master's degree in engineering is OES.
- A respondent with a bachelor degree and a master's thesis in economics is NOES.
- A respondent with a bachelor degree in engineering and a master's thesis in economics is NOES.

6.2.2 Tools

Data was collected with LimeSurvey, then processed and analysed with Microsoft Excel, R, Gretl, SPSS and Stata.

6.2.3 Robustness and liability of the elicited data

Because of the relatively small size of the pool of respondents, it was all the more necessary to assert to robustness of the elicited data.

6.2.3.1 Entrepreneurial orientation (EO) [248]

Questions 1 to 24 were treated together, as questions originating from the article by Maatlay et al. [248]. Questions 25 to 31 were treated together, as additional questions coined for the research project according to literature. The two set of questions were subjected to principal component analysis (PCA) using SPSS version 21.

6.2.3.1.1 Set (1-24)

Principal component analysis (PCA) and varimax rotation with Kaiser normalisation revealed the presence of nine components with Eigen values exceeding 1 explaining cumulatively 77.161% of the variance. However Eigen values were also imputable to the high number of questions. Kaiser-Meyser-Olkin value was 0.520. The nine components elicited from the PCA could be distributed in the 6 sub-dimensions from Maatlay et al. [248] without overlapping (our case some of the original sub-dimensions were split into several separated components). Indeed, in the original

study six sub-dimensions to EO exist: entrepreneurship desire, innovation, pro-activeness, risk-taking, confrontational tolerance, and networking (refer to 5.3.4).

After applying the same filters and steps for the derivation of variables than Maatlay et al., liability of our six sub-dimensions was established:

Table 6.1: Original sub-dimensions of EO and their Cronbach alpha

		Cronbach's alpha	
Sub-dimensions	**Questions**	**Obtained (2016)**	**Original (Maatlay et al., 2012)**
Innovation	1 5 12 14 19	0.752	0.780
Pro-activeness	2 3 6 9 10 16	0.542	0.690
	3 6 9 10 16	0.514	
	3 6 9	0.589	
	3 9	0.936	
Confrontational tolerance	10 16	0.669	0.700
Entrepreneurship desire	4 18	0.722	0.790
Risk-taking	7 8 11 13 15 17_*inv*	0.791	0.750
Networking	20 21 22 23 24	0.327	0.700
	23 24	0.642	

Considering the present study is an exploratory research, and considering the Cronbach's alphas from the original article by Maatlay et al., data elicited and the designed sub-dimensions are satisfactory. Indeed the estimation of reliability via Cronbach's alphas provides acceptable ($0.8 > \alpha \geq 0.7$) and higher bound questionable ($0.7 > \alpha \geq 0.6$) values [308]. Cronbach alphas of less than 0.7 should be mistrusted even for exploratory research. The values obtained in the present study are orbiting close to the original values by Maatlay et al., and vouch for the internal consistency of the sub-dimensions. However, it is worth mentioning that the great number of items relatively to the number of respondents can artificially inflate the value of the alphas [309].

6.2.3.1.2 Set (25-31)

Items 25 to 31 are additional items not present in the original measurement tool by Maatlay et al. (refer to 5.3.4). PCA and varimax rotation with Kaiser normalisation revealed the presence of three components with Eigen values exceeding 1 explaining cumulatively 77.308% of the variance. Kaiser-Meyser-Olkin value was 0.678. However, only two sub-dimensions were coined based on literature: entrepreneurial education (questions 25 & 26), and entrepreneurial projects (questions 27 to 31). Questions 27 ("*Generally speaking, you have a positive opinion about*

ambition, money and success") loaded lonely and heavily (0.954) on a third component, and it was decided not to take it into account.

Table 6.2: Additional coined sub-dimensions of EO and their Cronbach alpha

		Cronbach's alpha
Sub-dimensions	**Questions**	**Obtained (2016)**
(EO_edu)	25 26	0.651
Entrepreneurial projects (EO_proj)	28 29 30 31	0.823

The estimation of reliability via Cronbach's alphas provides good ($0.9 > \alpha \geq 0.8$) and higher bound questionable ($0.7 > \alpha \geq 0.6$) values. The first is a satisfactory estimate of reliability for the data; however Cronbach alphas of less than 0.7 should be mistrusted even for exploratory research. The use of the word 'university' in the questions may be the reasons for the weak alpha found. Indeed, it is conceivable that respondents have an entrepreneurial education (namely, have been taught, have learnt), but have been seeking this education elsewhere from their academic institutions. However, this measure delivers what it is suppose to elicit, the respondents' sentiment about their university.

6.2.3.2 Novelty-seeking [251] [252]

Novelty-seeking questionnaire is composed of 34 items, broken down into 4 sub-dimensions designed in the literature: variety-seeking (items 1 to 10), impulsiveness (11 to 20), extravagance (21 to 24), and rebelliousness (25 to 34) – refer to 5.3.6 and appendix C.6.

PCA and varimax rotation with Kaiser normalisation revealed the presence of nine components with Eigen values exceeding 1 explaining cumulatively 71.722% of the variance. However Eigen values were also imputable to the high number of questions. Kaiser-Meyser-Olkin value was 0.497.

The components elicited from the PCA were the same as the one in Cloninger et al. [251], however in our case some of the original sub-dimensions were split into several separated components. For instance the sub-dimension variety-seeking was broken down into components 2, 7 and 8 which did not overlap with (or include) other items belonging to different sub-dimensions. Item 5 loaded on components 7 (0.437) and 8 (0.374) belonging to sub-dimension variety-seeking. The sole incoherence affected item 31 belonging to the sub-dimension rebelliousness which loaded lonely and negatively on component 8 (which related to variety-

seeking). Item 31 (“I would never cheat on my taxes”) could perhaps summon desirability or denial bias, and since the ACP related it to two unrelated items, it was decided not to take it into account in the end.

Table 6.3: Sub-dimensions of novelty-seeking and their Cronbach alpha

		Cronbach’s alpha	
Sub-dimensions	**Questions**	**Obtained (Mondin)**	**Original (Cloninger et al., 1993)**
Variety-seeking	1 to 10	0.826	0.800
Impulsiveness	11 to 20	0.807	0.720
Extravagance	21 to 24	0.759	0.850
Rebelliousness	25 to 34 minus 31	0.843	0.800

The estimation of reliability via Cronbach’s alphas provides good ($0.9 > \alpha \geq 0.8$) and acceptable ($0.8 > \alpha \geq 0.7$) values, which are satisfactory estimates of reliability for the data and those sub-dimensions. The values obtained in the present study are orbiting close to the original values by Cloninger et al., and vouch for the internal consistency of the sub-dimensions. However, once again it is worth mentioning that the great number of items relatively to the number of respondents can artificially inflate the value of the alphas.

6.2.3.3 Harm-avoidance [251] [252]

Harm-avoidance questionnaire is composed of 39 items, broken down into 4 sub-dimensions designed in the literature: neuroticism (items 1 to 10), harm-avoidance (11 to 20), social discomfort (21 to 30), and low self-efficacy (31 to 39) – refer to 5.3.6 and appendix C.7.

PCA and varimax rotation with Kaiser normalisation revealed the presence of eleven components with Eigen values exceeding 1 explaining cumulatively 79.050% of the variance. However Eigen values were also imputable to the high number of questions. Kaiser-Meyser-Olkin value was 0.361.

The components elicited from the PCA were not exactly the same as the one in Cloninger et al. [251], indeed 9 components were loaded on by items from non-overlapping sub-dimensions. However two components (1 and 2) were loaded on by numerous items from sub-dimensions neuroticism, social discomfort and low self-efficacy.

Table 6.4: Sub-dimensions of harm-avoidance and their Cronbach alpha

		Cronbach's alpha	
Sub-dimensions	**Questions**	**Obtained (2016)**	**Original (Cloninger et al., 1993)**
Neuroticism	1 to 10	0.869	0.860
Harm-avoidance	11 to 20	0.815	0.780
Social discomfort	21 to 30	0.851	0.860
Low self-efficacy	31 to 39	0.786	0.770

The estimation of reliability via Cronbach's alphas provides good ($0.9 > \alpha \geq 0.8$) and acceptable ($0.8 > \alpha \geq 0.7$) values, which are satisfactory estimates of reliability for the data and those sub-dimensions. The values obtained in the present study are orbiting close to and even globally higher than the original values by Cloninger et al., which vouch for the internal consistency of the sub-dimensions. However, once again it is worth mentioning that the great number of items relatively to the number of respondents can artificially inflate the value of the alphas.

6.2.3.4 Risk evaluation [260]

In the very first part of the questionnaires, respondents were asked to evaluate their willingness to take risk following the model of Dohmen et al. [260]. First a general evaluation of their willingness to take risk (ERG), then within five contexts: when driving (ERD), in financial matters (ERF), in sports (ERS), in the domain of health (ERH), and career-wise (ERC).

PCA and varimax rotation with Kaiser normalisation were applied to the five contexts to investigate if sub-dimensions were drawn, and they revealed the presence of two components with Eigen values exceeding 1 explaining cumulatively 65.750% of the variance. Kaiser-Meyser-Olkin value was 0.590. The items ERF, ERS and ERC composed a first component (FINSPOCAR) without overlapping the second component (HEADRI) composed of ERH and ERD. Those two components were used for the data analysis.

Table 6.5: New sub-dimensions of ER and their Cronbach alpha

		Cronbach's alpha
Sub-dimensions	**Contexts**	**Obtained (2016)**
FINSPOCAR	Finance Sport Career	0.655
HEADRI	Health Driving	0.617

Alas, original values of the Cronbach's alphas were not provided in the article for the six ERs, and the original article did not mention any particular regrouping/aggregation of specific items such as what was designed in this study. There is no comparison to be made. Here, the estimation of reliability via Cronbach's alphas provides only questionable ($0.7 > \alpha \geq 0.6$) values, which are somehow weak. Indeed, Cronbach alphas of less than 0.7 should be mistrusted even for exploratory research.

6.2.3.5 Risk compensation

A measurement proxy themed on risk compensation was created based on literature and built around 3 sub-dimensions: daily risk compensation (DRC), pecuniary risk compensation (PRC) and health risk compensation (HRC) – refer to 5.3.7 and appendix C.8.

PCA and varimax rotation with Kaiser normalisation revealed the presence of six components with Eigen values exceeding 1 explaining cumulatively 71.084% of the variance. Kaiser-Meyser-Olkin value was 0.523. Items 4 to 8 of PRC were invalidated because they presented several problems and inconsistencies: for instance items PRC6 and 8 did not load on any component, and item PRC5 loaded positively and negatively on two different components. Eventually, PRC was only composed of two items: PRC1 and 2.

Table 6.6: Sub-dimensions of risk compensation (RC) and their Cronbach alpha

		Cronbach's alpha
Sub-dimensions	**Items**	**Obtained (2016)**
DRC	DRC 1 to 6	0.600
PRC	PRC1 & PRC2	0.900
HRC	HRC 1 & HRC2	0.655

Here the estimates of reliability are questionable for DRC and HRC ($0.7 > \alpha \geq 0.6$). Even if this index and its sub-dimensions are original to this study and built on the literature, Cronbach alphas of less than 0.7 should be mistrusted even for exploratory research.

6.2.3.6 Optimism [249] [250]

Optimism score is built on 6 out of the 10 items presented to the respondent (4 items are filler items) – refer to 5.3.4 and appendix C.5.

The original version from Scheier et al. was used in the English version of the survey, and the French-Canadian version validated by Trottier et al. was used in the French version of the survey.

Table 6.7: Internal consistency of optimism measure

		Cronbach's alpha		
	Questions	Obtained (2016)	Original (Scheier et al., 1994)	Validation (Trottier et al., 2008)
Optimism	1 3 4 7 9	0.826	0.780	0.760

The estimation of reliability via Cronbach's alphas provides a good value ($0.9 > \alpha \geq 0.8$), which is satisfactory. The value obtained in the present study is even higher than the original value by Scheier et al. and Trottier et al., which vouch for the internal consistency of the optimism measure.

6.2.3.7 Experimental economics games

To synthesise the results, an index was coined for the games with several choices (namely the balls and tables game (4 rounds) and the three envelopes game (2 rounds)), as well as the general index for experimental economics measure of risk-taking, the FRT (refer to 5.5). The index is an average score between 0 and 5 (for comparison purposes with the scores from questionnaires which are built on Likert scale with a [0;5] range).

6.2.4 Filters for t-tests

Even though the online survey was open to the public and advertised through several channels, only current students (from various education levels) answered the call and completed the survey.

The comparison of the results of the measures and games was based on several filters. Because of the relatively small pool of respondents, it was impossible to break down the population into some of the sub-populations initially thought of. For instance, one of the objectives was to study the risk profile and entrepreneurial orientation of students from the different engineering programs. Most of the programs were not represent by enough respondents, except from industrial engineering: 20 of the respondents have indeed studied within Polytechnique Montreal MAGI department (labelled as GINDUS). Data was also investigated under the scope of *Eng* and *OES* conditions: *Eng* determined whether or not the respondent has ever studied in engineering (44 did, 12 never did), and *OES* highlighted students respondents who have only studied in

engineering (31 respondents are *OES*, 25 have either never studied in engineering or have complete another program in a different academic institution). The academic background is another filter applied to the data, respondents had to assert their highest level of study, ongoing or achieved (for instance, respondent currently achieving a bachelor degree were labelled as 1 diploma). Eventually, analysis of data was performed controlling for the gender of the respondent.

Table 6.8: Control variables and number of respondents

Ndiplomas	**1**	**2**	**3**
Nrespondents	15	29	11

Gender	**Female**	**Male**
Nrespondents	26	30

GINDUS	**Yes**	**No (never)**
Nrespondents	20	46

Eng	**Yes**	**No (never)**
Nrespondents	44	12

OES	**Yes**	**Eng and another background, or never Eng**
Nrespondents	31	25

6.3 Data analysis

Nota bene: for an easier reading experience, acronyms of the measures (as presented earlier in the chapter 5 and 6) are used in the following sections. Nonetheless, here is a reminder to avoid disarray.

Table 6.9: Noteworthy acronyms used for the data analysis, and sub-dimensions of measures

ER - Evaluation of risk	Willingness to take risk
ERF	Evaluation of risk in finance
ERS	Evaluation of risk in sports
ERC	Evaluation of risk in career
FINSPOCAR	Sub-dimension of ER gathering ERF, ERS, and ERC
ERH	Evaluation of risk in health
ERD	Evaluation of risk in driving
HEADRI	Sub-dimension of ER gathering ERH, and ERD
EO	Entrepreneurial orientation
Innovation	EO sub-dimension
Pro-activeness	EO sub-dimension
Confrontational tolerance	EO sub-dimension
Entrepreneurship desire	EO sub-dimension
Risk-taking	EO sub-dimension
Networking	EO sub-dimension
Entrepreneurial education (EO_edu)	EO sub-dimension
Entrepreneurial projects (EO_proj)	EO sub-dimension
NS	Novelty-seeking
Variety-seeking	NS sub-dimension
Impulsiveness	NS sub-dimension
Extravagance	NS sub-dimension
Rebelliousness	NS sub-dimension
HA	Harm-avoidance
Neuroticism	HA sub-dimension
Harm-avoidance	HA sub-dimension
Social discomfort	HA sub-dimension
Low self-efficacy	HA sub-dimension
RC	Risk compensation
DRC	Daily risk compensation (sometimes only 'Daily_risk')
PRC	Pecuniary risk compensation
FRC	Sub-dimension from PRC, without insignificant enough items
HRC	Health risk compensation
FRT	Financial risk taking, score aggregating all the games
G1 = IG	Investment game
G2 = TE	Triple envelope game
G3 = BT	Balls and tables game
G31, 32, 33, 34	First, second, third, fourth round of G3
G4 = RSP	Retirement saving plan game
G5 = SME	Stock market entry game

6.3.1 Descriptive statistics

On a scale of 5, respondents scored on average an ERF of 3.026 and clearly rating higher their propensity to take risk regarding career, sport, and finance (FINSPOCAR: 3.179), driven by ERS (3.492) and ERC (3.390).

On the contrary, participants expressed clear aversion to risk in the sub-dimension HEADRI (2.110) with similar scores for ERD (2.103) and ERH (2.143).

The self-evaluation of the willingness to take risk in general and different context supports the idea that risk-preferences are context-dependent, though some common grounds exist.

It is interesting to parallel those results with data from other tools precisely investigating such questions. In health domain, ERH was at 2.143 but later in the risk compensation (RC) measure respondents indicated an even more pronounced aversion to risk with an average of 1,538 for HRC. This emphasises a strong polarisation against the topics of tobacco and alcohol. It can't be answered whether if the respondents clearly put a distinction between health in general and alcohol and tobacco, or if they did not consider those aspects when the first question was asked. Perhaps they actually do no not link those "activities" to health issues (least possible but impossible to ascertain). Risk in financial matters was steady during the whole experiment, whether it be in ERF (2.610), PRC (2.547) or the score elicited from experimental economics FRT (2.536). Yet, FRT as a synthesis of the experimental economics part of the experiment overshadows diversity in the answers of the five games. G1 (2.333), G2 (1.987) and G4 (2.273) display low scores of risk, whereas on the other hand scores where higher for G3 (2.841) and G5 (3.364).

G1 results do not vouch for a clear preference for certainty since only 3 respondents out of 56 (5.36%) decided not to bet any money on the coin flip, whereas 7 (12.56%) –more than twice as much- would gamble all of their money on the same game of chance. If the majority of the respondents bet, they however do it in low amounts: 12 participants bet $50 and 11 bet $100 (out of a maximum of $250 available). In the end, 36 respondents (64.29%) bet less than half of the money ($125) they are enticed with, and they are 44 (78.6%) if the threshold is moved up a little to $150.

Appeal for certainty is relatively more pronounced in G2 where 26 (first round) and then 25 (second round) respondents selected the certain gain. When the expected value of each gamble is written in black and white, a minute shift is observed and the higher risk envelope becomes more popular (15 selections in the second round versus 13 in the first pick), though the effect could me fickle since the change is meagre.

In G3, respondents cope with ambiguity by being less risk-taking, however they more surprisingly display a high spike of "counter measure" when exposed to loss and take much more risk. When ambiguity and loss are combined, this impulse is dampened a little.

Table 6.10: Risk scores for the third game, Balls and tables (BT)

Round	Rule(s)	Average risk score
G31	Normal	2.786
G32	Ambiguity	2.429
G33	Loss	**3.145**
G34	Loss + Ambiguity	2.945

In G4, respondents selected in majority (40/56) the risk neutral option. The nature or the subject of the question might have been too impalpable or not pragmatic enough (choosing a retirement saving plan) for the respondent pool (a majority of students).

The fifth game taken from literature, SME, scored the highest on average with 3.364. It is noteworthy that the situation exposed in the game musters ideas shared with the other measures that scored the highest: G5 (3.364), ERC (3.390), OPT (3.703), and EO (original test: 3.493; original test and additional sub-dimensions: 3.505; just additional sub-dimensions: 3.542). Such scores denote an appeal for success and positive expectations. Yet, it is important to note the measure of OPT does not address situations where the respondent is in control but a general feeling, whereas in the G5 they are to a certain extent actors of the situation (like in EO).

6.3.2 Risk profile and entrepreneurial profile depending on control variables

For tables 6.12 to 6.26, refer to the following key.

Table 6.11: Key for the statistical significance

P-Value / Statisical significance	Symbol
0.05 < p <= 0.10	
0.01 < p <= 0.05	*
0.001 < p <= 0.01	**
p <= 0.001	***

6.3.2.1 Gender

Table 6.12: Mann-Whitney-Wilcoxon statistical comparison of the mean for 'Gender'

	Female N_F=26	Male N_M=30	All N_A=56	M-W P-VALUE Two-tail	
	Mean	Mean	Mean	F vs. M	
EO_entrepreneurship_desire	3.404	**3.875**	3.648	0.0381	*
EO_Proj	3.115	**3.848**	3.495	0.0073	**
NS_IMPULSIVENESS	**2.608**	2.383	2.489	0.0843	
NS_REBELLIOUSNESS	2.470	**2.909**	2.698	0.0211	*
HA_NEUROTICISM	**2.774**	2.387	2.566	0.0606	
HA_LOW_SELF_EFFICACY	**2.487**	2.173	2.318	0.0853	
DAILY_RISK	2.969	**3.307**	3.154	0.0506	
G5 (SME)	2.788	**3.879**	3.364	0.0071	**
NB_DIPLO (1;2;3)	1.769	2.069	1.927	0.0949	
ERF	3.385	3.897	3.655	0.1089	
EO_RISK_TAKING	2.887	3.170	3.036	0.1154	
HA_HARM_AVOIDANCE	3.072	2.831	2.943	0.1098	
Age	26.423	28.533	27.554	0.1175	

Male respondents have a higher score of EO_Proj (0.0211/**) meaning they are more prone to already have projects, ideas and aspirations for stepping in entrepreneurship in a close future. They also express a higher desire for this career path (Entrepreneur desire, 0.0381/*). Other noteworthy results are a higher rebelliousness (from NS: 0.0211/*) and in the fifth game men also expressed a meaningful higher preference for investing more months of pay in the future of their company (SME: 3.879. 0.0071/**).

Male respondents were older (0.1175) and more educated (0.0949). They tend to have lower scores of neuroticism (NS: 0.0606), low self-efficacy (NS: 0.0853) and more surprisingly impulsiveness (NS: 0.0843). Still, they generally expressed a higher score of daily risk (RC: 0.0506).

6.3.2.2 Engineer (44 Eng vs. 12 NEng)

Table 6.13: Mann-Whitney-Wilcoxon statistical comparison of the mean for 'Eng'

	Never N_0=12	Yes N_1=44	All N_A=56	M-W P-VALUE Two-tail	
	Mean	Mean	Mean	0 vs 1	
ERC	**3.701**	3.311	3.389	0.0921	
PRC	1.909	**2.714**	2.547	0.0484	*
Age	27.917	27.455	27.554	0.0928	
OES (N=0; Y=1)	0.000	0.705	0.554	0.0000	***
GINDUS (N=0; Y=1)	0.000	0.455	0.357	0.0039	**
G2 (TE)	**2.813**	1.761	1.987	0.1131	

Links between Eng with OES and GINDUS are not relevant and only give information on the respondent pool. Given the limited impact of the recruitment campaign (a majority of engineering students from Polytechnique Montréal) and how it was lead (limited access to other institutions, student committees mentioned in 6.2.1 are more frequented by students from MAGI, and most of the classrooms where an intervention was set out are belonging to MAGI courses), the pool of respondents was relatively homogeneous for those parameters.

More surprisingly, Eng respondents report significantly higher knowledge and experience in finance and investment compared to people who have never set foot within an engineering institution (PRC: 0.0484/*). Since non-engineering respondents come from various domains and institutions (and not for instance particularly H.E.C. Montreal), this result is probably attributable to the fact that a large pool of respondents belongs to MAGI department, which as a higher vocation towards such topics.

On the other hand, NEng respondents report a stronger willingness to take risk in the context of their career (ERC: 0.0921). Eventually, Eng respondents take much more risk in G2 (2.813) than their NEng counterparts (1.761), but the p-value is low (0.1131).

6.3.2.3 Only Engineering Student (31 OES vs. 25 NOES)

Table 6.14: Mann-Whitney-Wilcoxon statistical comparison of the mean for 'OES'

	Never, or Eng+elsewhere N_0=25	Only N_1=31	All N_A=56	M-W P-VALUE Two-tail	
	Mean	Mean	Mean	0 vs 1	
ERC	**3.661**	3.180	3.389	0.0285	*
EO_PROACTIVENESS	**3.792**	3.258	3.491	0.0395	*
EO_RISK_TAKING	**3.222**	2.894	3.036	0.0561	
FRT	**3.015**	2.260	2.595	0.0183	*
G2 (TE)	**2.600**	1.492	1.987	0.0488	*
G3 (BT)	**3.250**	2.500	2.841	0.0188	*
Age	29.280	26.161	27.554	0.0019	**
NB_DIPLO (1;2;3)	2.208	1.710	1.927	0.0071	**
Eng (N=0; Y=1)	0.520	1.000	0.786	0.0000	***
GINDUS (N=0; Y=1)	0.200	0.484	0.357	0.0289	*
FINSPOCAR	4.611	4.322	4.451	0.1300	
PRC	2.364	2.628	2.513	0.1355	
G5 (SME)	3.750	3.065	3.364	0.1051	

Links between OES with NB_Diploma and Age are not relevant for the risk analysis and only give information about the respondent pool: participants who are not OES tend to have higher education and to be older. Having higher education (more diplomas) goes hand in hand with being older. It's not possible to account solely for respondents who have never set foot in an engineering academic institution, however it is obvious students that went through another academic institution (at least another one) have at least two diplomas. On the other hand, OES concerns a majority of current students doing a bachelor degree. Eventually on the academic ground, just like the previous Eng condition, students from MAGI responded en masse and thus the correlation is expected and not relevant.

Career-wise, OES are less willing to take risks (ERC: 0.0285/*). They also present a lower pro-activeness (EO: 0.0395/*) and risk-taking (EO: 0.0561). In the field of experimental economics, OES participants display a significant lower general index of risk (0.0183/*) and especially stand out as lower risk-takers in G2 (TE: 0.0488/*) and G3 (BT: 0.0188/*).

6.3.2.4 GINDUS (36 No vs. 20 Yes)

Table 6.15: Mann-Whitney-Wilcoxon statistical comparison of the mean for ‘GINDUS'

	Never N_0=36	Yes N_1=20	All N_A=56	M-W P-VALUE Two-tail	
	Mean	Mean	Mean	0 vs 1	
ERG	3.971	**4.700**	4.236	0.0337	*
ERD	2.686	**3.421**	2.944	0.0625	
PRC	2.425	**2.672**	2.513	0.0907	
Eng	0.667	1.000	0.786	0.0039	**
OES	0.444	0.750	0.554	0.0289	*
FRC	2.368	2.868	2.547	0.1087	

Industrial engineering was the sole program with enough respondents to be analysed and it is noteworthy that such programs offer courses and orientations in decision-theory or management of innovation.

GINDUS respondents expressed a significantly higher willingness to take risk in general (ERG: 0.0337/*) as well as in the context of driving (ERD: 0.0625). Lastly, the same trend concerns pecuniary risk (PRC: 0.0907). No additional correlation appears.

6.3.2.5 Number of diplomas (1 diploma:15; 2 diplomas :29; 3 diplomas:11)

Table 6.16: Mann-Whitney-Wilcoxon statistical comparison of the mean for 'NB_Diplo'

	1	2	3	All	K-W	
	N_1=15	N_2=29	N_3=11	N_A=55	P-VALUE Global Test	
	Mean	Mean	Mean	Mean		
EO_PROACTIVENESS	3.267	3.379	**4.091**	3.491	0.0487	*
EO_entrepreneurship_desire	3.233	**3.845**	3.700	3.648	0.1049	
EO_Proj	3.000	3.598	**3.909**	3.495	0.0629	
EO_edu	3.300	3.536	4.313	3.588	0.0698	
HA_HARM_AVOIDANCE	3.074	2.731	**3.333**	2.943	0.0312	*
HA_SOCIAL_DISCOMFORT	2.224	2.414	**2.673**	2.417	0.2487	
HA_LOW_SELF_EFFICACY	**2.589**	2.243	2.172	2.318	0.0803	
DAILY_RISK	3.114	**3.304**	2.824	3.154	0.2176	
FRC	2.333	**2.833**	2.136	2.547	0.1966	
FRT	2.385	**2.925**	2.040	2.595	0.0274	*
G1 (IG)	1.880	**2.857**	1.555	2.320	0.0215	*
G3 (BT)	2.817	**3.143**	2.045	2.829	0.0318	*
G5 (SME)	2.667	**3.707**	3.409	3.364	0.0881	
Age	24.200	27.966	30.636	27.473	0.0008	***
Gender (0=F; 1=M)	0.267	0.655	0.545	0.527	0.0525	
OES	0.867	0.483	0.364	0.564	0.0182	*
ERG	3.867	4.379	4.364	4.236	0.2980	
FINSPOCAR	4.310	4.517	4.455	4.451	0.3971	
EO_RISK_TAKING	2.762	3.176	3.017	3.036	0.2454	
NS_REBELIOUSNESS	2.459	2.829	2.687	2.698	0.2513	

Once again Age is not relevant because it is expected that earning higher degrees corresponds to reaching an older age.

Number of diplomas, synonym of a higher-level education, translates in several proxies and sub-dimensions. Pro-activeness grows with the number of diplomas (EO: 0.0487/*) and so does self-efficacy (HA: 0.0803). Respondents with a higher education tend to be more prone to have entrepreneurial projects and ideas (EO_proj: 0.0629) and are more incline to think their academic institution(s) are a reliable support and inspiration towards such a path.

Still, respondents with two diplomas report the highest score of entrepreneurship desire, though not with high significance (EO_entrepreneurship_desire: 0.1049).

Results tend to advocate for a higher entrepreneurial orientation when individuals have a higher education. However if this is true for master students in respect to undergraduate students, in practice individuals who persevere in post-grad studies and undertake the path of a doctoral diploma tend to embrace (or be confined) to research activities. On the other hand, longer post-grad studies offer more time, knowledge and opportunity to see an innovation appear. Conducting research for a long time might trigger the desire to then follow an entrepreneurial path in order to turn the science into a company.

Social-discomfort (HA: 0.2487) grows with the number of diplomas and harm-avoidance (HA: 0.0312/*) is higher in 3-diploma respondents.

Several risk measures manifest higher levels for 2-diploma respondents: daily risk (DRC: 0.2176), financial risk (FRC: 0.1966), the index of the financial games altogether (FRT: 0.0274/*) and more specifically in games G1 (SI: 0.0215/*), G3 (BT: 0.0318/*), and G5 (SME: 0.0881/*).

6.3.3 Correlations matrices

6.3.3.1 Risk profile

It is interesting to compare the correlation matrices for ERG (which is the self evaluation of the willingness to take risk), risk-taking from EO (which is express a general appeal or disavowal for risk), and FRT (which is the synoptic measure of all the experimental economics games designed to elicit a measure of actual risk-taking).

Table 6.17: Correlation matrix for ERG

	ERG	P-VALUE	
ERF	0.632	0.0000	***
ERS	0.515	0.0001	***
ERC	0.558	0.0000	***
FINSPOCAR	**0.719**	0.0000	***
ERD	0.381	0.0044	**
HEADRI	**0.269**	0.0493	*
INNOVATION	0.235	0.0842	
PROACTIVENESS	0.310	0.0214	*
ENTREPRENEUR	0.383	0.0043	**
RISK-TAKING	0.756	0.0000	***
CONFRONTATIONNAL	0.291	0.0348	*
EO_proj	0.243	0.0761	
VARIETY_SEEKING	0.267	0.0483	*
IMPULSIVENESS	0.393	0.0030	**
REBELIOUSNESS	0.240	0.0810	
NEUROTICISM	-0.355	0.0084	**
HARM_AVOIDANCE	-0.462	0.0004	***
LOW_SELF_EFFICACY	-0.297	0.0289	*
OPTIMISM	0.198	0.1482	
DAILY_RISK	0.335	0.0141	*
FRT	0.345	0.0106	*
G1 (IG)	0.214	0.1197	
G2 (TE)	0.192	0.1597	
G3 (BT)	0.257	0.0611	+
G4 (RSP)	0.339	0.0113	*
G5 (SME)	0.281	0.0374	*
GENDER	0.211	0.1222	
GINDUS	0.330	0.0138	*

ERG is correlated to the other context-specific evaluations, especially the sub-dimensions composing FINSPOCAR (0.719; 0.0000/***). It is correlated to a lesser extent to HEADRI. The difference is not surprising; respondents are more willing to take risk in financial, sport and career domain because it feels less threatening. Higher risk aversion in health and driving domains summons self-preservation: health has a prevailing connotation and so does the risk associated with driving a car (danger and consequences are heavy, violent, and immediate). On the other hand it is also somehow surprising because usually people are “close to their wallet”, money is on the line as a short-term effect whereas people tend to not be concerned by their health on a daily basis. ERG is very strongly correlated with the sub-dimension measuring risk-

taking in the EO test (0.756; 0.0000/***), as well as very negatively correlated to harm-avoidance sub-dimension of HA (-0.462; 0.0004/***) which is rather an expected result since harm-avoidance captures the intensity of a subject's response to aversive stimuli and eagerness to avoid such stimuli. Two additional items from HA are also negatively correlated with ERG: neuroticism (-0.355; 0.0084/**) and low self-efficacy (-0.297; 0.0289/*). Quite the reverse, ERG is correlated with scores of impulsiveness (0.393; 0.0030/**), variety-seeking (0.267; 0.0483/*) , and rebelliousness (0.240; 0.0810), three out of four sub-dimensions of NS. Once again such results are encouraging and help addressing hypothesis H4. The EO measurement tool globally correlates well with ERG since 5 out of the 6 original sub-dimensions are prominent in the correlation matrix, especially entrepreneurship_desire (0.383; 0.0043/**). Networking sub-dimension is absent, but it is indeed in essence the more far-fetched link purely risk-wise. One additional EO sub-dimension, EO_proj is weakly correlated to ERG (0.243; 0.0761). It is not determined whether respondents with an entrepreneurship bud put themselves in a 'willing to take risks' mindset, or if the mindset talks them into forging and simmering a project. The fact that the respondent has been or not in Industrial Engineering correlates weakly (0.330. 0.0138/*) and Gender reads irrelevant values. Eventually, there is a light correlation with FRT (0.345; 0.0106/*), however the games by themselves do not particularly stand out.

Table 6.18: Correlation matrix for FRT

	FRT	P-VALUE	
ERG	0.345	0.0106	*
ERF	0.433	0.0011	**
FINSPOCAR	0.288	0.0368	*
INNOVATION	0.293	0.0315	*
RISK-TAKING	0.430	0.0015	**
NEUROTICISM	-0.222	0.1101	
HARM_AVOIDANCE	-0.307	0.0254	*
OPTIMISM	0.228	0.0969	
DAILY_RISK	0.204	0.1465	
FINANCIAL_RISK	0.217	0.1230	
G1 (IG)	0.601	0.0000	***
G2 (TE)	0.778	0.0000	***
G3 (BT)	0.826	0.0000	***
G4 (RSP)	0.453	0.0006	***
G5 (SME)	0.446	0.0007	***
OES	-0.373	0.0054	**

The measure of risk-taking from actual decisions, FRT, is correlated ERF (0.433 0; 0.0011/**), the risk-taking measure from EO tool (0.430; 0.0015/**), and negatively with OES indicator (-0.373; 0.0054/**). Other notable correlations are EO innovation (0.293; 0.0315/*) and HA harm-avoidance (-0.307; 0.0254/*). Optimism plays a minute role (0.228; 0.0969) too.

Table 6.19: Correlation matrix for component 'risk-taking' of EO measure

	RISK-TAKING	P-VALUE	
ERG	0.756	0.0000	***
ERF	0.583	0.0000	***
ERS	0.460	0.0006	***
ERC	0.505	0.0001	***
FINSPOCAR	0.756	0.0000	***
ERD	0.356	0.0096	**
HEADRI	0.314	0.0232	*
INNOVATION	0.320	0.0197	*
PROACTIVENESS	0.309	0.0245	*
ENTREPRENEUR	0.314	0.0235	*
NETWORKING	0.215	0.1295	
CONFRONTATIONNAL	0.264	0.0608	
EO_proj	0.316	0.0227	*
VARIETY_SEEKING	0.361	0.0079	**
IMPULSIVENESS	0.385	0.0045	**
REBELIOUSNESS	0.308	0.0264	*
NEUROTICISM	-0.526	0.0001	***
HARM_AVOIDANCE	-0.635	0.0000	***
LOW_SELF_EFFICACY	-0.403	0.0031	**
OPTIMISM	0.281	0.0418	*
DAILY_RISK	0.420	0.0022	**
FINANCIAL_RISK	0.358	0.0098	**
FRT	0.430	0.0015	**
G1 (IG)	0.313	0.0240	*
G2 (TE)	0.230	0.0983	
G3 (BT)	0.349	0.0112	*
G4 (RSP)	0.424	0.0016	**
G5 (SME)	0.221	0.1124	
GENDER	0.212	0.1275	
OES	-0.243	0.0796	

The risk-taking measure from EO is very strongly correlated with the self-evaluation of risk measures, especially ERG (0.756; 0.0000/***) and FINSPOCAR (0.756; 0.0000/***) (as well as FINSPOCAR components), and to a lesser extent HEADRI (0.314; 0.0232/*).

Relatively to HA measure, strong negative correlations appears with three out of four sub-dimensions: harm-avoidance (-0.635; 0.0000/**), neuroticism (-0.526; 0.0001/**), and low self-efficacy (-0.403; 0.0031/*). On the opposite of neuroticism, risk-taking is correlated to OPT, though with a weaker effect (0.281; 0.0418/*).

Other strong correlations arise with variety-seeking (0.361; 0.0079/**) and impulsiveness (0.385; 0.0045/**) from NS, DRC (0.420; 0.0022/**) and F

RC (0.358; 0.0098/**), as well as the global score of financial risk-taking from the games FRT (0.430; 0.0015/**).

6.3.3.2 Entrepreneurial profile

Table 6.20: Correlation matrix for component 'innovation' of EO measure

	INNOVATION	P-VALUE	
ERG	0.235	0.0842	
ERS	0.202	0.1424	
ERC	0.267	0.0490	*
*FINSPOCAR	0.267	0.0506	
PROACTIVENESS	0.287	0.0338	*
RISK-TAKING	0.320	0.0197	*
EXTRAVAGANCE	-0.226	0.0964	
REBELLIOUSNESS	0.218	0.1135	
HARM_AVOIDANCE	-0.216	0.1174	
FRT	0.293	0.0315	*
G3 (BT)	0.204	0.1398	
G4 (RSP)	**0.280**	**0.0383**	*
G5 (SME)	**0.278**	**0.0398**	*

Innovation is correlated with two other sub-dimensions of EO: pro-activeness (0.287; 0.0338/*) and risk-taking (0.320; 0.0197/*). Other relevant correlations are with ERC (0.267; 0.0490/*) and FRT (0.293; 0.0315/*), in particular two games stand out: G4 (0.280; 0.0383/*) and G5 (0.278; 0.0398/*), and G5 is precisely dealing with a career theme.

Innovation brings along changes and unknown which are a certain degree of risk. In games G4 and G5, respondents have the choice of stable, known and traditional options, or the choice to go for more daring and diversified options.

Table 6.21: Correlation matrix for component ‘pro-activeness’ of EO measure

	PROACTIVENESS	P-VALUE	
ERG	0.310	0.0214	*
ERF	0.219	0.1085	
ERC	0.257	0.0581	
FINSPOCAR	0.252	0.0655	
INNOVATION	0.287	0.0338	*
RISK-TAKING	0.309	0.0245	*
EO_proj	0.200	0.1467	
VARIETY_SEEKING	0.291	0.0312	*
NEUROTICISM	-0.351	0.0093	**
LOW_SELF_EFFICACY	-0.262	0.0560	
OPTIMISM	0.206	0.1314	
FRT	0.182	0.1866	
G2 (TE)	0.242	0.0745	
G4 (RSP)	0.252	0.0631	
NB_DIPLO	0.272	0.0447	*
Eng	-0.191	0.1620	
OES	-0.272	0.0449	*

Pro-activeness is notably correlated with another item from EO, risk-taking (0.309; 0.0245). Then the variety-seeking component of NS stands out (0.291; 0.0312), as well as the level of education (0.272; 0.0447) and the OES quality (-0.272; 0.0449). Eventually, pro-activeness is also correlated to ERG (0.310; 0.0214/*).

Table 6.22: Correlation matrix for component ‘entrepreneurship desire’ of EO measure

	ENTREPRENEURSHIP DESIRE	P-VALUE	
ERG	0.383	0.0043	**
ERF	0.192	0.1652	
ERS	0.296	0.0315	*
ERC	0.268	0.0497	*
FINSPOCAR	0.350	0.0103	*
RISK-TAKING	0.314	0.0235	*
EO_proj	0.677	0.0000	***
EO_edu	0.272	0.0537	
REBELLIOUSNESS	0.272	0.0488	*
NEUROTICISM	-0.307	0.0252	*
HARM_AVOIDANCE	-0.259	0.0607	
OPTIMISM	0.212	0.1238	
DAILY_RISK	0.233	0.0959	
G5 (SME)	0.220	0.1106	
NB_DIPLO	0.207	0.1336	
GENDER	0.263	0.0548	

Entrepreneurship desire is strongly correlated with EO_proj (0.677; 0.0000/***) and ERG (0.383; 0.0043/**). Other relevant correlation are with FINSPOCAR (0.350; 0.0103/*), risk-taking measure of EO (0.314; 0.0235/*), rebelliousness from NS (0.272; 0.0488/*) and neuroticism from HA (-0.307; 0.0252/*).

Table 6.23: Correlation matrix for component ‘networking’ of EO measure

	NETWORKING	P-VALUE	
ERC	0.247	0.0749	
FINSPOCAR	0.210	0.1358	
RISK-TAKING	0.215	0.1295	
VARIETY_SEEKING	0.328	0.0166	*
IMPULSIVENESS	0.240	0.0832	
NEUROTICISM	-0.249	0.0725	
SOCIAL_DISCOMFORT	-0.392	0.0037	**
LOW_SELF_EFFICACY	-0.293	0.0332	*
OPTIMISM	0.239	0.0845	

Networking is strongly negatively correlated with social discomfort (-0.392; 0.0037), variety-seeking (0.328; 0.0166), and low self-efficacy (-0.293; 0.0332).

Table 6.24: Correlation matrix for component ‘confrontational tolerance’ of EO measure

Chapter 7	CONFRONTATIONNAL	P-VALUE	
ERG	0.291	0.0348	*
ERF	0.249	0.0722	
ERC	0.269	0.0510	
FINSPOCAR	0.236	0.0921	
RISK-TAKING	0.264	0.0608	
VARIETY_SEEKING	0.252	0.0692	
IMPULSIVENESS	0.277	0.0445	*
HARM_AVOIDANCE	-0.278	0.0440	*
G2 (TE)	0.220	0.1140	

Confrontational tolerance is correlated with ERG (0.291; 0.0348), impulsiveness from NS (0.277; 0.0445), and harm-avoidance from HA (-0.278; 0.0440).

Table 6.25: Correlation matrix for component ‘EO_proj’ of EO measure

	EO_proj	P-VALUE	
ERG	0.243	0.0761	
ERF	0.330	0.0148	*
ERC	0.247	0.0721	
FINSPOCAR	0.317	0.0207	*
PROACTIVENESS	0.200	0.1467	
ENTREPRENEUR	0.677	0.0000	***
RISK-TAKING	0.316	0.0227	*
EO_edu	0.222	0.1168	
REBELLIOUSNESS	0.325	0.0176	*
NEUROTICISM	-0.210	0.1305	
SOCIAL_DISCOMFORT	0.279	0.0427	*
FINANCIAL_RISK	0.219	0.1192	
G4 (RSP)	0.237	0.0847	
G5 (SME)	0.201	0.1458	
NB_DIPLO	0.297	0.0294	*
GENDER	0.338	0.0125	*

EO_proj is strongly correlated with two components of EO: entrepreneurship desire (0.677; 0.0000) and risk-taking (0.316; 0.0227). Other relevant correlations are with FINSPOCAR (0.317; 0.0207), rebelliousness from NS (0.325; 0.0176), social-discomfort form HA (0.279; 0.0427), level of education (0.297; 0.0294) and eventually gender (0.338; 0.0125).

Table 6.26: Correlation matrix for component ‘EO_edu’ of EO measure

	EO_edu	P-VALUE	
ENTREPRENEUR	0.272	0.0537	
EO_proj	0.222	0.1168	
VARIETY_SEEKING	0.207	0.1444	
IMPULSIVENESS	0.249	0.0781	
NEUROTICISM	-0.242	0.0902	
HEALTH_RISK	-0.273	0.0579	
NB_DIPLO	0.296	0.0347	*

EO_edu is only correlated with level of education (0.296 ; 0.0347).

CHAPTER 7 EXPERIMENT AND DATA ANALYSIS

7.1 Discussion

7.1.1 Profiles of risk and entrepreneurship

Regarding risk, gender has no appreciable effect on the measures of risk, whether it be ER, risk-taking in EO, or FRT. The only exception is the daily risk compensation (DRC) where male respondents rate higher than their female counterparts, which corresponds to the general consensus from the literature. Still, gender differences appear in several personality traits and psychological resources: male respondents scored higher in impulsiveness, rebelliousness, and low self-efficacy, while female participants stand out with higher score of neuroticism. On the academic ground, engineers display a lower desire to take risk career-wise, and the trend is accentuated with OES. It is an important result which goes along with the tendency not to engage in entrepreneurial activities (the "highest" risk career-wise). OES have lower scores of pro-activeness, risk-taking (EO), and financial risk-taking (FRT). Nevertheless, it is noteworthy that OES were younger and less educated (lower level of education, number of diplomas earned) than the respondents with education from several or others institutions. Interestingly, according to the results of games G2 (TE) and G3 (BT), OES are more loathing loss and ambiguity when choosing between gambles. Eventually, GINDUS trait has a catalyst effect on the self-evaluation of risk-taking: respondents that have been involved in programs of MAGI department tend to think they are willing to take more risks, but it wasn't particularly illustrated in other measures, or in the tools related to EO. Eventually, the number of diplomas does not have a direct effect on risk-taking measures (ERG, risk-taking (EO), or FRT), however there are notable effects on psychological resources: pro-activeness and harm-avoidance rise, but it might be attributable to age and maturity.

Based on those observations, it can't be said there are ardent and strong differences, in nature or amplitude, in risky behaviours when controlling for gender or academic background.

Entrepreneurial orientation and its sub-dimensions are more expressed within respondents who are male and highly educated: entrepreneurship desire is stronger. EO_proj has higher values too, meaning male respondents with higher degrees tend to already have an idea or a project in its inception, still EO_edu value are not striking meaning they consider their academic institutions as

not particularly good instigators for such activities. It is possible that Polytechnique (from where most of the respondents are) is not an ideal venue for this kind of inquire, however the institutions provides a lot of support towards research, innovation and entrepreneurship, thus it was interesting to ask the question.

7.1.2 Comparison of the different measurement tools

Using a wide range of measurement tools stemming from several domains of science allowed the identification of different natures and amplitude of risk. Self evaluation of risk highlighted a gap between FINSPOCAR and HEADRI, and such trends were found again with the scores of risk compensation (RC) and FRT. In a nutshell, respondents were more conservative considering health and driving activities, but more risk-seeking in finance or career-wise. Such result are explained by several correlated psychological resources and personal traits found within NS and HA measurement tools.

Still, data elicited did not provide a lot of highly significant correlations, and the behaviour were quite average. The relative low number of respondents and the fact that the vast majority of them are only from engineering academic institutions did not provide a really deep view on the subject and it was impossible to really put the behaviour of engineering students regarding risk and entrepreneurship in contrast with other academic backgrounds (for instant, business students). A couple of relevant correlations are found with sub-dimensions of NS and HA, they concern personality traits and shed some light on the underlying resources working along risk-preferences: pro-activeness, harm-avoidance, neuroticism, impulsiveness, and variety-seeking. Surprisingly the measure of optimism did not come into view anywhere.

According to our hypothesis, respondents who scored positively in novelty-seeking and negative in harm-avoidance (in their sub-dimensions) tended to score positively in components of entrepreneurial orientation as well as financial risk-taking (and vice-versa). However, optimism as measured via LOT-R did not reveal any significant link with the other measures and can’t be considered as a relevant proxy for risky behaviours.

In the end, the set of tools used in this study are not very deeply intertwined. As such, they are not dull since they play their part within their own field of study, however they just don’t help to build a better, more accurate and comprehensive picture of risk-taking and its underlying causes.

Nonetheless, several sub-dimensions, components of those measurements tools, are revealing interesting link and could be by incorporated by themselves in risk behaviour measurement and entrepreneurial orientation profiling.

Considering the data elicited in the course of this project, there is not a Rosetta stone translating a conceptualisation of risk from one field to another.

CHAPTER 8 CONCLUSION AND RECOMMENDATIONS

8.1 Limits and constraints of our project

8.1.1 Sample size

Though the lower bound of 30 respondents was exceeded, our objective of 100 respondents was not met and this is problematic for the assessment of the reliability of our data. In section 11.2.3 the Cronbach alphas obtained are encouraging but obviously “boosted” by the number of items in each of the measurement proxy. A greater sample size would also have allowed comparing different programs in engineering, or even different academic orientations (business vs. engineering).

Behavioural finance studies often mention sample size as a shortcoming of their design, and this is why reproduction of studies in important in such domains of science.

8.1.2 Sample origin

As aforementioned, our respondent pool is in the vast majority students or former students from engineering academic institutions. Establishing a risk profile and an entrepreneurial orientation of the engineering population is less germane without another large and different population to compare with.

8.1.3 Modus operandi and financial incentive

The experiment was an online survey and there was no financial incentive for its completion. In experimental economics, Holt & Laury found that risk behaviour varies depending on whether an experiment is designed with hypothetical or real incentives. With real payoffs, risk aversion increases sharply when payoffs are scaled up, whereas on the other hand behavior is largely unaffected when hypothetical payoffs are scaled up [310] [311]. It would be interesting to re-conduct the project with real monetary incentives for the respondents when completing the experimental economics section of the survey.

8.2 Conclusion and contributions

The study of risk and the different strategies of cognition and behaviour to cope with it is crucial to understand Human nature and human activities. Risk rules our daily plain decisions, our hopes and aspirations, the management of companies from big groups to start-ups. Models of decision-making involving risk have always been developed and enhanced to provide the best solutions, but have for the most part relied on axioms that did not take into account the Human component of the system.

Nowadays, several domains of sciences study the different layers and components of decision-making, the funcitoning of our cognitive mechanisms and the underlying machinery, from brain regions down to the genes shaping their architecture and their communication modes. Proxies and tools to measure risk were developed, and few bridges exist to relate one concept of risk to another view, one approach to another notion. In this exploratory project, we aimed at building bridges between the different domains by comparing the tools they use while exploring the underlying causes of risk preferences.

We proposed an online survey made of several questionnaires and measurement tools to a population of engineering students from engineering academic institutions, with the objective of paitning a risk profile of the population depending on control variables (gender, program, age) and illustrated by the different concepts of risk. As entrepreneurial orientation is another expression of risky behaviour as well as a significant concern for univeristies and society, measuring the entrepreneur vein in the respondent pool could help picture the entrepreneurial potential of the students and understand what are the underlying traits and resources found in other measurements tools. To our knowledge, as of today no such study existed.

The data elicited in the framework of this exploratory project revealed few glaring or large commons ground between the various proxies. According to the evidence, self-evaluation of risk as well as risk-taking in EO is correlated to several components, or sub-dimensions, of the NS and HA tests: impulsiveness, rebelliousness, variety-seeking, neuroticism, and harm-avoidance. However when measuring risk prefrences through a set of five experimental economics games, fewer links were found with those psychological traits. Additionaly, no highly significant correlation were found on the grounds of gender or academic differences.

The entrepreneurial orientation test and its sub-dimensions offer a picture of the respondent appeal for entrepreneurship and as such displays several points for recommendations (7.3). Several links were found between the sub-dimensions of entrepreneurship and the same psychological traits linked to ERG and risk-taking (EO) : impulsiveness, rebelliousness, variety-seeking, neuroticism, and harm-avoidance; such results shed some light on the psychological resources that have to be summoned and perhaps trained to open the the horizon to entrepreneurship and ease its acess to students (see 7.3). For instance, the score of EO_edu, the measure of how the academic institution is seen as a support and inspiration to kindle an entrepreneurial career, did not stand out as high within the respondents with high entrepreneurship desire, nor the ones having entrepreneurial projects in inception.

More generally, this exploratory project is a first step towards interesting fields of studies (7.4). It is a first work merging several disciplines and different approaches of a common subject.

8.3 Recommendations

Concerning the exploratory project and its design, the results call for a multiplication of such studies, higher sample sizes and different populations. It would be stimulating to reproduce the study on a bigger scale with a large pool of students from engineering academic institutions, or specifically from Polytechnique Montréal with several (if not all) programs represented, as well as a wide population of participants from another orientation (e.g. business, or more specifically business in H.E.C. Montréal).

Despite the heavy and long recruitment campaign the number of respondents was disappointing, and prevents more asserted conclusions.

It would be all the more interesting if such studies could be encouraged by the academic institution itself. If such a project was directly sponsored by the academic institution in the eyes of the students and professors, it would provide a pristine picture of its population, and consequently a better analysis and guidance.

Regarding the concept of the study, I believe that one of the essence of engineering is the building of bridges between different ideas and disciplines in order to better understand and address issues and push knowledge forwards. This is the underlying idea that has been fuelling this project: precisely and widely understand the concept of risk from the basics (both

chronologically and conceptually), dive and delve into the core mechanisms as understanding progressed, and draw the pieces of the puzzle from all the disciplines that tackle the subject. On the edge of scientific knowledge, disciplines like behavioural finance would be great domains to investigate within and apply the thought processes and methods found in engineering programs. Financial engineering is also a booming and vast-growing domain, and more attention should be turn to such studies in order to bolster the movement and become pioneers. The purposes and challenges tackled are really relevant to the engineering sphere.

Eventually, the other main theme of this exploratory project is the measure of entrepreneurial orientation and finding its underlying driving forces. In the light of our results, several psychological traits arise as important in the determination of EO and could be the object of development and improved by the academic institution: training courses focusing on cultivating the traits of variety-seeking, encouraging pro-activeness, dealing with harm-avoidance (how to find the resource to deal with expected harm), offsetting neuroticism, or encouraging appeal and interest for innovation.

Many studies are measuring trends relative to entrepreneurship in Quebec and Canada, whether it be the entrepreneurial culture, the intent to create a company, the number of owners of a company, openings and closings of companies, exports, sustainable development orientation, etc. Such studies tend to find a striving willingness to follow an entrepreneurial path; however a difference between intention and action is to be noted. In Quebec, the intent to start an entrepreneurial activity is stronger than anywhere else in Canada [312] : 19,1% of Quebecois would like to start their company within the next 3 years. However as highlighted in the introduction another study emphasise the fact that by 2018 entrepreneurship will decrease by 13,9% in Quebec, versus an increase of 5,3% in the whole Canada [3]. Quebecois from 18 to 34 are the engine of this effervescent intent, as well as immigrants populations who have a high potential in the entrepreneurial chain [278]. Despite this willingness and potential, the actual creation of companies is below other countries. In this framework, project such as the present study might be useful to better understand what is missing to turn the intent into realisations and achievements. For instance, Quebecois might be immensely imaginative and innovative, but endure dismay when it’s a question of stepping in because they tend to have higher risk aversion. What are the components of entrepreneurship Quebecois? Is there a specific relationship with risk, and what is it fuelled by?

Other question related to entrepreneurial orientation embrace the role and impact of public policies, academic programs, or other initiatives designed to bolster entrepreneurial orientation among the population. Indeed, the way is paved to encourage such careers, especially in academic institutions with a multitude of programs and leads. For instance, the Centre d'entrepreneurship HEC-Poly-UdeM offers mentoring, support and help to build a business plan; and ÉTS also has its Centre d'entrepreneurship technologique (CENTECH). Programs especially targeted for students with the venture fibre teach how to start a company, innovation management, and commercialisation of an idea [313]. Once again, it is surprising reports and studies relate lower enthusiasm for actual entrepreneurial activities (compared to intentions) whereas numerous means and structures are at disposition to incubate venture aspirations. If engineers are supposedly a strong backbone for entrepreneurial activities, driven by technical innovation [314], something seems to be missing. Projects such as the present studies, tackling the subject under the point of view of the relationship with risk, decision-making mechanisms and psychological resources related to such activities might help to better understand what the missing part of the puzzle is. Perhaps stimulating and encouraging entrepreneurship should be undertaken for every students and not only a special orientation. Perhaps familiarising the population with risk and the concept of entrepreneurship could help to plant a seed : for instance, in Quebec the initiative *La grande journée des petits entrepreneurs* aims at developing resources such as creativity, desire, responsibility, autonomy and self-trust among children aged 5 to 12 [315]. Often the great success stories about present entrepreneurs start with the early endeavour they took on and which put them into motion towards greater achievements: perhaps it always begins "with a lemonade stand"?

8.4 Future paths and research

As exposed in the review of literature, risk-preferences and cognitive mechanisms of decision-making can be investigated from the angle of psychological surveys and empirical data, down to the activation of precise brain regions, the electrical and chemical activity and eventually the very fabric of the Human nature: the genes. It would be very interesting and daring to coin a research project built on this multi-layer concept. Focusing on a precise psychological trait, then analysing the brain activity of the participants in the brain, be able to measure hormone or neuro-modulator

levels at different points of a risky task, and eventually investigate the variation of genes coding the clutches that are involved in all that process.

On another ground, the present exploratory project could not tackle all of the psychological traits or attributes that have identified in the literature as positively affecting entrepreneurship, for instance overconfidence and locus of control. Other aspect such as social class, as well as the level of education and current occupation of the parents has not been recorded and could provide more comprehensive data concerning the students' entrepreneurial orientation.

In a nutshell, it is important to conduct future research by building bridges between the difference discipline and put efforts in understanding such global issues from various point of views.

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APPENDIX A – SUPPLEMENTS TO CHAPTER 2

A.1 Origin of risk – Introduction to chapter 2

The etymology of *risk* paints a well-rounded picture of the meaning it stands for. It has roots in ancient Greek, where *ῥιζικόν* is *hazard*, from the hazards of sailing along rocky coasts. Other roots trace back to Arabic, where *رزق* means working to gain income and make profit. In Italian, *rischiare* means to run into danger. Eventually, in Oxford Dictionary risk is the exposure to the possibility of loss, injury, or other adverse or unwelcome circumstance; a chance or situation involving such a possibility. Nowadays risk is a vast notion embracing a wide spectrum of meanings, often mingled with uncertainty. Thus risk is the potential, unpredictable and uncontrollable consequence of an action taken in presence of uncertainty. The possibility of gaining or loosing something of value, albeit risk is most of the time only associated with the negative aspect of the unpredictability. The perception of this risk is the judgement or assessment of the situation, a subjective gauge varying between individuals weighing the severity and probability of the possible outcomes of the given situation.

Every aspect of human life is in a relation with risk, close or far. It is in human nature to deal with risk, inherited by evolution from our hunter-gatherers ancestors. Too much risk-taking would mean exposure to unnecessary dangers and probable death, too little risk-taking would be a natural filter vouching for un-resourcefulness and not dynamic enough individuals unable to cope with borderline or threatening situations. Recent psychology papers link Novelty-Seeking (NS), a trait expressing a certain degree of risk-taking behaviour and a measure for psychology and neurology studies, to a precise version of a gene related to the function of dopamine, a neurotransmitter [316]. It is understood that individuals with that version of the gene would trigger and lead great migrations of population across territories, driven by an unquenchable thirst for novelty, leaving known areas for unknown regions, better or worse. Recently, the same variation of the same gene, DRD4, has been linked to financial risk-taking in men [204].

In this chapter we will focus on the economic, entrepreneurial, investment and financial conception of risk, and tell the history of how risk was considered, measured, expressed and analysed. This step-by-step evolution also provides a portrayal of ambivalent agents: for instance,

some are indeed risk-takers on small bets but become more risk-averse on bets with larger economic consequences.

A.2 Bayesianism (supplement to Savage's subjective probabilities)

Bayes' theorem describes the probability of an event, based on conditions that might be related to the event: this is a degree of belief; it takes into account prior knowledge. Baeysian inference allows updating the probability for a hypothesis as more evidence or information becomes available, making it possible to link the degree of belief in a proposition before and after accounting for evidence: the degree of belief may rise, fall or remain the same depending on the results.

For proposition A and evidence B,

$$P(A|B) = \frac{(P(B|A) * P(A))}{P(B)}$$

Where

- $P(A)$ is the prior; the initial degree of belief in A. Prior probability indicates one's previous estimate of the probability that a hypothesis is true, before gaining the current evidence.
- $P(A|B)$ is the posterior; a conditional probability, it is the probability of observing A given that B is true. A posterior probability is the probability of a hypothesis given the observed evidence. Here it is the degree of belief in A having accounted for B.
- $P(B|A)$ is the likelihood; it indicates the compatibility of the evidence with the given hypothesis.
- The quotient $\frac{P(B|A)}{P(B)}$ represents the support B provides for A.

The process of bayesian inference derives the posterior probability as a consequence of two antecedents, a prior probability and the likelihood function derived from the observed data. In other terms, the posterior probability of a hypothesis is determined by a combination of the inherent likeliness of a hypothesis -the prior- and the compatibility of the observed evidence with the hypothesis -the likelihood-. This process can be applied iteratively: after observing some

evidence, the resulting posterior probability can then be treated as a prior probability, and a new posterior probability computed from new evidence. This methodology is Bayesian updating.

It is in opposition with frequentist inference, which relies only on the evidence as a whole with no reference to prior beliefs. Frequentist interpretation is the realm where a probability measures a proportion of outcomes (which is objective). Consequently, an event's probability is the limit of its relative frequency after a large number of trials. In principle, probabilities can be found by a repeatable objective process and are thus ideally devoid of opinion and subjectivity. Obviously it does not support all needs: gamblers typically require estimates of the odds without experiments.

A.3 Allais' Paradox [41]

The models using subjective utility and subjective probabilities still dwell on the rationality of the player, who *respects axioms*. Allais first tackled such shortcomings with a well-known eponymous paradox in *Le comportement de l'homme rationnel devant le risque - Critique des postulats et axiomes de l'Ecole Américaine* (1953). He coined a choice problem in order to confront observed choices made by decision-makers with the predictions of EUT, which proved inconsistent and brought to light the violation of the axiom of independence.

A.3.1 Choice problem

The experiment is a two-round choice between two gambles, the comparison of which sparks the paradox.

First the respondents have to choose between the gambles 1A and 1B.

Table A.1: Gambles 1A and 1B, first round of Allais' experiment

Situation 1	Gains and probabilities
1A	• Certain gain of 100 million dollars
1B	• Gain of 500 million dollars with a probability of 0,1 • Gain of 100 million dollars with a probability of 0,89 • Nothing to gain with a probability of 0,01

Then the respondents have to choose between the gambles 2C and 2D.

Table A.2: Gambles 2C and 2D, second round of Allais' experiment

Situation 2	Gains and probabilities
2C	• Gain of 100 million dollars with a probability of 0,11 • Nothing to gain with a probability of 0,89
2D	• Gain of 500 million dollars with a probability of 0,1 • Nothing to gain with a probability of 0,90

Several studies involving hypothetical or real monetary payoffs [41] [42], as well as health outcomes [43], have supported the general result that most people would choose 1A over 1B, and 2D over 2C. For instance, data collected in 1953 by Allais reads that 46% of the participants went for 1A over 1B, and for 2D over 2C.

Choosing 1A over 1B, or choosing 2D over 2C is perfectly fine when one choice alone is considered. That the same person would opt for 1A and 2D together is the inconsistent fact which unveils the paradox violating EUT. This combination of choices is not compatible with the axiom of linearity. Indeed, equal outcomes added to each of the two gambles should not have any effect on the desirability, or ranking, of a gamble over the other one. Simply put, the fact of adding equal outcomes and probabilities to the gambles cancels out.

It is plain to see this when gains and probabilities of all the gambles (1A, 1B, 2C, 2D) are broken down as (1A', 1B', 2C', 2D'), respectively.

Table A.3: Gambles 1A' and 1B', reformulation of first round of Allais' experiment

Situation 1	Gains and probabilities
1A'	• **Gain of 100 million dollars with a probability of 0,89** • Gain of 100 million dollars with a probability of 0,11
1B'	• Gain of 500 million dollars with a probability of 0,1 • **Gain of 100 million dollars with a probability of 0,89** • Nothing to gain with a probability of 0,01

Table A.4: Gambles 2C’ and 2D’, reformulation of second round of Allais’ experiment

Situation 2	Gains and probabilities
2C’	• Gain of 100 million dollars with a probability of 0,11 • **Nothing to gain with a probability of 0,89**
2D’	• Gain of 500 million dollars with a probability of 0,1 • **Nothing to gain with a probability of 0,89** • Nothing to gain with a probability of 0,01

Then, commons outcomes (in bold) of situations 1 and 2 are ignored: choices 1A’’ and 2C’’ are the same, choices 1B’’ and 2D’’ are the same.

Table 2.6: Gambles 1A’’ and 1B’’, first round of Allais’ experiment

Situation 1	Gains and probabilities
1A’’	• Gain of 100 million dollars with a probability of 0,11
1B’’	• Gain of 500 million dollars with a probability of 0,1 • Nothing to gain with a probability of 0,01

Table 2.7: Gambles 2C’’ and 2D’’, second round of Allais’ experiment

Situation 2	Gains and probabilities
2C’’	• Gain of 100 million dollars with a probability of 0,11
2D’’	• Gain of 500 million dollars with a probability of 0,1 • Nothing to gain with a probability of 0,01

The general result that most people would choose 1A over 1B, and 2D over 2C is incoherent and violates the independence axiom of EUT.

Participant considers A over B
$\leftrightarrow A > B$
$\leftrightarrow U(A) > U(B)$
$\leftrightarrow 1*U(100) > 0,1*U(500) + 0,89*U(100) + 0,01*U(0)$
$\leftrightarrow 1*U(100) > 0,1*U(500) + 0,89*U(100)$
$\leftrightarrow (1 - 0,89)*U(100) > 0,1*U(500)$
$\leftrightarrow 0,11*U(100) > 0,1*U(500)$
$\leftrightarrow 0,11*U(100) + 0 > 0,1*U(500) + 0 + 0$

*↔ 0,11*U(100) + 0,89*U(0) > 0,1*U(500) + 0,89*U(0) + 0,01*U(0)*
↔ U(C) > U(D)
↔ C > D
↔ Participant should consider C over D

A.3.2 Explanation of Allais' paradox

The paradox stems several explanation and research prospects.

- Independence axiom and common consequence effect

The independence axiom stands as follow: if a decision-maker is indifferent between two plain gambles G1 and G2, the decision-maker shall be indifferent between G1 mixed with another gamble G3 and G2 mixed with the same gamble G3. This should be true when the gamble G3 has a lower payoff than G1 and G2. However, when the payoff of G3 increases and overlaps the ones of G1 and G2, the two initial gambles become *consolation prizes* for the gamble G3. Consequently, the decision-maker modifies the choice between the two initial gambles in order to minimise the risk and the potential disappointment induced by not winning the bigger prize associated with G3. This is the common consequence effect.

- Framing effect (1979) [44]

The framing effect materialises when identical outcomes result in different choices if they are differently explained (or framed) to the decision-maker. The text book example is when presenting a survival rate or a death rate to a patient. Refer to the framing effect section in the cognitive biases section (2.2.2) and refer to the prospect theory section (2.1.3).

- Complementarities [45]

Complementarities are the fact that one part of a gamble may depend on the possible outcome in the other part of the gamble.

The 1% chance of getting nothing in the gamble 1B carries with it a great sense of disappointment in the eventuality of picking the gamble and indeed actually loosing, whereas the agent could have won with 100% certainty by picking the other gamble 1A. The feeling of disappointment is contingent upon the outcome in the other portion of the gamble, the feeling of certainty. Allais argues that it is not possible to evaluate portions of gambles or choices independently of the other choices presented (as displayed in tables A.1 and A.2), as the independence axiom requires, and this is a poor judge of the rationality of an action. It is not

irrational to value 1A over 1B; it is the expected utility theory that is not robust enough to capture such bounded rationality choices arising from complementarities.

Allais' paradox dealt with the axiom of independence and presented objective lotteries. Ellsberg's tackled other lotteries involving ambiguity.

A.4 Introduction the psychology section

The Greek roots behind the word psychology mean the study of the breath, the soul. In Blankaart's Physical Dictionary (1694), "Anatomy treats the body, and Psychology treats the Soul". In this section we will study first the expressions and defaults of our thinking process, then the following chapter 3studies the anatomy, the structure from which they arise.

Psychologists investigate concepts such as perception, cognition, attention, emotion, intelligence, phenomenology, motivation, brain functioning, personality, behaviour, social relationships, and many other areas. This field is often described as a "hub science" because its findings are linked to research and perspectives from the social sciences, natural sciences, medicine, and philosophy. It is the science of mental life, its phenomena as well as their conditions.

A.5 Heuristics [77]

Heuristic is the tendency to use rules of thumb that make decision-making easier and faster. They offer practical methods which are not guaranteed to be optimal or perfect, but which are sufficient for the immediate goals (because the immediate situation summons a fast answer and there is not enough time to apply a careful process, or because the stakes are not affecting the decision-maker too strongly). They are built on experiences, assumed facts, and are also subject to other cognitive biases, and as such they can sometimes lead to impairments, especially when conditions change from one situation to another. Consequently such "snap decisions" can lead to suboptimal investment decisions. For instance, when faced with a choice for how to invest retirement money, many people allocate using the 1/*n* rule [78], that is to say if there are three funds one-third goes into each for no particular reason.

The study of heuristics in human decision-making was developed Kahneman & Tversky, supplying the study of behavioural finance and cognitive biases [77].

A sub-dimension of heuristics is affect heuristics.

A.5 Affect, heuristics and reflexes

The term affect refers to a momentary judgment based on a preconceived idea, and emotional judgment: something you like or dislike. This status will affect the rationality of the related decision and the emotional impulse prevents the individual from considering the situation, the risks and the benefits rationally and independently.

In a nutshell, if the decision-maker has positive feeling about something, it will taint the related beliefs about the risks and benefits: the risks are believed to be smaller and the benefits greater than they actually are. And this emotional impulse can disprove additional objective information brought to their attention. For instance individuals doing extreme sports, even though practising and riskier activity, will subconsciously tweak the risk-benefit ratio, and tell that they are in control and safer than most of the people (they are, by definition, not).

Some studies reveal that even seemingly insignificant factors can have decisive influence on our emotions, our actions and our decisions. For instance, studies mentioned in section 2.3 [17] [18] [19] are some expressions of affect heuristics. Other flabbergasting examples of how affect can forge and change our action or decision abilities [79] [80] can be found in the appendix A.

In the end, affect heuristics arise when we make complex decisions not only by consulting our thoughts but also under the influence of the master of puppets that are emotions.

The sight of an animal, the drawing of an animal or a cuddly toy with the characteristics of newborns and babies -a big head (relative to the body), a high and bulging forehead, big wide eyes- sparks the sensation that this animal is adorable and cute, and instantaneously gives the desire to check if the baby is alone, left, or in danger. There is the desire to protect and take care [317].

Kawaii is a Japanese word meaning “cute” or “adorable”. It comes from an ancient Japanese expression: “Kawa Ayushi”, Kawa being the visage, the face, and Ayushi meaning “blushing”. The original sense of the expression was blush out of shame, can’t stand watching, feeling pity for. It is the sensation that we feel in face of the distress of another, a self-centred meaning, the other being the cause of what we feel. But the sense of the expression has changed, has evolved towards the other: it now expresses the help we feel compelled to bring. The emotion is the starting point of the movement urging us to do something [317]. The essential is not us anymore,

but the other. This is the first dimension of empathy, an emotional contagion and resonance. Then the consequence, the second dimension: sympathy and the desire to find a way to help [81]. This effect is an example of the impact of a sensation we perhaps feel unconsciously. It deeply transforms our emotional state, making us focus and feel joy. But the tenderness and joy felt have even deeper effects. A first study [79] compared the dexterity of a sample of respondents in a particular manual task: a video game which goal is to operate and heal a patient. This role is to protect and cure. Respondents who played after seeing pictures of puppies and kittens significantly improved their score, whereas other respondents who saw pictures of adult dogs and cats did not.

Seeing for a brief moment pictures of babies enhances performance, focuses the attention and increases controls of the gestures involved in a task, even if the task does not concern directly the babies in the picture but nonetheless a task conveying the action of healing, taking care.

A second study [80] delved deeper into the Kawaii effect on the mind. The study revealed that respondents exposed to baby pictures took more time to perform the manual task: the enhanced performance comes along a slowing down of the action, more attentive and watchful. The researchers raised interrogations about other reflex mechanisms that may need a fast response, like detecting a danger in the environment. Would it be slower, and less efficient? Using sets of cute or normal pictures, they tested the capacity of respondents to detect precise numbers (e.g. “9”) in a picture composed of lots of numbers. Respondents exposed to baby pictures performed better, revealing that the sight of Kawaii pictures enhanced the capacity to rapidly detect precise details. The deep sensation induces by the cuteness of a baby does not trigger a global slowing down. Actions and gestures are slower and more thoughtful, whereas visual attention is more precise and faster. In a final experiment, respondents were shown a set of big capital letters composed of small capital letters (for instance, a big capital M composed of small capital P). Respondents who were shown baby pictures were able to identify the small letters faster than the big letters. They see more accurately the trees than the forest. In a nutshell, perceiving cuteness exerts immediate effects on cognition and behaviour not only in contexts related to care-giving or social interaction, but also in wider contexts as seen with the observation performances. Experimenting with numbers and letters demonstrated a tendency for details.

The explanation is that such behaviours are adaptive traits. As a social species new (newborns) and old (elders) generations need the support of the current (adults) generation to survive. Being cautious, aware of the environment and more focused helped societies to strive and buttressed the social aspect of human species. The common heritage can summon deep mechanisms affecting our cognitive processes and actions.

Several other studies tackle this effect, called subliminal affective priming effect, which induces shifts in judgements [318] [319].

A.6 Ambiguity aversion

The principles of ambiguity aversion have been explored in the section dealing with Ellsberg's paradox [46], then in prospect theory [44] [55]. Humans favour known probabilities over unknown ones and have a tendency to overvalue certainty, id-est are willing to pay a high amount or give up high potential outcome to drop uncertainty. They prefer to know than to stay prey to unpredictability: "when in doubt, know your way out". This tendency is inherited through evolution, indeed our ancestors did not have the luxury to ponder for a long time what was behind the veil of uncertainty. Those who fight further and survive longer were the one to act swiftly and foresee the worst when a situation could not be ascertained [81].

The relative novelty of economics (compared to the dynamics of evolution and how behavioural traits passed on) create a situation were dealing with uncertainty is not a survival question anymore, but is something humans have to cope with without being radical. As we have seen earlier, risk means that the probabilities as well as the wide spectrum of all the possible outcomes are known, whereas on the contrary uncertainty involves a touch of unknown, unforeseen, unconceivable [47]. The intangible nature of uncertainty makes decisions much more difficult, and the instinctive response is to ward it off in an attempt to act pragmatically. With risk you can make calculations, not with uncertainty. Economy, entrepreneurship as well as all related disciplines dwell in the realm of uncertainty, first and foremost because they are disciplines trying to foresee the future.

The difference between risk and uncertainty is embodied by the conception of credit default swaps. Indeed, credit default swaps (CDS) are financial instruments to hedge and trade credit risk, id-est insurance policies against specific defaults of payment. The argument is made that the CDS is an inherently defective concept because it is based on the assumption that future states of

the economy are subject to probabilistic risk as opposed to uncertainty in the Keynes-Knight definition. This confusion contributed to the financial crisis that has scourged since 2007 [23], illustrating the fleeting nature of predictions and the impact of the misunderstanding of risk and uncertainty.

Humans have to compose with ambiguity, meaning they have to understand and tolerate uncertainty. As Ellsberg's and the ongoing financial crisis illustrate, humans have not tamed it yet. Memories and emotions drive our reactions to uncertainty, and the mechanisms behind those reactions tackle the way our brain function.

A.7 Overconfidence effect [82]

Alpert & Raiffa led the first study tackling the tendency of people to rely too much on their expertise, highlighting the fact that people systemically overestimate their knowledge and their ability to predict, thus applying the overconfidence effect to forecasts such as stock market performances or entrepreneurial achievements [83].

According to Taleb, overconfidence measures the difference between what people actually know and how much they think they know. Taleb reports than 84% of Frenchmen estimate they are above-average lovers. 93% of the U.S. students estimated to be above average drivers [84].

Overconfidence Effect is linked to others documented cognitive biases such as the Illusion of asymmetric insight (people perceive their knowledge of others to surpass other people's knowledge of themselves, they believe people perceive their knowledge of others to surpass other people's knowledge of themselves [85] [86]) and the above average effect [87] (also known as illusory superiority, superiority bias, leniency error, sense of relative superiority, the primus inter pares effect).

It is suggested that this illusory superiority (as well as other biases) can be explained by a simple information-theoretic generative mechanism that assumes an inaccurate noisy conversion of objective evidence (observation) into subjective estimates (judgment). When assessing self-performance and skill, people tend to readjust their estimates of their own performance more than they readjust their estimates of others' performances. Eventually, overconfidence effect may be related to the profusion of information, experience and data about oneself relatively to the lessen

amount of information about the capacity and experience of others. A “self-centered” point of view.

People tend to be overconfident about their abilities. Experts suffer even more from the overconfidence effect than normal people do, and entrepreneurs are especially likely to be overconfident.

Overconfidence manifests in a number of ways. One example is too little diversification, because of a tendency to invest too much in what one is familiar with. Thus people invest in local companies (or companies they are related to, know somebody involved with). People also invest way too much in the stock of the company they work for. Delays and cost overruns are also another manifestation of overconfidence. The examples are abundant, daily, famous, and often break records after records whether it be the Airbus A400M [88], or the Sydney Opera House [89] [90]. However individuals with a direct interest in any project may also have other incentives to underestimate the costs, whether they are consultants or suppliers (incentive super-response tendency and motivation crowding).

Men tend to be more overconfident than women. Women tend not to overestimate their knowledge and skills as much. This manifests itself in many ways, including trading behaviour. Barber & Odean recently analysed the trading activities of people with discount brokerage accounts; they found that the more people traded the worse they did on average (with increased experience, more heuristical behaviours may develop) [91]. Moreover, men traded more and did worse than women investors (refer to the sections 3.2.1.3 and B.8.4 about androgens).

Additionally to the overconfidence effect, people tend to show presence of the egocentric bias (the tendency to overstress changes between the past and present in order to make oneself appear more worthy or competent than one actually is), or the bias blind spot effect (the tendency to see oneself as less biased than other people, or to be able to identify more cognitive biases in others than in oneself).

Eventually, optimists are not the only victims of the overconfidence: a study found that self-proclaimed pessimists also overrate themselves, however less extremely.

A.8 Gambler's fallacy, regression towards the mean fallacy, representativeness, and averages

Gambler's Fallacy is the term coined to qualify people's tendency to believe in a balancing force of the Universe, the evening out or levelling towards an average for pure random events occurring. It applies to games of chance, lottery, or any kind of independent situations with fixed probabilities. Gambler's fallacy leads people to believe that things must change in a way to reach the level of balance dictated by probabilities, for instance if a flipped coin reads heads fifty times in a row, there should be a balancing forces asserting that the next flip has a higher probability to read tails. And if the next flip of the coin reads heads, then it's extremely surprising, and consequently the next flip of the coin has all the more chance to read tails, "*because of harmony*". Gambler's fallacy is an uncontrollable force driving gamblers, entertaining and reviving the desire and intention to bet "one more time".

On the contrary, the regression towards the mean fallacy describes the tendency of individuals to fail to account for natural fluctuations in more complex feedback mechanisms than game of chances, like financial markets (or weather forecasts). Individuals are most likely to act when variance is at its peak. Then when the situation goes from extreme to normal, they ascribe a cause (their action) to the changes that occurred, whereas in fact it was not causal. It was to be expected. More generally, when dealing with interdependent events (compared to independent events in lotteries) regression towards the mean dictates that if a variable is extreme on its first measurement, it will most probably be closer to the average on its second measurement. On the contrary, if the first measurement is close to the average, it will probably derive from the mean on the second measurement. Individual fail to account for the natural variations in performances. Such a bias is very pervasive in decision regarding financial markets (where investors tend to act when an action is supposed to be at a decisive value, peaking at the summit or digging below), entrepreneurial ventures, or management (carrot and stick management). Regression to mean is a purely statistical correlation, not a causal link.

Often averages are misunderstood because individuals tend to neglect distribution. A lot of phenomena follow power laws, where averages are meaningless because a few extreme dominate the distribution (the way the values stack up). A single instance or a group of instances radically alter the global picture, and the concept of average has no sense. Dealing with averages is a risky

undertaking because they by nature don’t give any indication regarding the distribution and thus put a veil on the global picture. This is relevant in games of chance with the gambler’s fallacy, as well as in business, entrepreneurship, and finance where “average” has neither real grasp of the reality nor any practical use. “Don't cross a river if it is four feet deep on average” says Taleb.

Another cognitive bias related to averages is Representativeness. People underweight long-term averages and tend to put too much weight on recent experience as well as underestimate long past ones. When equity returns have been high for many years such as 1982-2000 in the US and Western Europe, people begin to believe that high equity returns were normal. For Kahneman & Tversky, representativeness is the degree to which a situation is similar in keys characteristics to its parent population (or previous occurrences) and supposedly reveals the significant features of the process by which it is generated. Individuals susceptible to representativeness bias when making decisions are deceived and are mislead, since more represented events are not necessarily more probable.

A.9 Loss aversion, disposition effect, framing effect & context effect

As explained earlier with the diminishing marginal utility principle (section 3.1.6), the vast majority of people tend to display loss version: they will reject a fair bet (50% chance to win $100, 50% chance to lose $100) because the loss of utility when losing the bet is more important than the gain of utility when winning the bet. This aversion was pointed at by Kahneman & Tversky in their prospect theory, and developed as an answer to Ellsberg’s paradox: individuals feel more pain from losses than they feel joy from an equivalent gain, and will act on it whether it be consciously or unconsciously.

This tendency may find its roots in human evolutionary past: carelessness and recklessness meant survival or not, with this perspective it is normal that a loss feels more impactful that a similar gain (a study weighs a loss twice as “heavy” as the corresponding gain) [92].

The disposition effect is an extension of loss aversion. It refers to the pattern following which people tend to avoid realising “paper losses” and seek to realise “paper gains” [93]. The fear of losing something, or actually realising a loss, motivates people more that the prospect of gaining something of equal value: for instance, if someone buys a stock at $100, which then drops at $75 and eventually rises up to $90; most traders won’t want to sell until the stock gets above $100. The disposition effect manifests itself in lot of small gains and small losses being realised, and

shows up in aggregate stock trading volume. Unrealised loss isn't as painful as a realised (official one), thus traders tend to sit on such stocks even though the chance of recovery is small and the probability of further decline is large [94].

Framing is the notion that how a concept is presented to individuals matters. For instance, restaurant may advertise "early-bird" or "after theater" discounts or specials, but they would never use for peak-period the term "surcharges". They have more business if people feel they are getting a discount at off-peak times rather than paying a surcharge at peak periods, even if the prices are identical. Cognitive psychologists have documented that doctors make different statements and recommendations if they see evidence that is presented as survival probabilities rather than mortality rates, even though survival probabilities plus mortality rates add up to 100% [95].

Framing and loss aversion express themselves daily around us and marketing department always resort to it (for good or less "philanthropic" reasons). For instance, they will highlight how a product help buyers dodge risk and disadvantages rather than shed light and focus on the advantages it provides. Researchers found that in a campaign promoting breast self-examination for cancer, populations presented with the campaign "research shows that women who do not do BSE have a decreased chance of finding a tumor in the early, more treatable state of the disease" became far more aware and concerned than the population of respondents presented with the campaign "research shows that women who do BSE have an increased chance of finding a tumor in the early, more treatable state of the disease". Another poignant example is as follow: in a study concerning meat labeling, the majority of the respondents preferred the product labeled "98% fat free" compared to the product labeled "1% fat".

A 2-round study by Kahneman & Tversky presented an epidemic-control strategy decision concerning a pool of 600 affected patients.

First round of the experiment, decision between strategies 1A and 1B:

- Strategy#1A cures and saves 200 people;
- Strategy#1B has 1 in 3 chances that the 600 affected patients are cured and survive, and 2 in 3 chances that the 600 affected patients die.

The majority of the respondents chose Strategy 1A.

Second round of the experiment, decision between strategies 2A and 2B:

- Strategy#2A kills 400 patients;
- Strategy#2B offers 1 in 3 chances that everybody will be saved and 2 in 3 chances that everybody will die.

The majority of the respondents chose Strategy 2B.

Thus, depending on the phrasing, the participants to the study made completely opposite decisions, whereas the exact same outcomes and probabilities were at stake. In the first round of the experiment the decision for 1A may be driven by the certainty effect and the framing effect (or the framing effect induces a penchant for the certainty effect), and in the second round of the experiment the decision for 2B may be driven by loss aversion induced by the framing effect. It is plain to infer that a combination of loss aversion and framing effect can be a dreadful cocktail when collection and analysing information prior to an important decision of investment in entrepreneurship or finance.

Context Effect is another term illustrating a special case for framing effect. It was theorised by Kahneman & Tversky in 1986 to express and take into account the change of perception and beliefs in the evaluation process. In a nutshell, the context of choice and the formulation of the enunciation of a problem affect the comparative appreciation of the decision-maker, thus the choice. Context effect focuses of the change of referential used to specify the outcomes of random perspectives.

These cognitive biases are very relevant when considering the prospect theory. Indeed as explained in chapter 2, prospect theory is a descriptive theory and it focuses on changes in wealth, whereas expected utility theory focuses on the level of wealth. Gains and losses are measured relative to a reference point. Prospect theory also assumes loss aversion and incorporates framing, using that reference point.

Those effects have an importance for a single event or decision, but may also apply in set of several decisions: when two related events occur, an individual has a choice of treating them as separate events (segregation) or as one (integration). For instance, if a person goes to the racetrack and makes two bets, winning one and losing one, the gambler may integrate the outcome and focus on the net payoff. If the net payoff is positive, a gain has occurred, and focusing on this makes the gambler happier. If there is a net loss, segregating the two bets allows the bettor to feel disappointed once, but happy once.

Eventually, biases such as loss aversion, disposition effect and framing are also impactful in regards to entrepreneurship and risk-taking within the firm. Within a company, an employee won't take more risk than necessary because it brings at best a bonus, and at worst a sanction (to the extent of laying off). Safeguarding a career most often trumps any potential reward or perspective of promotion. However, sometimes individuals in a stable situation will take high risk but within the context of group decision (this effect is called social loafing).

A.10 Confirmation bias, coincidences, apophenia, selection bias, and the law of near enough [96]

The tendency for humans to confirm their own belief rather than testing them objectively is named confirmation bias (sometimes confirmatory bias). It has been pointed out and commented on since antiquity, and always described as shackles of the mind and a predominant flaw hindering reason.

> Opinion – hasty – often can incline in the wrong side, and the affection for one's own opinion binds, confines the mind [97].

Confirmation Bias is the tendency to seek for, analyse, or memorise information according to one's prior beliefs, to favour one's conception and hypotheses, and on the contrary to discredit and confute alternative or opposite ideas. Confirmation bias is designated as a systemic error of inductive reasoning because it sways every steps of the thought process: the gathering of information, the interpretation of the information, and the storage of the information and conclusions. The effect is all the more marked for emotionally charged topics and deep rooted beliefs, consequently the confirmation bias will be self-sustained because as people accumulate memories and experiences, they will strengthen their beliefs and will be less likely to receive new contradictory pieces of evidence, bolstering again the prior belief.

Since the 50s, experiments have repeatedly put forward that people are biased towards confirming their prior beliefs and explained this behaviour by a disposition for testing ideas in a one-side way (own-sided way), focusing on a dominant possibility and disregarding the others (often the contradictory ones). This mechanism is the fruit of unconscious, automatic strategies rather than deliberate mechanisms [98] [99]. For instance, individuals will unconsciously emphasise the cost of being wrong compared to the cost of the genuine truth obtained by a neutral investigation. Availability Heuristic may have a role in the Confirmation Bias, because believing

in an idea makes that idea more susceptible to be available in the mind. People create a representation of reality using the examples and memories that most easily come to mind, and they prefer and favour information that is easy to obtain [100]. Motivational explanations involve an effect of desire on belief, namely the wishful thinking [101]. Depending on the desirability of the conclusion, individual will demand a higher standard of evidence for unpalatable ideas and a lower standard for preferred ideas, thus making desired conclusion likely to be true. MacCoun and Kunda explain the confirmation bias by "cold" and "hot" impulses: the hot-emotional motivation is the spark of the bias, and cold-mechanical cognitive factors delimit the size of the fire [102] [103].

On the information seeking side, the confirmation bias affect people as they tend to test hypotheses in a ones-sided way and search for evidence consistent with their prior hypothesis. This mindset will influence the modus operandi of the experiment, whether it be in social science or in "hard" science. Experimenter will possibly change the orientation of their questions, and respondents, themselves subjects to the ascendancy of confirmation bias, will change their answers. Kunda found that people who are asked "are you happy" with your social life?" report greater satisfaction than those asked "are you unhappy with your social life?" [103] : the respondents will answer to the question by searching through available information and the words of the sentence echo and influence this enquiry (for further development on the confirmation bias and the influence on scientific research, refer to the section 8.1 about limitations of our study). The researcher forges his modus operandi under the influence of confirmation bias, respondents answer under this influence too, then the confirmation bias can strike another time when comes the interpretation of the data. Even if two individuals have the same information, the way they interpret it can be biased (as a lot of biases are at work). Confirmation bias operates by pointing to details that supports the prior viewpoint and disregarding anything contrary. People set higher standards of evidence for hypotheses that go against their current expectation [104]. Eventually, even if people gather and interpret evidence in a neutral manner, they may still remember it selectively to reinforce their expectation: indeed information matching prior beliefs will be more easily stored and accessed than information that goes against expectations [105].

The confirmation bias can be mingled with or fueled by other closely related cognitive biases. One of them is apophenia, the perception of connections or patterns in information. Pareidolia (a

type of apophenia) is the seeing or hearing of things that are not meant to be there, for instance hearing your name being called in the sound of running water or in the racket of a train station. This tendency can drive people to dazzling conclusions, such as the Face on Mars which is a natural rock formation appearing on a satellite photo of the Cydonia region of Mars. Indeed, when the photography was made public, people saw a face in the aggregate of rocks, and treated it as a sculpture proving that Martians existed. Apophenia is just a manifestation of the skills developed by our brain during evolution. Being hyper attentive to patterns, or disturbances in patterns (such an unnatural movement in vegetation), can save your life. And our natural tendency to see faces everywhere, from clouds to rocks, illustrates our social traits. For cohabitation and social development, seeing and recognising a face is crucial. If there is ambiguity on whether a form hiding in the shadows is a threat or just a shadow, it's advantageous for the brain to decide for a threat and turn into survival mode, ready to fight or flee. Organisms with a healthy sense of apophenia live long enough to have descendants, thus it naturally becomes the norm.

Selection bias and confirmation bias are intertwined. if one really wants two things match, one will often look for pieces of evidence that support what they already believe, while marginalising things against it. As McLuhan expressed it: "I wouldn't have seen it if I hadn't believed it."

Humans are hard-wired to overreact to coincidences and they actively look for them up to the point of artificially creating them. Confirmation bias contributes to overconfidence in personal beliefs and bolsters beliefs in face of contrary evidence. Poor decisions due to these biases have been found in every domain, from politics to business and finance [107] [108]. In finance, Confirmation bias can lead investors to be overconfident, ignoring evidence that their strategies will lose money [109] [110]. A 2010 study by Park et al. analysing 502 investors highlighted that investors with stronger prior beliefs are even more likely to accept confirming opinions, and have higher expectations about their investment performance. However, investors with stronger confirmation bias engaged in excessive trading and eventually experience lower realised performance [111].

In business and entrepreneurship realm, Confirmation Bias reduces the capacity to be flexible in the face of changing conditions and dampen the capacity to respond to negative information : executives enthusiastically celebrate any sign that the strategy they follow is a success, these

signs will be confirming evidence of their business sense, on the contrary any indication to the contrary remains unseen, alleviated or quickly dismissed as an exception, special case or unforeseeable event independent of the decision-maker's will. Warren Buffet often mentions the Confirmation Bias as a predominant hindrance for good business ventures: "what the human being is best at doing is interpreting all new information so that their prior conclusions remain intact".

> Là dessus ils ne consultent pas tant l'Histoire pour savoir si leur persuasion est véritable, que pour trouver qu'elle est véritable, et on ne saurait dire l'illusion que cela fait aux sens et au jugement. En effet il arrive de là qu'on observe beaucoup mieux les faits que l'on désire de trouver, que les autres, et que l'on grossit ou que l'on diminue la qualité des évènements selon la préoccupation. (Pierre Bayle, Pensées sur la comète.)

Humans are so good at teasing out patterns from random noise that actual random sequences don't always feel random. What to humans say about coincidences? The Universe is rarely so lazy. For instance, originally Apple's iTunes shuffle feature generated complaints from users. Users reported similar songs or songs from the same artist appearing in a string, which of course is to be expected from randomness. But it did not feel random enough, and Apple introduced a "smart" shuffle that avoided totally random sequences that nonetheless did seem random to our pattern loving brains. "We make it less random to make it feel more random." – Steve Jobs.

Our impressive ability to imagine patterns expresses itself daily, in every situation and domain, from finance to connecting songs and moving images. Selection bias helps a lot those misconceptions. Human fall prey to Selection Bias when they reject all the times evidence or data does not "sync" with the pattern, focusing instead on the more relatively surprising times when it does.

The digits of the speed of light (299 792 458 m/s) are exactly the same as the latitude of the pyramid of Giza (29.9792458°N). This coincidence is a lot less flabbergasting when you consider the fact we got to control where we put the decimal point and where we exactly pinpoint on the map, for a number of degrees this precise isn't necessary to locate the pyramid. By the fourth decimal we are only talking about a matter of a few meters so it's easy to make the rest fit the speed of light exactly and still pick the point on the pyramid.

Getting struck by lightning is a proverbially unlikely situation. However, a man named Walter Summerford was struck 3 times, although it never killed him. Yet, 4 years after his death his

gravestone was also struck by lightning. While for the average person the chance of being struck is quite low, for an avid outdoor sportsman like Summerford, it's not as low. In The Improbability Principle – Why Coincidences, Miracles And Rare Events Happen Every Day by David J. Hand, this phenomenon is called The Probability Lever. What maybe rare on average or when considering all possible scenarios can be less rare for specific scenarios even if they are only marginally different. And the law of truly large number also comes into play here. With lighting striking earth 40 to 50 times every second, billions of people on Earth for it to strike, and thousands of years of recorded history, it's actually not surprising at all than at least once a story like this would have happened. Unexpected as it seems at first, given enough time and enough interest in finding them, mathematics and psychology will work towards the finding of coincidences and connections, even unlikely ones. The coincidences between Abraham Lincoln and John F. Kennedy are famous. Unintentional extraordinary things happen, in fact, all the time. Littlewoods' Law tells that given the number of hours we are awake every day and assuming an event only take about a second to occur, if you calculate the odds of something happening to you are only one in a million, you should expect that thing to happen to you about once every 35 days. Hand took this even further by applying this calculation to the 7 billion people on Earth. Then, the chance that an event within one in a million probability of happening to each of us won't happen today is 1 in 10 to the 3040.

"The truly unusual day would be a day where nothing unusual happens." Persi Diaconis.

A.11 Black Swan

Black Swan is a metaphor for absolutely unexpected events (in the sense that they are not conceivable, no amount of imagination could fantasise or conceptualise a Black Swan) that have major effects and possibly change the organisation of the world. In the concept of Black Swan lays also the idea that once such an event has occurred, it will be rationalised, and a reasonable explanation for its occurrence as well as why the eventually of its occurrence has been eluded will be coined with the benefit of hindsight.

"A rare bird in the lands and very much like a black swan": all swans were believed to be only white because since the midst of time, observed swans were indeed white. The observation of a single black swan would disprove not only the principle (all swans are white) but also the system of thought that led to this conclusion (all observed swans are white, itaque all swans are white).

Consequently, once a Dutch explorer named de Vlamingh stepped in Australia and discovered black swans, the animal became the symbol for the improbable.

The term was recently popularised by the eponym book and theory by Nassim Taleb. According to Taleb, Black Swan type events have 3 characteristics:

- The event is a surprise;
- The event has a major effect;
- The event is rationalised and explained retroactively, as it could have been expected. Data was probably available but unaccounted for.

> What we call here a Black Swan (and capitalize it) is an event with the following three attributes. First, it is an outlier, as it lies outside the realm of regular expectations, because nothing in the past can convincingly point to its possibility. Second, it carries an extreme 'impact'. Third, in spite of its outlier status, human nature makes us concoct explanations for its occurrence after the fact, making it explainable and predictable.

Taleb dedicated two books to the Black Swan theory: first *Fooled By Randomness* (2001) which only concerned financial events, then *The Black Swan* (2007) which illustrated the concept to events of all types. Indeed, Taleb explain that most of the major scientific discoveries, historical events, and artistic achievements or revolutions that stud History are Black Swans. Altogether, such events play the main role in History.

The inability to prevent and cope with Black Swan is born with our memory and information processing mechanism. We learn from experiences and then apply critical thinking to better cope with future challenges and choices. Ideally, we “hope for the best and prepare for the worst”, but uncertainty and Black Swans escape from that grasps simply because we can’t conceive and compute truly extraordinary events. As Donald Rumsfeld put it: “There are things we know, there are things we do not know, and there are things we do not know that we do not know”. As refined as models can be, by definition they can only consider the things we know and the known unknowns, but can’t input the unknown unknowns.

A.12 Cognitive Dissonance

Cognitive dissonance occurs when there is a retrospective reinterpretation of a situation or an event that offers a better scenario for the observed outcome. The textbook example is when a job applicant does not get the job, and then convinces themselves they did not really want it in the

first place and were just applying for training purposes. The genuine truth is just that another candidate was better suited for the job.

Carlsmith & Festinger led an experiment where two groups of students had to perform a boring one-hour task. For the completion of the task, every student in group A was awarded $1 whereas students in group B were awarded $20. Students from both group then had to eulogistically depict the task to other students who did not know what it was about. For the last stage of the experiment, students from group A and B had to disclose to the researchers how they really did find the task: Those who were paid $1 rated the activity a positive 1.35 (+1.35), while those who were paid $20 gave it a rating of negative 0.5 (-0.5). According to Festinger & Carlsmith, the participants experienced dissonance between the conflicting cognitions of telling someone that a particular task is interesting when the truth is, they found it rather uninteresting and boring. Those who were paid $1 were forced to rationalize their own judgments and convinced themselves that what they were doing is enjoyable because they had no other justification. On the other hand, the ones who were paid $20 apparently had the money as their primary justification for carrying out their task. In a nutshell, the payment of $1 was so meaningless that the students convinced themselves that the task was, in fine, no that troublesome to conduct.

One explanation was formulated by Festinger himself: it's the Social Comparison Theory. This is the idea that there is a drive within individuals to search for outside images in order to evaluate their own opinions and abilities, the outside images being references to physical reality or in comparison to other people.

Another explanation highlights the human tendency to forget or to alleviate bad experiences, eventually bad memories turn into good ones or at least the individual will lessen the bad aspects of the memory and put forth and valorise the good aspects of the memory. It's a form of survival process, and individual can't just dwell on failure or a bad experience and has to carry on. In a way, pain (physical, emotional, mental) feels good, especially if it could have been worse. Of course on the contrary sometimes stress carves a bad memory vividly in the mind because remembering negatives events and learning from them is also a good curve towards future survival (see 'Association Bias'). Experience can impair or distort the judgment.

A.13 Association bias

Association bias delves directly into the mechanism of our mind. The brain is a network of connected cells, the neurons, and works by creating links and relationships. The brain is mapped as such and knowledge is based on this principle. However, this is also how false connections, or false knowledge, will be carved into the mind. Pavlov was a Russian scientist who linked two functionally unrelated things: the sound of a bell and the production of saliva by dogs. The dogs became simply accustomed to being fed as the bell rang.

The false connections are not always harmful or neutral, they can be positive. Recent studies have pointed at the positive impact of flavour or scent in mnemonic mechanisms, whether it is with young students or people affected by memory deficiency. To a relative extent, smelling a fragrance or chewing a savoury gum while studying can facilitate the learning process and the access to the recorded knowledge later, when using the same scent or gum.

False connections are the result of the Association bias, which influences the quality of our judgement. Marketing and advertising are always resorting to this kind of means in order to create a link between their products and a positive emotion. Association bias creates a distorted view of the real situation and summons emotional responses, occulting objective input.

APPENDIX B - SUPPLEMENTS TO CHAPTER 3

B.1 A brief history of Neurology: Animal Spirits, La Reazione Nera, and Clarity

An acceptable definition for Science is the search and the will to see within the invisible, beyond time, beyond space. This kind of utopian and fanciful motto has been applied to study everything, from the deepest part of ourselves and what makes everything that surrounds us, to the far extent and astonishing Universe that surrounds us. The common point is the very quest of unquenchable thirst for knowledge that has been driven by this question: who and what are we. In the course of the adventure that brought us modern Sciences there were privileged moments, cornerstones where those two approaches crossed and sometimes connected: see within us and see far away.

One of these moments looms in the middle of Renaissance, in 1543, when two books are published. Those books are going to change in very different ways, but very deeply and irreversibly, the look humans take at themselves and at their place in the Universe.

The first book is the Polish astronomer Nicolaus Copernicus' *De Revolutionibus Orbium Coelestium*, *On The Revolutions Of The Heavenly Spheres*, which brings a new perspective on the Universe. It's an outlandish and unexpected vision: wonderful by its extraordinary and harmonious simplicity, and disturbing for it suggests our home, our Earth, is not this reassuring and prideful immobile centre of the Universe, around which everything is organised and orbits.

After geocentrism, Science has progressively transgressed another ancient taboo: the autopsy of the human body, which was considered a fathom breaking into the vessel of the soul. Until then, the sight, the touch, as well as the painting and sculpting arts only unveiled the edges and the surface of the outward appearance.

The second book is the tale of this exploration. Entitled *De Humani Corporis Fabrica*, *On The Fabric Of The Human Body*, written and illustrated by a Dutch anatomist named Andreas Vesalius. With drawings of astonishing precision, it unveiled the invisible parts upon which humans are built, unknown territories and mysterious continents they are made of. Splendid and troubling, it is both an unascertained form of beauty and a disconcerting form of unsightliness, burrowed and hidden but always present. It's really about us, what we are and who we are.

The work of Vesalius was a turning point in understanding the structural organisation of the nervous system as well as the role of the brain and neurons. It is also a contribution that inherits a long reflection, a search for understanding the machinery commanding our thoughts and actions.

B.1.1 Animal Spirits

Aristotle postulated that the seat of our mental activities was our heart. Today we still allude to that conception with common language expressions such has having a heavy heart, a broken heart, or when our heart is racing at the slightest emotion. Back then, the brain was considered to only assume the role of a thermal regulator cooling down the excess heat produced by the heart.

A contemporary intellectual and philosopher, Hippocrates, first theorised that our thoughts, feelings, mental processes and ideas came from the brain, thus dropping the conception that the heart and sometimes the stomach were the throne commander of emotions, of thinking, and of the very flame of human condition.

During the 2nd century, Galen of Pergamon practised medicine in Alexandria and Rome, and was the roman emperor Marcus Aurelius's physician. He left behind him an important legacy consisting of treatises of anatomy considered seminal works until Renaissance. Galen combined the writings of the before mentioned Greek intellectuals and proposed that it was not the heart but the brain that was commanding our mental activities. He advanced that vital spirits spread from the heart to the basis of the brain, where they would be turned into animal spirits filling up ventricles in the cavities of the brain. This would result in making our mental activities emerge. As the majority of the manuscripts from Greek and Roman Antiquity, Galen's treatises would be long lost and forgotten, then rediscovered in Europe during Renaissance as soon as the 13th century in the form of translations realised by Arab and Persian intellectuals who had them preserved, transcribed, studied, commented, and broadened with their own writings like the great philosopher and physician Avicenna. However, none of Galen's drawings, if he realised any, eventually managed to reach us.

The oldest drawing of a part of the nervous system is an illustration of a nerve binding the eye to the brain. It was sketched by the Persian mathematician and optical specialist Alhazen.

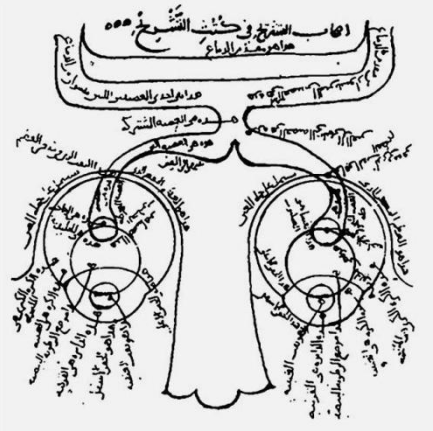

Figure B.1: Diagram from Kitâb al-manâzir (Book of Optics) by Ibn al-Haitham (Alhazen, c.965–1038), showing a chiasm—'the joining nerve'. The Sulimaniye Library (Fatih Collection), Istanbul

In the 15th century, Leonard Da Vinci covertly realised autopsies and produced drawings where science and art are intertwined.

In the middle of the 16th century, Vesalius realised public autopsies in Padua that gathered an important audience of curious. He synthesised the whole of his finding in the revolutionary book mentioned earlier: *On The Fabric Of The Human Body*. This book allowed to see the buried continents of the sheaves of muscles and tendons enabling us to move, the arborescence of the nerves and blood vessels, the branching of the bronchial tubes endowing us to breathe, the ocular globes revealing the organic behind the scene of our sight, and our brain from which arise our thoughts, sensations, emotions, will, souvenirs and dreams. What these drawings show is what remains of us after the light has gone, our muscles when nothing puts them in motion, our lungs when there is no more respiration nor breath, our brain the seat of our thoughts when our thoughts have vanished, the seat of our memory when our souvenirs have faded, the source of our hopes and fears when there is in us no more hope nor fear. Regarding the nervous system, nerves are still keeping their secrets, but Vesalius postulated they were hollow conduits where the animal spirits were travelling.

In 1660, Descartes postulated animals are clockwork figures driven by animal spirits travelling across the body between the nerves and the brain. Modelled on this blueprint, our human body is also an automaton, a machinery, with the distinction humans possess an immortal soul of divine origin that is located in the brain. Thus, the brain is that link weaving and articulating the

relations between soul, spirits, and the body. More precisely, Descartes pinpoints the pineal gland as the location of the soul; indeed, on the contrary to the other components of the brain, the pineal gland is not present in two symmetrical copies or parts, which makes it a privileged place for the soul.

Figure B.21: Illustration of pain pathway, from René Descartes's Treatise of Man

Across the Channel in England, the physician and anatomist Thomas Willis stated that the study of the immortal soul eludes every scientific approach and is not within the domain of Science. He suggested distinguishing the immortal soul from a corporeal soul: the corporeal soul can be examined by Science, is shared with the animals and is linked to the activities of the brain, allowing the perception, the learning, the memorisation, and the knowledge. Helped by Christopher Wren, Thomas Willis realised an extremely precise description of the structure of the brain, and proposed that all of our mental activities (our corporeal soul, our capacities of conscious perception, of memory and of will) happen in the filled and solid parts of both brain hemispheres, and not in the empty cavities of the ventricles. Willis was also the first to postulate the principle of a regionalisation of the brain's activities. Eventually, he was among the firsts to suggest that the troubles of the mind, the madness, are troubles of the corporeal soul, meaning they are troubles of the brain's functioning that medicine could study, understand, and heal.

B.1.2 Spark of life

Antonie van Leeuwenhoek, who will later been known as the father of microbiology, developed his own microscope and soon discovered in a simple drop of water a whole minuscule universe of living beings invisible to the naked eye. After this technological step, nerves revealed they were no longer simple hollow pipes spreading in the whole body, but were filled with living matter. However, it is still not understood what circulates into the nerves. Seeing does not grant a full answer, the visible is not enough to understand what is seen.

The next important step occurred in 1780, when Luigi Galvani realised an unprecedented experiment and discovered that the leg muscles of dead frogs twitched when struck by an electrical spark. Electricity then became the link binding the body and the spirit, the body and the brain, the vital force animating the body. This discovery will set the foundations of our understanding of the nervous system, as well as leave a print in everyone's mind. In 1818 Mary Shelley published her first and most famous novel, *Frankenstein; or, The Modern Prometheus*, the story of a human demiurge using science to bring back to life a deceased man. It is to electricity that is attributed the power to revive the body and the spirit.

> Like the entomologist in search of colourful butterflies, my attention has chased in the gardens of the grey matter cells with delicate and elegant shapes, the mysterious butterflies of the soul, whose beating of wings may one day reveal to us the secrets of the mind. (Recollections of My Life, Santiago Ramon y Cajal)

Then, at the dusk of the 19th century, the neuroanatomist Santiago Ramon y Cajal used Golgi's method (a chemical solution composed of silver nitrate) to visualise nervous tissue with unprecedented details. This *Reazione Nera*, this black reaction, reveals in a brush stroke the hidden structure of the mind:

> What an unexpected spectacle! On the perfectly translucent yellow background, sparse black filaments appeared that were smooth and thin or thorny and thick, as well as black triangular, stellate, or fusiform bodies! One would have thought that they were designs in Chinese ink on transparent Japanese paper. [...] Here everything was simple, clear and unconfused. A slender fibre that originated from the cell elongated over enormous distances and suddenly opened out in a spray of innumerable sprouting fibres. [...] The amazed eye could not be torn away from this contemplation. The technique that had been dreamt of is a reality! [...] (Histology of the Nervous System of Man and Vertebrates, Santiago Ramon y Cajal)

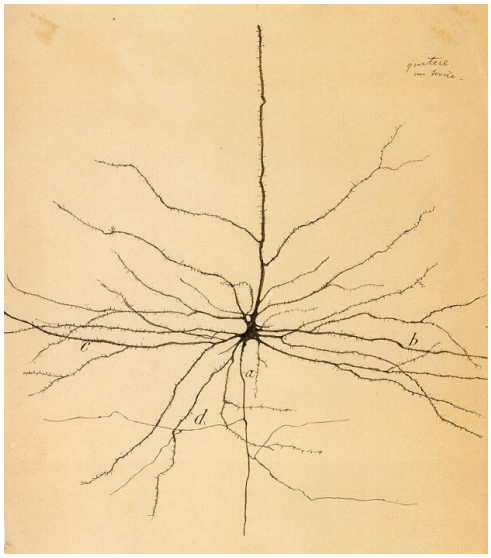

Figure B.3: Santiago Ramón y Cajal, 1899. A pyramidal neuron drawn from a histological stain of a human retinal cell

B.1.3 Elementary operating unit of the brain and the nervous system: Neuron

Just a few more years after the first drawing of a neuron, and Charles Scott Sherrington proposes the concept of synapse. Located on the small spots described by Santiago Ramon y Cajal, where the extensions of nerve cells join in an area both splitting and binding the link, the synapse is the locus where the pursuit or interruption of electric impulse that journeys through nerve cells takes place.

The nerve impulse propagates as electric current along a nerve cell and its extensions, the axon and the dendrites. However in the small spaces, the synapses, that cut off one cell from the others, it is not electricity that relays the nerve impulse but the release of chemical molecules, the neuro-mediators. From now on, neurobiology will be based not only on the study of nerve cells and electricity, but also on the study of molecules. Neurology reaches the molecular scale: this is the birth of modern neurosciences.

An adult human brain is composed of 100 billion nerve cells on average, each and every single one of them linked, via its extensions (axon and dendrites) to several thousands of other cells (for the most part also nerve cells). The set of these connexions materialises a gigantic network of possible interactions, a circuitry of several millions of billions of synapses from which arise our mental representations and our behaviours. This discontinuity between every nerve cells, those countless switches, passing and sorting points of nerve impulses, enable the appearance and the

self-organisation of the extraordinary complexity of our brain, from a limitless field of possible variations.

Nowadays, 140 years after the discovery of Golgi and Santiago Ramon y Cajal, the means to analyse the cellular and molecular components of the brain, as well as the activity of nerve cells and their countless networks, achieved spectacular innovations. As soon as 1920, the electroencephalogram records in real time the electric currents that wander and roam the different regions of our brain. Since the 1940s, electrodes that are implanted directly into the brain during surgical operations allow to record the activities of a small group of nerve cells, now down to the observation of one single cell. And for the last 20 years, functional imaging of the brain enables to study in real time the activities of the networks and nodes via the proxy measure of the consumption of sugar and oxygen by the cells.

Those indirect analyses translate, based on the visible, the invisible activities of cells and molecules along the countless networks and ramifications that build and liven up our brain. Just as Golgi and Ramon y Cajal used to do, cells and molecules within their communication networks are still observed though the microscope, on thin layers of brain. However, the power of the devices and the use of multiple markers that fix on molecules and glow at various wave lengths have radically transformed the interpretation of thin brain layers. They are not anymore *La Reazione Nera*'s sophisticated Chinese ink drawings on Japanese yellow-transparent paper that enthralled Ramon y Cajal, but henceforth gorgeous colourful kaleidoscopes of a flabbergasting keenness and precision, as well as marvellous beauty. Those living paintings display such a large amount of data that its interpretation requires heavy computer science analysis.

This reading of the networks is still done on thin layers of brain of the thickness of a strand of hair. Thus, to reconstruct a three-dimension image of a mouse's brain, it has to be built on a computer based on hundreds of thousands of digitised thin layers. This reconstitution is consequently very long, complex, and a source of numerous errors.

In 2013, 140 years after the discovery of Golgi that enabled for the first time the observation of the cellular structure of the brain, a publication in Nature revealed a brand new method to picture the brain. The development of this new method had been undergoing for 6 years, at the end of which the brain of a dead mouse was made transparent. The research was conducted by a

multidisciplinary team of Stanford University under the supervision of Karl Deisseroth, a neurosciences researcher who is also a psychiatrist and engineer (and who realised a few years ago another major innovation in the exploratory techniques of the functioning of the brain). The reason why it is only possible to study on the microscope the cells, the connexion networks and the molecules that compose the brain on thin layers of brain of the thickness of a strand of hair, is because the fatty acids (carboxylic acids, lipids) of which the internal and external membranes of our cells are made, as well as the myelin sheath that isolates nerves, reflect light in every direction just like a puddle of oil on water reflecting the Sun into an iridescent rainbow. Those fatty acids not only lead to diffraction, but also ward off numerous chemical markers which then can't circulate deeply enough, thus not imbuing the fabric of the brain and not revealing the presence of the different molecules composing the cells and the networks. Extracting the fatty acids would allow seeing through the brain using different colorations, as well as exposing and unfolding the multiple depths and molecular components. Still, lipids are playing a key role in the upkeep and support of the brain framework, and dissolving (or extracting) them make the structure collapse.

In the brains of dead mice, removed and stored at 4 degrees Celsius, the team infused artificial molecules that fix to the majority of the biological molecules, except form lipids. When the temperature is brought to 37 degrees Celsius, those artificial molecules are bound to one another, forming a solid gel that preserves the framework of the brain. Then, the researchers simply extracted the lipids, and the whole brain became transparent. The brain of a mouse has between 5 and 6 mm of thickness, a distance through which the present-day optical microscopes are able to see. The brain is yet an unexplored world, composed of numerous unseen continents and unknown territories. Under the focusing lens of a microscope, on a small strip of glass on which they wrote a sentence from Ramon y Cajal, the researchers from Deisseroth's team placed the brain of a mouse. It prevents to read half the words of Cajal's quote. But after making the brain transparent, all of the words are readable. The brain can't be seen per say. The researchers have entitled this method Clear Lipid-exchanged Acrylamide-hybridized Rigid Imaging / Immunostaining / In situ hybridization-compatible Tissue-hYdrogel, or CLARITY, out of clarity.

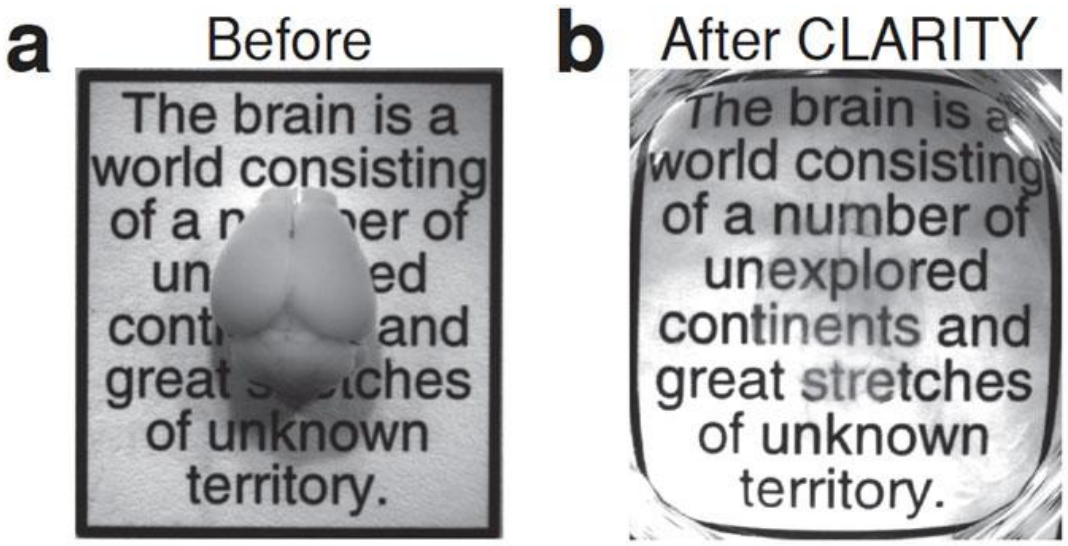

Figure B.4: CLARITY transformation of a mouse brain at left into a transparent but still intact brain at right. - Kwanghun Chung and Karl Deisseroth, Howard Hughes Medical Institute/Stanford University

Additionally, the use of a set of colourful markers allows revealing diverse families of cells, as well as their connexions and their composing molecules. The brain is drawn as a semblance of heavenly vault, sceneries in relief of an extreme precision and of an extreme beauty. The marking of an axon emitted from a particular cell can be tracked down all along its path. The markers can then be washed away, and some others then used to reveal other families of cells, other territories, other networks of connexions and nodes, other molecules.

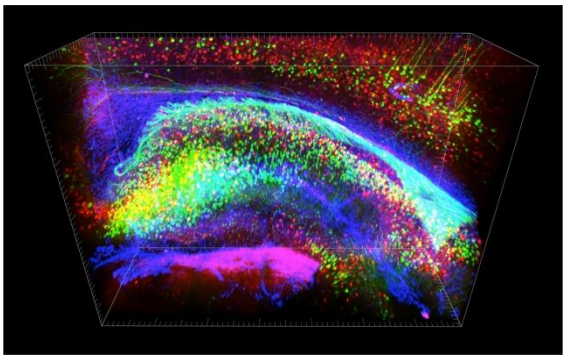

Figure B.5: Kwanghun Chung & Karl Deisseroth, HHMI/Stanford Univ. Neurons in an intact mouse hippocampus visualized using CLARITY and fluorescent labelling

The Clarity method is able to be applied to other organs, however no other organ is as mysterious as the brain, and today this method brings new means to analyse with extreme precision at a wide range in three dimensions the composition and the connexion networks of the brain. Clarity will certainly contribute to unveil the unknown part of this invisible universe, of which functional imaging explores indirectly the activities. It marks a further step in this long and fascinating adventure consisting of making visible what was until then invisible, to understand the innermost mechanisms of our brain and by that our many behaviours. It's a wonderful new window open to the sight, comparable to what were in their time Vesalius' anatomy drawings or Golgi's Reazione Nera. During this journey, if seeing allowed understanding, seeing was never enough to understand completely. And seeing better is but a beginning. The long story through centuries to explore our brain, to the very depths of our human condition, and the immensity of the Universe that surrounds us, this long story taught us that with the invisible and the unknown come questioning, imagination, intuition, interpretation and inspiration to explore, test, and probe. This is only with the help of the spirit eye that what was once made visible was understood.

The following sections will present an exhaustive overview of the blueprints of the brain and the nervous system, and will introduce the recent researches highlighting the links between brain regions and brain functions, where in the brain and how decision are made, as well as how cognitive biases manifest in this organisation.

However first of all it is important to have even a brief glance at the different techniques used in neurology to unveil the concealed machinery.

B.2 Studying the brain

Invasive study consists in actually using instruments inside the skull, directly in contact with the brain. Generally invasive studies are led on animals, but are also possible to realise during necessary brain surgery on human patients. A classic invasive study is the activation of a precise brain structure by electric stimulation via electrodes implanted directly in the brain (on the surface, or deep).

Non-invasive studies present a wider set of possible approaches. For instance, electroencephalographs (EEG) record the whole electrical activity in the brain via electrodes placed on the scalp. However the EEG illustrates the activity of the brain with a general picture and only one proxy, the electrical signal. Several other relatively recent imaging methods offer a

better picture of the brain's architecture and activity. Magnetic Resonance Imaging (MRI) translates the magnetic fields and radio waves the brain emits into computer-enhanced pictures of the brain structure. Function MRI (fMRI) measures brain activity by detecting changes associated with blood flow using the blood-oxygen-level dependent (BOLD) contrast. Areas of the brain in activity need to be provided with more blood and higher doses of oxygen. In Computerised tomography (CT), a number of X-rays pictures are taken from different angles then combined to produce a picture of a horizontal slice through the brain. Researchers can inject people with harmless radioactive chemicals (markers) that will attach to particular areas of the brain: this is positron emission tomography (PET). Some markers will fix especially in active areas. The radioactive markers are tracked and reveal which parts of the brain are activate during specific tasks: reaction to stimuli (picture, sound, a situation explained, and stress), moving arms, legs, making-decision, and thinking about abstract situation.

Last but not least, brain studies can be conducted on patients who are victims of accidents (head injuries) which cause lesions in the brain. When struck by a shock to the head, a lesion in the brain can occur in a precise area and the functions and mechanisms taking place in this section of the brain will be impaired. Comparing the reactions of patients with and without lesions in a precise area puts an emphasis on the function(s) related to it.

B.3 Organisation of the nervous system

The nervous system is a complex and organised network of tissues that communicate via electro-chemical signals, which coordinates the receiving and processing of all the information in the body. The nervous system is composed of two main ensembles: the central nervous system and the peripheral nervous system.

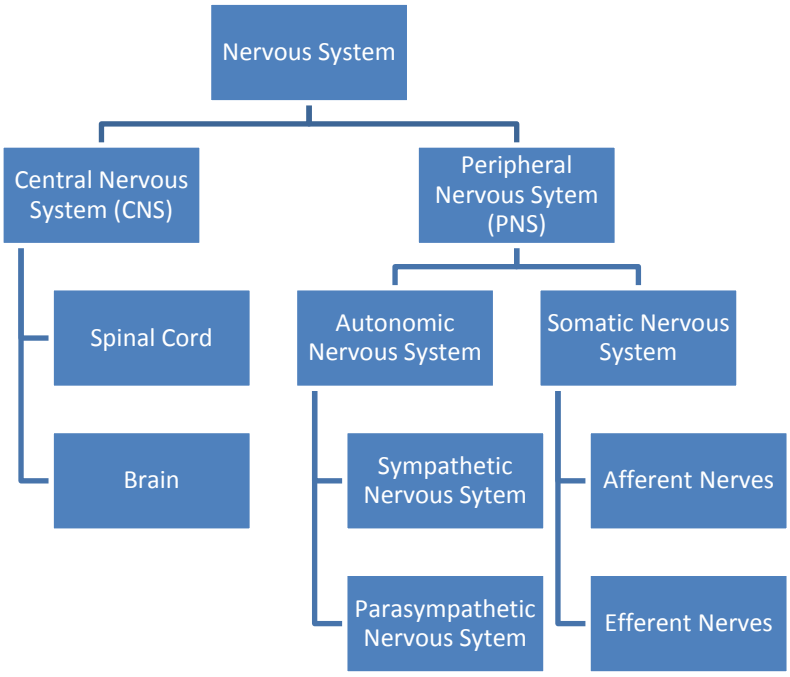

Figure B.6: The nervous system is composed of two mains ensembles: the central nervous system and the peripheral nervous system

The CNS acquires and analyses the information from the body thanks to the brain and the spinal cord that connects the brain to the rest of the body and relays the signals. The brain is the commanding organ in the nervous system which operates, consciously and unconsciously, all the information. The brain is the throne of all mental and physical activities.

The PNS is composed of all the nerve networks and ramifications spreading in the body, and is itself consisting of two entities: the Somatic Nervous System and the Autonomic Nervous System. In Greek, the term sômatikós connotes the body; the SoNS consists of all of the nerves that connect the CNS to skeletal muscles involved in motion, as well as the sensible organs. Two types of nerves compose the SoNS: efferent nerves carry the nerve impulse from the CNS to the muscles and sense organs, and afferent nerves transfer the information the other way around.

On the other hand, the autonomic nervous system (ANS) is the network connecting the CNS to the heart supplying the blood flow, the blood vessels irrigating the body, the glands producing hormones and neuromediators, and the involuntary muscles handling vital organs such as the stomach or the lungs. This is the management unit of all the independent and automatic functions of the body. Eventually, two entities compose the ANS: the parasympathetic nervous system

which is triggered in states of relaxation in order to conserve energy, and the sympathetic nervous system involved in the response to stressful stimuli.

B.4 Structure and functions of the brain

Mapping the brain and understanding the blueprint allows understanding which are the relevant areas involved in decision-making and risk preferences.

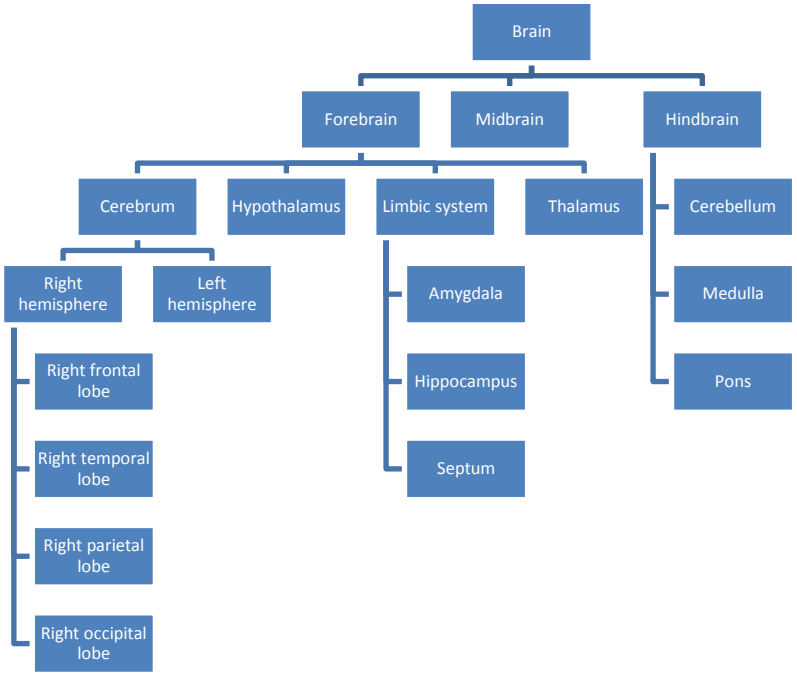

Figure B.7: Main regions of the brain and their organisation

We will only make a clarification about the regions that are relevant to our purpose.

The midbrain is area between the hindbrain (the back of the brain next to the junction with the spinal cord) and the forebrain and notably contains a system of neurons responsible for the release of dopamine, an important neurotransmitter.

The forebrain is perhaps the most important as well as complex part of the human brain. It particularly hosts the limbic system which processes emotional experiences, for instance through the amygdalae which deal with aggression and fear and the hippocampus which relates to the memory processing. The major component of the forebrain is the cerebrum which controls complex processes such as abstract thought and learning. The cerebrum is itself composed of sub-regions, among which the frontal lobe that treat memory, planning, goal-setting, rational decision making, creativity and judgment.

B.5 Specific regions of the brain and relations with risk preferences and decision-making

B.5.1 Prefrontal cortex

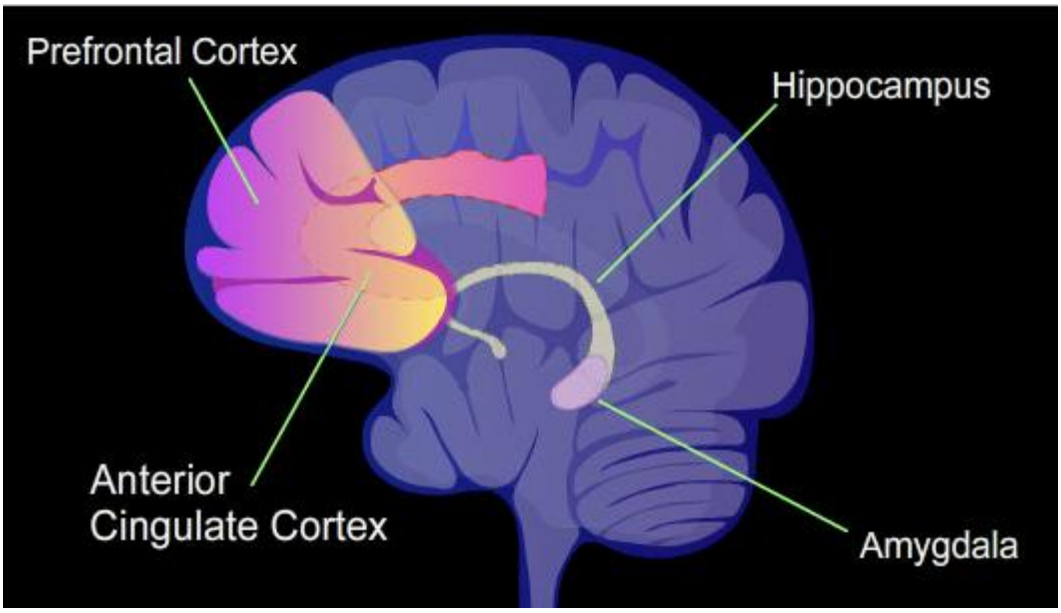

Figure B.8: Illustration of the prefrontal cortex.

In an experiment by O'Doherty et al., respondents went through several trials where they had to choose between two abstract forms. One of the forms was "incorrect" and the other one was "correct". Which of the two forms was the correct one was set at random, and the correct or incorrect status was reset after several trials. The rules for every trial were as follow: selection of the correct form led to a 70% probability of receiving a monetary reward and a 30% probability of obtaining a monetary punishment; on the contrary picking the incorrect form led to a 70% probability of receiving a monetary punishment and a 30% probability of obtaining a monetary reward. The researchers used fMRI during the trials and were thus able to monitor specific areas of the brain and their activation. Their results showed that different sub-regions of the prefrontal cortex (PFC) have different roles during such an affective learning task (the affective side comes from the impact of the reward or the punishment on the respondent's gain) [122]. Regions of medial and orbital PFC are involved in representing the outcome, with increased responses to rewarding outcomes. After the respondents went through the choice trials, they completed another part of the experiment. The situation was exactly the same, however respondent did not

choose anymore, it was a computer that chooses one form randomly and the respondents then were punished or rewarded accordingly. The fMRI pictures displayed different patterns from the ones taken during the choice task, which vouches for that in the choice task knowledge of the value of outcomes is critical for future behavioural choice, whereas this is not the case in the imperative task.

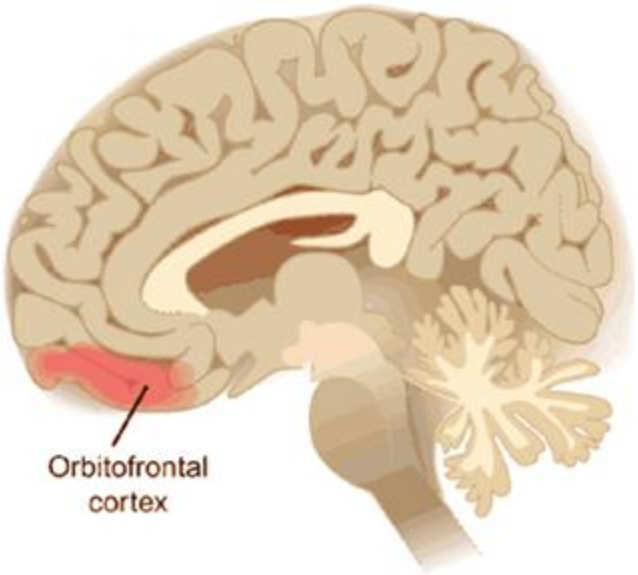

Figure B.9: Schematic of a cross-sectional view of brain, depicting the OFC [123]

Dorso-lateral prefrontal cortex (DLPFC) is particularly important for the maintenance and manipulation of cognitive representations in working memory as well as the planning of future actions based on those representations. It is suggested that DLPFC is related to the representation of prospects and subsequent decision utility computations. In several experiments, patients with lesions to the DLPFC showed decision-making impairments associated with the inability to learn to choose optimally [124] [125].

Another sub-region of the frontal cortex, the ventro-medial prefrontal cortex (VMPFC), has been especially linked to the evaluation of desirable stimuli [127] and the receipt of rewards [128]. Patients with lesions to the VMPFC never develop a preference for the riskless options (options offering positive expected value) and keep on choosing from the risky options. They also do exhibit normal skin conductance response (SCR – a measure widely used in experimental psychological studies as an objective measure of conscious and unconscious emotional

processing and attention) to experienced losses vouching for the fact that VMPFC is not necessary for the emotional experience of a loss [118].

Another study by Rogers et al. exposed the respondents to choices between different gambles varying in their outcomes. The experiments consisted in two phases. First the decision phase during which participants decided to play between gambles for monetary reward. The gambles differed in their magnitude of gains and losses, as well as the associated probabilities. Then the outcome phase during which the result of each choice was indicated to the participant. For the all procedure the participant's brain activity was monitored through fMRI, and the The experiment demonstrated that neural activity within specific parts of the brain (medial and lateral orbitofrontal cortex, pregenual ACC (pACC), and striatum mediate) displayed distinct representations of reward-related information at different stages of the decision-making process [129].

B.5.2 Amygdala

Part of the limbic circuitry and particularly of the reward system, the amygdala is a complex sub-cortical structure that is heavily involved in emotion and learning, especially for negative outcomes. It is closely involved with several other noteworthy areas of the brain aforementioned (cortico-limbic circuitry).

Its function stems from survival defense and learning mechanisms induced by fear, and it acts as an alarm that can eventually trigger fear reaction after having processed relevant sensorial stimuli, as well as carve such experience in emotional long term memory. In a nutshell, the amygdala is essential for both the production of fear responses and for the learning of associations between particular stimuli and fear responses [130]. Neuro-imaging has shown a correlation between amygdala activation and episodic memory for strongly emotional stimuli [131]. For instance, it is involved in the perception of fearful facial expressions [132]. Another flabbergasting example is the case of the very rare recessive genetic disorder known as the Urbach–Wiethe disease, which causes a general thickening of the skin. Patients may also be afflicted by neurological symptoms caused by the hardening of brain tissue such as calcification of the amygdala. An experiment involving a very rare patient with Urbach-Wiethe disease repeatedly demonstrated an absence of apparent fear reactions and display, and an overall diminished experience of fear [133].

Hsu et al. showed that the level of ambiguity in choices correlates positively with activation in the amygdala and orbito-frontal cortex, and negatively with the caudate nucleus, a sub-region of the striatal system and also a part of the reward circuitry [137]. Moreover, striatal activity correlates positively with expected reward. Another part of the study dealt with subjects with orbito-frontal lesions. Such participants were insensitive to the level of ambiguity and risk in behavioral choices, a result which bolstered the idea of a general neural circuit responding to degrees of uncertainty.

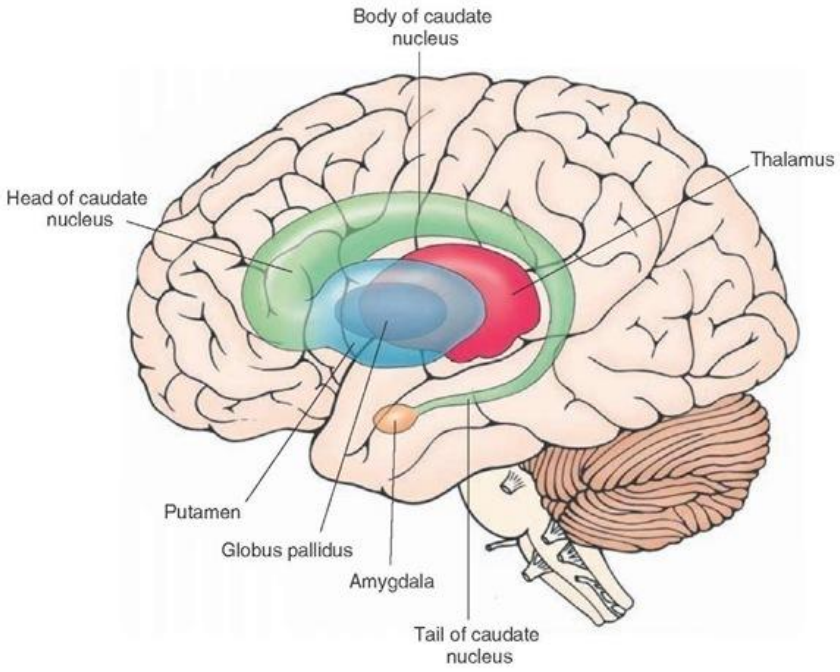

Figure B.10: Components of the caudate nucleus and parts of the basal ganglia system associated with procedural learning, cognition and emotion [138]

B.5.3 Striatum

The striatum is a complex structure that can be separated into the ventral striatum (including the nucleus ccumbens (NAcc) and ventral putamen) and the dorsal striatum (including the caudate nucleus and dorsal putamen).

Ventral striatum receives projections primarily from important structures of the limbic circuitry: hippocampus, amygdala, and VMPFC, serving as a locus for signal integration (Wagar et al.,

2004). In an experiment by Breiter et al. (2001), fMRI revealed modulations of ventral striatal responses depending on the expectation and experience of monetary gains and losses. The ventral striatum appears to respond to both experienced rewards and anticipated rewards (Knutson et al., 2001). Particularly, neuro-imaging showed an increase in activity during exposure to a riskless (gains only) stimulus. However, the ventral striatum is amongst the primary targets of the dopaminergic system (see further below, as well as refer to the section dedicated to dopamine in chapter 3), and consequently shifts of brain activity in this region may be a direct effect of dopaminergic activity, or a true intrinsic activity of ventral striatal neurons.

Dorsal striatum (which includes the caudate nucleus) receives signals primarily from dorsal and lateral prefrontal cortices. It appears to play a distinct role in the processing of experienced reward amplitude (small or large reward) and valence (positive or negative outcome, win or lose) (Yeung & Sanfey, 2004). The caudate nucleus responded most for large rewards and least for large punishments (Delgado et al., 2003).

B.5.4 Nucleus Accumbens (NAcc) & Anterior Insula (AI)

The NAcc, a central brain area appearing on both halves of the brain right behind the prefrontal cortex, has been another of the areas of focus of the scientist in multiple studies. For instance, Breiber et al. showed that the NAcc of the ventral striatum manifests proportional activation during anticipation of monetary gains. In another article, NAcc activation represents gain prediction [320].

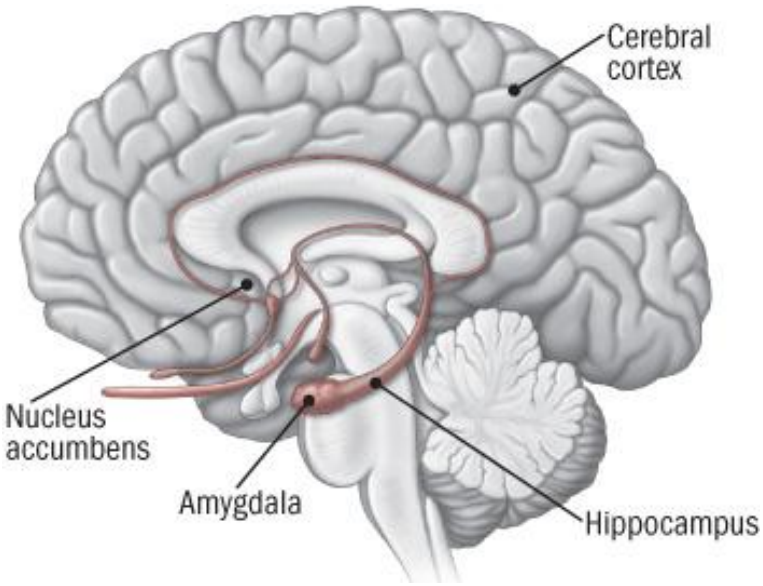

Figure B.11: Location of the brain reward centre (amygdale, hippocampus), Nucleus Accumbens (NAcc) and the Cerebral Cortex

The Anterior Insula (AI) is another area of interest for researchers. Indeed, the AI receives a direct projection from the basal part of the ventral medial nucleus of the thalamus and a particularly large input from the central nucleus of the amygdala. In addition, the AI itself projects to the amygdala. A 2003 study highlighted that the AI activates strongly during risky choice in games involving non-monetary incentives, which correlates with subsequent risk-aversion and trait measures of negative aroused affect (Paulus et al. 2003). A recent review suggests that activation in this region is more common under negative than positive affective circumstances [321]. Another study involving the experimental economics Ultimatum Game showed that unfair offers elicited activity in the Anterior Insula (area related to both emotion) and the dorso-lateral prefrontal cortex (related to cognition). Moreover, the researchers recorded a strong activity in the AI linked to rejected unfair offers, which suggests an important role for emotions in decision-making.

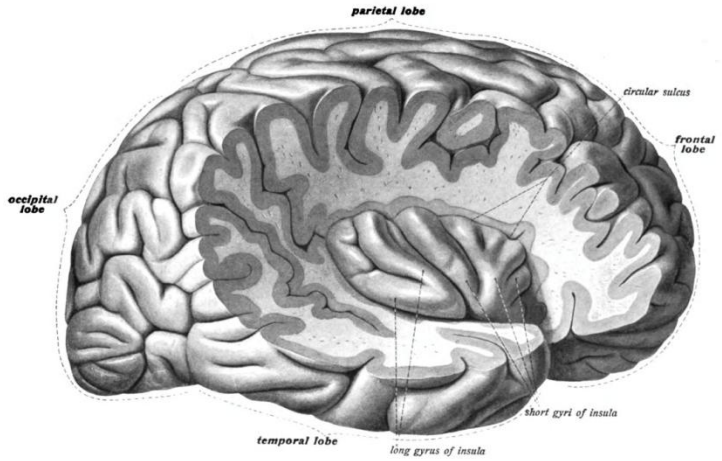

Figure B.12: The Insula of the right side, exposed by removing the opercula, Dr. Johannes Sobotta - Sobotta's Textbook and Atlas of Human Anatomy 1908

In 2005, Kuhnen & Knutson studied the neural basis of risk-taking specifically in the context of finance. They tackled down the question of whether or not anticipatory neural activity would predict optimal and suboptimal choices in a financial decision-making task. They found additional conclusions regarding the NAcc and the AI.

With fMRI taken during an investment game entitled BIAS (Behavioral Investment Allocation Strategy), they compared the respondents' actual investment to rational risk-neutral decisions (those of a player maximising expected utility), and sub-optimal choices were identified as deviations from this model. Sub-optimal choices were of two kinds: first risk-seeking mistakes (participants take risks when they should not) and risk-averse mistakes (participants don't take risks when they should).

It resulted that the NAcc would activate just before risky choices as well as just before risk-seeking mistakes. On the contrary to AI activation which preceded wary choices as well as risk-averse mistakes. Distinct neural circuits are linked to anticipatory affect and promote different types of financial choices. More importantly, the study suggests that excessive activation of particular circuits may lead to investing mistakes. In conclusion, risk-seeking choices and risk-averse choices are presumably driven by different neural networks relating or including the NAcc and the AI.

B.5.5 Anterior cingulated cortex (ACC)

The anterior cingulate cortex (ACC) is another sub-ensemble of the limbic system. On the basis of early lesion studies in humans and in animals, the ACC has been related to affect, then in the late 1980s, neuro-imaging research suggested the ACC was the error detection centre as well as correction apparatus (Gemba, *et al.)*

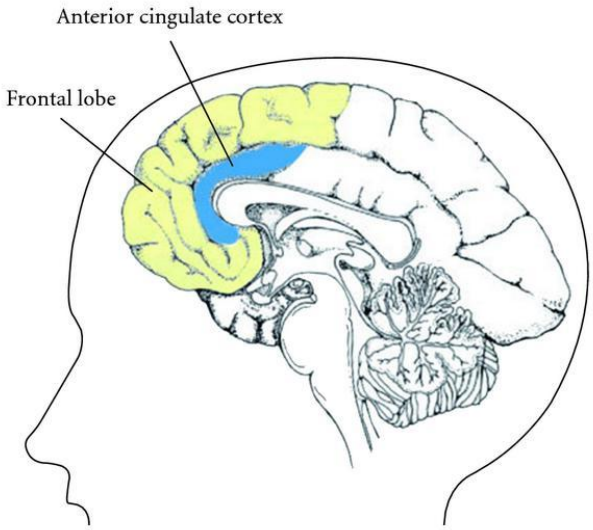

Figure B.13: Graphical illustration of a cross-section view of the human brain, highlighting the location of the frontal lobe (in yellow) and the anterior cingulate cortex (ACC, in blue)

Indeed, separate areas of ACC are involved in cognition and emotion, and they are sensitive to the experience of negative outcomes, as reflected in the feedback response effect called error-related negativity (ERN). ERN signals are observed after errors are committed for instance during a choice task even when the participant is not explicitly aware of making an error (though when the error is unconscious, the ERN signal is weaker). In a neuro-imaging study of the ACC by Bush et al, it is suggested ERN response is influenced by affect and motivation. In another experiment, ERN response was measured greater for losses than for gains in a gambling task (Gehring et al., 2002).

Other studies have emphasised the behaviour control role of the AAC. For Botvinick, the ACC is an interface area for all the adjacent parts of the brain, thus act as a mediator between motivation, cognition, and action. As such, it takes a central role in the evaluation of the options in uncertain environments in order to optimise the decision, a process called reinforcement information to

control behaviour. Kennerley confirmed the ACC's critical role in reinforcement-guided behaviour, however this role is not to detect or correct errors, but to influence voluntary choices according to the history of previous actions and outcomes (Kennerley et al., 2006).

Eventually, Holroyd et al. (2002) emphasised the fact that ERN response in the ACC may be a reflection of dopaminergic activity (refer to the dopamine section further below).

B.6 Conclusion on brain regions and risk preferences

Such findings promote the idea that risk-seeking choices (such as investing, launching a company or playing in a casino) and risk-averse choices (buying insurance, not daring gambling or entrepreneurial activities) may be driven by distinct neural circuitries. Variation or unbalance in the activity of brain regions can lead to a shift in risk-preferences and consequently different decisions. In practice, such results construe the development of particular marketing strategies, for instance why casinos girdle customers with rewarding cues and tantalising freebees (free food or beverages, presents, the illustration of potential gains with previous jackpots earned): anticipation of reward and activation of pleasure centres could talk the players into switching their behaviour from risk-averse to risk-seeking behaviours. It goes the other way around for marketing strategies by insurance companies.

This section, (and appendix B) provide neural tracks for investigating risk and behaviour phenomena involved in prospect theory (loss aversion, framing effect, ambiguity aversion, information processing). In fine, neurology research may develop a more comprehensive theory of individual decision-making than the rational agent models and thus may ultimately generate new insights relevant to economic policy and institutional design applied to finance and entrepreneurship.

B.7 Blueprint of a neuron and communication in the brain

There are two kinds of cells in the nervous system: glial cells which make up the support structure of the nervous system, and neurons which are the communication relays receiving and passing information.

A neuron is constituted of a soma, the cell’s main body, notably containing the nucleus. The collection of fibres sprouting out from the soma is the dendritic tree, and the branches of the tree are the dendrites. They are the cable elements of the neurons, mapping the network and

connecting cells together, and their role is specifically to receive information from other cells (neurons, muscles or sense organs). The axon, a longer single extending fibre standing out from the dendritic tree, is the path through which the information is sent. At the extremity of the axon are extensions called terminal buttons, and once they receive the electric signal they release special chemical elements or molecules called neurotransmitters. These neurotransmitters operate the connexion space between two neurons, the synapse, passing along the signal from one cell to the other.

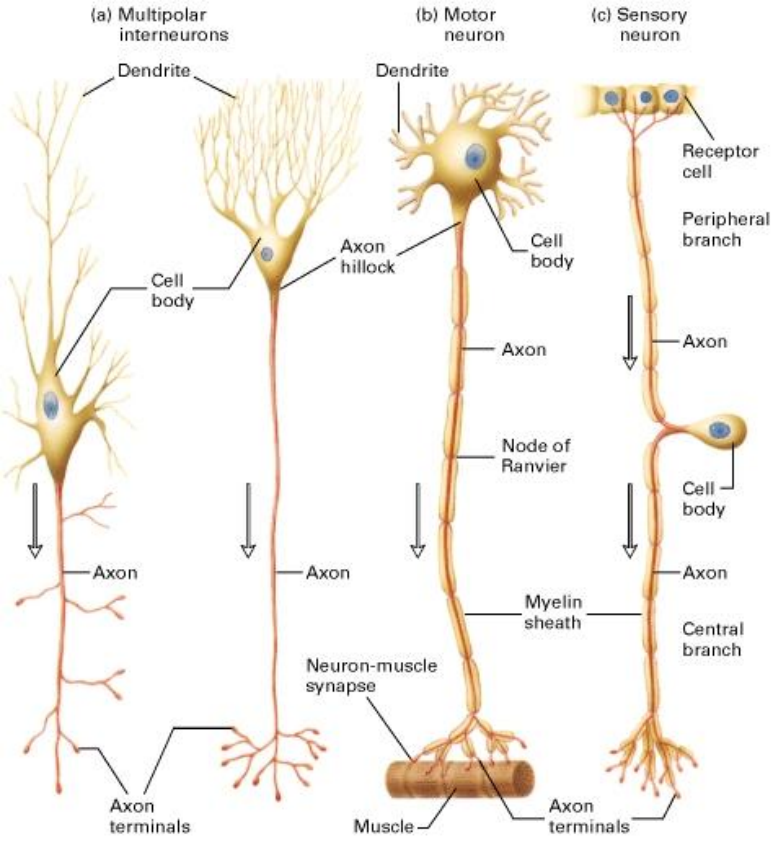

Figure B.14: Structure of typical mammalian neurons - Lodish H, Berk A, Zipursky SL, et al. Molecular Cell Biology. 4th edition. New York: W. H. Freeman; 2000. Section 21.1, Overview of Neuron Structure and Function

Nerves bathe in and are irrigated by fluids containing positive and negative ions. A higher concentration of negative ions compared to positive ones creates a global negative charge in the neuron, the resting potential, which corresponds to an inactive state.

As the signal is passed along and stimulates the neuron, gates in the cell membrane open and discharge positive ions, then the global charge of the cell shifts from the resting potential to the

action potential. Once a signal is passed along, a short period of time called the absolute refractory period prevent another activation of the neuron which lies dormant.

Neural impulses have always a standard level (the action potential), and the impulse is triggered once a certain threshold is reached by the stimuli. Consequently, a powerful stimulus does not translate into a more potent neural impulse but will reach the threshold and fire faster: the only difference between a strong or weak stimulus is in the response rate.

The discovery of the electro-chemical nature of the reactions in the brain dates back to the works by Hodgkin & Huxley in 1952.

When the action potential is passed along the axon and reaches the terminal buttons, it activates pouches called synaptic vesicles which in turn release neurotransmitters. The molecules are poured into the synapse and connect to the receiving end of another neuron, the dendrites, biding themselves to matching specific receptors. As the neurotransmitters link to the receptor sites they induce a change of potential called the postsynaptic potential.

B.7.1 Neurotransmitters

As of today, scientists have identified several different neurotransmitters for an inventory of more than twenty distinct types. It is thanks to that expansive alphabet, as well as the series of precise matching receptor sites, that the nervous system communicates like clockwork.

Neurotransmitters can be implicated in seldom and definite regions of the brain, involved in whole systems composed of several sub-parts (like the limbic-system, or the reward circuitry), or be widespread throughout the whole nervous system.

Table B.1: Most relevant neurotransmitters and their functions

Neurotransmitter	Associated function(s)
Acetylcholine	Muscle movement, **attention**, arousal, **memory**, **emotion**
Dopamine	Voluntary movement, **learning**, **memory**, **emotion**
Serotonin	Sleep, wakefulness, appetite, **mood**, *aggression*, **impulsivity**, sensory perception, temperature regulation, pain suppression
Endorphin	Pain relief, *pleasure*
Norepinephrine	**Learning**, **memory**, dreaming, awakening, **emotion**, stress-related increase in heart rate, stress-related slowing of digestive processes
Gama Amino Butyric Acid (GABA)	Main **inhibitory** neurotransmitter in the brain
Glutamate	Main **excitatory** neurotransmitter in the brain
Histamine	

B.7.2 Neuromodulators

Neuromodulators are a sub-class of neurotransmitters diffusely released into the neural tissues and not at precise synapse sites. Consequently they are more of a catalyst, or reactant, global function and they operate in a broad brain region instead of between to particular neurons relaying neural impulses. They set the tone.

Indeed, neuromodulators function with a different type of neuroreceptors. The targeted, synaptically-released neurotransmitters use fast-acting ionic receptors transmitting electrical signals. On the other hand, neuromodulators use another kind of neuroreceptors called "metabotropic" or "G-protein" receptors which are slow-acting receptors. As such, they tune, influence, and modulate the functioning of the neurons in a region of the brain over longer periods.

In a nutshell, neuromodulators are neurotransmitters tuning the functioning of neural circuits in neural tissue rather than sending signals directly into particular neurons.

Table B.2: Most relevant neuromodulators and their associated receptors

Neurotransmitter	Associated receptor(s)
Dopamine	D receptors
Serotonin	5HT receptors
Acetylcholine	M receptors, nicotinic receptors
Norepinephrine	Alpha receptors, beta receptors
Histamine	H receptors

B.7.3 Endocrine system and hormones

In addition to the nervous system, the endocrine system, made up of hormone-secreting glands, also affects communication inside the body.

While the nervous system uses neurotransmitters to transmit chemical signals, the endocrine system uses hormones secreted by glands which are spread in the whole body: the pancreas, kidneys, heart, adrenal glands, gonads, thyroid, parathyroid, thymus, and even fat are all sources of hormones.

Hormones are chemicals that help to regulate various bodily function, from the activation and control of basic behavioural activities (emotion, responses to stress, eating, drinking, sex), to the regulation of growth, reproduction, energy use, sleep, and metabolism.

The glands produce hormones and dump them into the bloodstream, through which the hormones travel to various parts of the body. As the neuromodulators, hormones act more slowly than neurotransmitters, but their effects tend to be longer lasting.

The endocrine system works as a feedback mechanism. In the brain, hormones have an effect on neurons relevant to the pituitary gland, the “master gland of the endocrine system”, a small pea-sized protrusion located at bottom of the hypothalamus (close to the base of the brain). When stimulated by the hypothalamus, the pituitary gland releases various hormones that control other glands in the body.

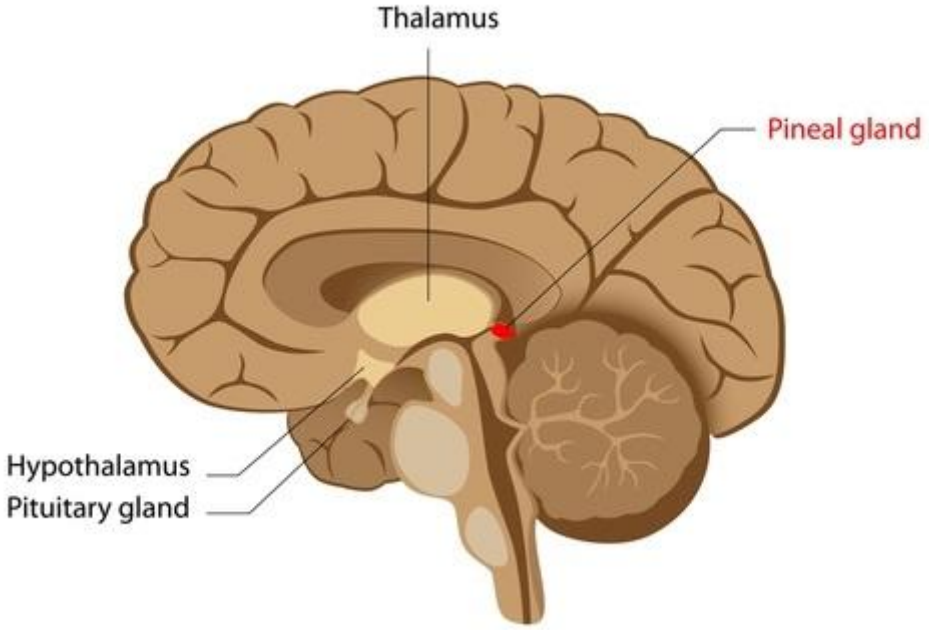

Figure B.15: Location of the Pituitary gland and the hypothalamaus. - Anatomy of the Human Head - Bones, Brain, Sensory Organs, D'Onofrio (2009)

The pituitary gland secretes various hormones that themselves have an influence on the endocrine glands spread in the body. The pituitary gland commands either the increase or decrease of hormone production.

The way the brain responds to hormones indicates that the brain is very malleable and capable of responding to environmental signals. In the brain, hormones alter the production of gene products that participate in synaptic neurotransmission as well as affect the structure of brain cells. As a result, the circuitry of the brain and its capacity for neurotransmission are changed over a course of hours to days. In this way, the brain adjusts its performance and control of behaviour in response to a changing environment. Hormones are important agents of protection and adaptation, but stress and stress hormones, such as the glucocorticoid cortisol, can also alter brain function, including the brain’s capacity to learn. Severe and prolonged stress can impair the ability of the brain to function normally for a period of time, but the brain is also capable of remarkable recovery.

Table B.3: Notable hormones and their production site and function(s)

Hormone	Produced by	Involved in regulating
Thyroxine	Thyroid gland	Metabolic rate
Insulin	Pancreas	Level of blood sugar
Melatonin	Pineal gland	Biological rhythms, sleep
Cortisol, Norepinephrine, Epinephrine, Adrenaline	Adrenal glands	Bodily functions during stressful and emotional states
Androgens (testosterone)	Testes, as well as ovaries and adrenal glands	Male secondary sex characteristics, sexual arousal in males and females
Oxytocin		
Estrogens	Ovaries, as well as testes and adrenal glands	Breast development and menarche in females
Progesterone	Ovaries, as well as testes and adrenal glands	Preparation of uterus for implantation of fertilized egg

Nota bene: Norepinephrine functions in the human brain and body both as a hormone and a neurotransmitter.

B.7.4 Receptors, binding sites, and a(nta)gonists

Once the electric signal reaches the tip of the axon, neurotransmitters are released and fill the synapse, the severance area between two neurons. On the recipient neuron's side, receptors sites called postsynaptic cells capture the different molecules, and as the binding occurs the postsynaptic potential enliven the recipient neuron.

On the postsynaptic cell, receptor sites are excitatory or inhibitory, depending on the neurotransmitter they are paired with. Excitatory neurotransmitters are not necessarily exciting – they are what stimulate the brain. Those that calm the brain and help create balance are called inhibitory. Inhibitory neurotransmitters balance mood and are easily depleted when the excitatory neurotransmitters are overactive.

Certain chemicals, which are not neurotransmitters can per se, can interject and bind themselves to receptors, thus mimicking the presence and consequently the action of a particular neurotransmitter, generating the expected postsynaptic potential. Such molecules are called agonists. Considering agonists and their effects is important because they can modify or even impair normal reactions and mechanisms in the brain. For instance, the nicotine molecules found

in plants and notably tobacco is an agonist molecule. Indeed, nicotine mimics the neurotransmitter acetylcholine to the extent it competes for and fills acetylcholine receptors. Neuron will thus receive signals corresponding to acetylcholine release in the brain, whereas there is not. Moreover, as nicotine and acetylcholine attach to receptor, the nerve fibres become highly stimulated which results in a feeling of alertness and bliss. This stimulant effect is a contributing factor to the addictive properties of tobacco smoking. For the relevant information regarding acetylcholine receptors and agonists' effect, refer to the nicotinic receptors section below.

Another type of interfering molecules is antagonist. Antagonists, instead of mimicking and competing with a neurotransmitter are blocking the action of a particular neurotransmitter on the receptors: they link themselves to receptor sites, however a postsynaptic potential is not produced. Because they occupy the receptor site, they dampen or even completely prevent neurotransmitters from acting.

B.8 Specific molecules and their implication in decision-making mechanisms

B.8.1 Dopamine

The neurotransmitters dopamine is present in most of the brain region aforementioned in chapter 3 and appendix B: ventral tegmental area (VTA), basal ganglia (composed of the striatum), frontal and prefrontal cortices, nucleus accumbens (NAcc), caudate nucleus, putamen, and islands of Calleja. Working along the neurotransmitters is a family of five related receptors named D1 to D5. Each of them works in specifics area of the brain, for instance the dopamine receptor D4 (DRD4) prevails in the limbic system, the prefrontal cortex as well as the striatum, our areas of interest.

Moreover, by using particular drugs to act as dopamine antagonists, Berrige & Robinson illustrated the precise impact of dopamine in the reward circuitry as respondents subjected to dopamine blockade expressed "liking" without "wanting" [142].

B.8.2 Serotonin

On the fertile ground of psychology and pharmacology research, studies on serotonin and its effect have flourished, highlighting its multi-level implications on mechanisms relative to

decision-making. Serotonin appears to play a role in affective learning, particularly in the effective acquisition of stimulus–reward linkages [144] [120].

On other grounds, studies have shown the implication of serotonin in the effective processing of negative information [147] [148], as well as in anxiety [149] [150]. Such results might be linked to loss aversion, framing effect or other bias. In a nutshell, lower serotonin levels impair decision-making by inducing a failure to process expected losses adequately: punishment cues might fail to generate anticipatory anxiety states associated with risky or maladaptive choices. Genetic studies related to serotonin and decision-making are introduced in chapter 3 and below in appendix B.

B.8.3 Nicotinic Receptor ($CHRNA_4$)

Nicotine is a chemical acting as an antagonist, and neuronal nicotinic cholinergic receptors (notably $CHRNA_4$) are of general interest because they modulate the release of several neurotransmitters including dopamine, serotonin, gamma-amino butyric acid (GABA), and glutamate in several noteworthy areas of the brain involved in cognition and decision-making, including VTA [151]. $CHRNA_4$ is deeply present in the central nervous system and modulate the meso-limbic dopamine function [152], which suggests it is an appropriate target for studies concerning reward processing and risk attitudes. Refer to section 3.3.2.2 for studies concerning genes related to nicotinic receptors and risk-preferences, as well as further below.

B.8.4 Androgens, estrogens, testosterones: sex hormones

Previous chapters address the gender differences in decision-making. And indeed, research found that sexual differentiation in the brain is caused by sex hormones acting in foetal and early postnatal life, and recent evidence implies that genes on either the X or Y chromosome also contribute to this process. Scientists have found statistically and biologically significant differences between the brains of men and women that are similar to sex differences found in experimental animals: these include differences in the size and shape of brain structures in the hypothalamus and the arrangement of neurons in the cortex and hippocampus. Sex differences go well beyond sexual behaviour and reproduction and affect many brain regions and functions, ranging from mechanisms for perceiving pain and dealing with stress to strategies for solving

cognitive problems. In spite of such hints of differences, the brains of men and women are more similar than they are different.

Anatomical differences have also been reported between the brains of heterosexual and homosexual men. Research suggests that hormones and genes act early in life to shape the brain in terms of sex-related differences in structure and function, but scientists are still putting together all the pieces of this puzzle.

One possible mechanism for these risk preferences differences may be the production, the regulation, the sensibility to testosterone. As of today, if hints, clues and experimental economics facts galvanise the motivation to investigation the role of testosterone in these preferences, little is known regarding a direct relationship, an explained mechanism or a direct biological link.

So far, explanations follow different paths: for instance, individuals with higher exposure to testosterone are more likely to take risk because they have been used to performing well in a wide range of tasks, and because they are better able to absorb the costs if the outcomes of such risky actions are poor. Thus, androgen exposure may not directly regulate risk preferences but may instead represent markers of health and genetic fitness which in turn shapes risk preferences. It is also plausible that a reciprocal relationship between phenotypic appearance and environment exists so that masculine men take more risks not only because they are expected to, but also because they are expected to succeed. That is, others may perceive masculine individuals as more likely to succeed when engaging in risky behaviours.

Another research by Apicella et al. studied risk-taking in an investment game with potential for real monetary payoffs correlates positively with salivary testosterone levels and facial masculinity (a proxy of pubertal testosterone exposure) [167]. However on 2D:4D did not correlate significantly with risk preferences, putting in perspective the results by Dreber & Hoffman [165] and Coates [166].

B.9 History of the investigation regarding heredity of risk-preferences: from twin study to genetic loci

Long before Watson & Crick discovered the molecular double-helix structure of DNA, the notions of genes and alleles loomed up with the discovery of the rules of heredity, Mendelian Inheritance, established by the Austrian botanist Gregor Mendel in 1865. The “father of modern

genetics" experimented on hybrid plants to postulate the notion of dominant and recessive phenotypes.

> In this generation, along with the dominating traits, the recessive ones also reappear, their individuality fully revealed, and they do so in the decisively expressed average proportion of 3:1, so that among each four plants of this generation three receive the dominating and one the recessive characteristic.

Long before the blossoming field of gene association to specific behaviour that exists nowadays, the trail of heredity was investigated via Twin Studies.

In 1875 Francis Galton concluded the first scientific inquiry into the behaviour of twins by remarking that "There is no escape from the conclusion that nature prevails enormously over nurture" (Galton, 1875). In fact, Galton was so taken with his results that he continued, "My only fear is that my evidence seems to prove too much and may be discredited on that account, as it seems contrary to all experience that nurture should go for so little." Although his methodology would be considered dubious by modern standards (if not flawed), Galton's work laid the conceptual basis for behaviour genetics (Bouchard & Propping, 1993) (Plomin et al., 2001), the study of genetic and environmental influences on variation in human behaviour.

Today ample evidence for the importance of genetic influences ("nature") on variation in human behavioural traits has amassed. However, the debate about the rather nebulous concepts "nature" and "nurture" still rages.

The study of genetic factors that may affect human behaviour in decision-making contexts is not without precedent. For example, personality researchers such as Loehlin, McCrae, Costa, and John (1998) have shown that around half of the variation across people along many of the Big Five personality dimensions may be attributed to genetic causes. Further, studies in organisational behaviour have pointed to the genetic components of a variety of constructs, such as the result telling that job satisfaction is heritable (Arvey et al., 1989). Most of these studies use a twin methodology to examine the genetic versus environmental influence on various human attributes.

One example of this literature with particular relevance comes from Stoel et al. (2006) who examine the extent to which sensation-seeking, the need for varied, novel and complex sensations is inherited from one generation to the next. By comparing the expression of this trait in identical (monozygotic) twins, fraternal (dizygotic) twins, and their other siblings, the authors decomposed

the observed variation into individual and shared environmental components in addition to a genetic component estimated to be as high as 60% for males (Stoel et al., 2006). As we will discuss later in a following section, sensation-seeking, although not directly connected to economics, is a valuable measure of risk-preferences.

Eventually, there is additional evidence that many aspects of human behavior are influenced by genes (Benjamin et al. 2003, Plomin and Walker 2003) including personality (Ebstein et al. 1996, Benjamin et al. 1996), attitudes (Bouchard et al. 2004), intelligence (Plomin and Spinath 2004), job satisfaction (Arvey et al. 1989), work-related values (Keller et al. 1992), and interests (Lykken et al. 1993). If genetic factors influence other aspects of human behavior, they are likely to influence the tendency of people to engage in entrepreneurial activity as well.

B.10 Notable Twin-Studies in Economics

The seminal paper using behaviour genetic techniques in economics is due to Taubman (1976), who employed the twin design to estimate the heritability of earnings for U.S. males. Later papers in this procession, based on either twins or adoptees, include Behrman and Taubman (1989), Sacerdote (2002, 2007), Plug and Vijverberg (2003), Bjorklund, Lindahl, and Plug (2006), and Bjorklund, Jantti, and Solon (2007). In short, these studies find that both "nature" and "nurture" are important determinants of life outcomes and uniformly corroborate the importance of genetic influences on educational attainment and earnings.

Some recent work in economics also focuses on the issue of intergenerational transmission of preferences. Cipriani, Giuliani, and Jeanne (2007) report mother–son correlations for contributions in a standard public goods game and find no significant associations, interpreting this as evidence that peer effects influence contributions. Dohmen et al. (2006), on the other hand, use survey evidence on attitudinal questions and find modest intergenerational correlations in self-reported trust and risk attitudes. Naturally, these papers suffer from the limitation that it is impossible to separately identify genetic (parents passing on genes for a certain trait to their biological children) and cultural transmission.

Other evidence of heritability attitude in economics can be found in articles examining the ultimatum game responder behaviour (Wallace et al. 2007) and cooperation in the trust game (Cesarini et al. 2008).

In 2009, Cesarini et al. move beyond the calculus of intergenerational correlations and offer a direct test of the hypothesis that economic preferences are under genetic influence. Preferences were elicited experimentally with a subject pool of twins recruited from the population-based Swedish Twin Registry. The virtue of this approach is that by comparing monozygotic (MZ) twins (who share the same set of genes) to dizygotic (DZ) twins (whose genes are imperfectly correlated), it is possible to estimate the proportion of variance in experimental behaviour due to genetic and to shared and unique environmental effects. The researchers found strong evidence that preferences for risk taking and giving are broadly heritable. Their conclusions suggest that approximately twenty percent of individual variation can be explained by genetic differences. Furthermore, the study suggests only a modest role for common environment as a source of variation.

This estimation is similar to other estimates in the behaviour genetics literature, where survey based studies have documented substantial genetic influences on variation in economically relevant abilities, preferences, and behaviours such as intelligence (Bouchard et al. 1990), personality (Jang, Livesley, and Vernon 1996), addiction (True et al. 1997), pro-sociality (Rushton et al. 1986; Rushton 2004), sensation-seeking (Stoel et al., 2006), religiosity (Bouchard et al. 1999; Kirk et al. 1999; Koenig et al. 2005), political preferences (Alford et al., 2005), and political participation (Fowler, Dawes, and Baker 2008).

Eventually, Zhong et al. (2009) estimated the heritability of risk attitudes near 60% among a Chinese sample. An earlier work focused on of pathological gambling evaluate the heritability of this trait near 60% in a U.S. sample [322].

B.11 Genetic Loci

The first step was to ascertain that risk preferences are, in part, heritable. The next challenge for behavioural scientists and economists is now to identify the genetic loci associated with such risk preferences. While the twin study method has begun to influence the economic literature, the next-step approach of linking specific genetic loci to the phenotypic expression of economic behaviour is yet in its infancy.

Despite the work on twins that demonstrated that some variation of risk preferences is influenced by individual heritable differences, until very recently there had been no study investigating possible genetic loci associated with financial risk taking in healthy individuals. Whether

researchers use the classic twin study methodology to infer general heritability of traits (Bouchard & Propping 1993) or look for direct associations between traits and specific genes (Plomin et al. 2009), the field of behavioural genetics is flourishing.

B.11.1 Dopamine & Serotonin

Novelty-seeking (NS) and harm-avoidance (HA), two measures of risk-taking coming from psychology (refer to 5.3.5), were originally hypothesised to be driven by variation in the dopamine and serotonin systems, respectively [194]. Several studies have shown associations in NS and HA with polymorphisms thought to affect dopamine and serotonin receptors and transporters, including DRD2, DRD4, DRD5 and DAT [191] [195] [196] and SERT [197] [198]. NS or HA also have been associated with polymorphisms thought to impact dopamine and serotonin synthesis or metabolism, for instance the gene catechol-o-methyl transferase (COMT) [199] as well as the gene related to tryptophan hydroxylase-2 (TPH2) [200] [201].

Such genetic variations related to dopamine and serotonin have been linked to risk attitudes derived from financial choice tasks. Roussos et al. associated risk tendencies measured during the Iowa Gambling Task (IGT), a classic gambling task often used to elicit risk-preferences, with a COMT polymorphism [202]. Kuhnen and Chiao associated risky investment behaviour observed during an investment game with polymorphisms in SERT and DRD4 [203]. In a study by Dreber et al., The 7R+ polymorphism of the DRD4 gene accounts for roughly 20% of the heritable variation in financial risk taking [204]. In 2011, a study by Carpenter, Garcia & Koji Lum indicates that the 7-repeat allele of the DRD4 gene regulating dopamine uptake in the brain predicts risk-taking and time preferences in economic experiments that allow for ambiguity, losses and discounting [205]. Indeed, respondents carrying the 7-repeat DRD4 allele (as opposed to the 4-repeat allele) are more likely to increase the amount of risk they expose themselves to when the outcomes become ambiguous or when potential losses are allowed compared to the benchmark. Such a study indicates that genotypes can directly predict financial choice behaviour: in this case 7-repeat individuals make choices that appear more impulsive, risky and short-sighted relative to their 4-repeat counterparts [205]. As of today, the 7R allele of the DRD4 gene is accepted as being linked to a behavioural phenotype associated with risk-taking. This is consistent with previous evolutionary explanations suggesting that selection for this allele was for

behaviours associated with migration and male competition, both of which, both of which entail an element of risk.

B.11.2 Nicotinic Receptors

Polymorphisms in CHRNA4 have been associated previously with response inhibition as measured using cognitive tests such as the Stroop test, matching familiar figures test, tower of London test and the continuous performance test [206], but also in the context of smoking cessation programs [152].

In 2009, Roe et al. identified two SNPs in the gene encoding the alpha 4 nicotine receptor, CHRNA4, that are significantly associated with harm avoidance, a risk attitude measurement drawn from the psychology literature [207] [208].

These explanatory results provide a starting point for understanding the genetic basis of risk attitudes by searching beyond the traditional direct focus on dopamine and serotonin receptor and transporter genes.

APPENDIX C – QUESTIONNAIRES AND GAMES COMPOSING THE ONLINE SURVEY

C.1 Demographic information [EN]

- Please indicate your age.
  Your answer must be between 18 and 99.
  Only an integer value may be entered in this field.
- Please indicate your gender.
  Please choose only one of the following: Female / Male
- Please indicate your current activity.
  Please choose all that apply:
  Student
  Employed - salaried employee
  Employed - freelance or independent worker
  Unemployed
  Other

C.2 Tendance à prendre des risques (Willingness to take risk) [FR] [246]

De manière générale, comment évalueriez-vous votre tendance à prendre des risques?

Utilisez l'échelle suivante :

[1] = Ne pas vouloir du tout prendre des risques

[2] = Ne pas vouloir prendre des risques

[3] = Plutôt ne pas vouloir prendre des risques

[4] = Moyennement vouloir prendre des risques

[5] = Plutôt vouloir prendre des risques

[6] = Vouloir prendre des risques

[7] = Vraiment vouloir prendre des risques

En utilisant la même échelle, indiquez une évaluation de votre tendance à prendre des risques dans les contextes particuliers de :

- La conduite de voiture ;
- Les questions financières ;
- Les sports et loisirs ;
- La santé ;
- L'évolution de carrière.

C.3 Academic background [EN] [247]

Please indicate your academic background, chronologically, including obtained degree and/or degree in progress.

IMPORTANT: You will be able to fill in three triplets (university/cursus/program). The first one (on this very page) is mandatory, the following two are optional, and you will be allowed to access the next parts of the form by clicking on the 'next' button at the bottom of the page.

Example 1: if you are currently a Bachelor student, on this first page please fill in your Bachelor's Degree in progress, then pass on the second and third page by clicking on the 'Next' button at the bottom of the page.

Example 2: if you are currently a Doctorate student, on this first page please fill in your obtained Bachelor's Degree, on the second page please fill in your obtained Master's Degree, on the third page please fill in your Doctorate Degree in progress.

- Indicate your university.
  Please choose only one of the following:
    - Polytechnique Montréal
    - H.E.C. Montréal
    - Université de Montréal - UdeM
    - Université du Québec à Montréal - UQAM
    - McGill University
    - Concordia University
    - Ecole de Technolige Supérieure - ETS
    - Université de Sherbrooke
    - Other
- Indicate your degree.
  Please choose only one of the following:
    - Bachelor's Degree
    - BMI (Integrated Bachelor's and Master's Degree)
    - Master's Degree - Course (Professional Master's Degree)
    - Master's Degree - Research
    - Doctorate

Advanced Graduate Diploma (D.E.S.S., Diplôme D'études Supérieures Spécialisées)

MBA - Master of Business Administration

Other

- Indicate your program.

  For instance: Mechanical engineering, Project Management, Microbiology, Innovation Management...

C.4. Orientation entrepreneuriale (*Entrepreneurial orientation* - EO) [FR] [248]

Veuillez fournir votre degré d'accord sur les affirmations suivantes à l'aide de l'échelle ci-dessous :

[1] - Totalement en désaccord

[2] - Plutôt en désaccord

[3] - Neutre

[4] - Plutôt d'accord

[5] - Totalement d'accord

1. Au cours des trois dernières années, vous avez effectué beaucoup plus de changement dans votre vie que vos amis.
2. En présente d'autres personnes, typiquement vous suivez les actions que d'autres personnes initient.
3. Dans votre entourage, vous êtes rarement du genre à être la personne qui commence à utiliser des nouveaux produits, services, technologies, etc.
4. L'entreprenariat est pour vous le choix de carrière idéal
5. Ces trois dernières années, les changements que vous avez effectués ont globalement été très importants.
6. En présente d'autres personnes, typiquement vous initiez les mouvements et actions et les autres personnes suivent le pas.
7. Lorsque vous êtes confronté(e) à des situations de prise de décision impliquant l'incertitude, typiquement vous adoptez une attitude audacieuse et active afin de maximiser l'opportunité qui vous est offerte et en tirer des bénéfices
8. En général, vous êtes attiré(e) par les projets à faible risque.

9. Dans votre entourage, vous êtes typiquement la personne qui commence à utiliser des nouveaux produits, services, technologies, etc.
10. Dans une situation de conflit, vous évitez plutôt l'affrontement et optez pour une posture tolérante et détachée.
11. Lorsque vous êtes confronté(e) à des situations de prise de décision impliquant l'incertitude, typiquement vous adoptez une attitude avisée et expectative afin de minimiser les possibilités de prendre une mauvaise décision
12. Au cours des trois dernières années, les changements que vous avez effectués ont globalement été minimes.
13. En général, vous êtes très enclin(e) à participer à des projets à haut risque.
14. Ces trois dernières années, vous avez entrepris beaucoup moins de changement dans votre vie que vos amis.
15. De façon générale, en raison de la nature de la situation et/ou de l'environnement, vous pensez que se résoudre à des actes téméraires et d'envergure est nécessaire.
16. Dans une situation de conflit, vous adoptez plutôt une approche très directe et compétitive.
17. J'ai envie de tout essayer au moins une fois
18. L'entreprenariat est pour vous le choix de carrière le moins enviable
19. En général, vous préférez des produits et services testés et traditionnels plutôt que nouveaux et innovants
20. Vous préférez passer la majorité de votre temps avec un nombre restreint de personnes de confiances plutôt qu'avec un large nombre de personne dont la composition change
21. Vous êtes très consciencieux, utilisant votre temps sur les études ou le travail
22. De manière générale, vous tracez nettement la ligne entre votre vie professionnelle de votre vie personnelle.
23. Vous êtes très convivial, usant de votre temps pour discuter et communiquer avec d'autres personnes
24. Vous usez activement de vos réseaux de contacts pour avancer dans votre travail ou vos études
25. Vos études universitaires vous donnent (vous ont donné) une bonne image de l'entrepreneuriat

26. Vos études universitaires sont favorables et un soutien pour développer vos idées d'entreprises et vos projets.
27. De manière générale, vous avez une opinion positive de l'ambition, de l'argent et du succès.
28. Vous avez l'intention de créer votre propre entreprise, ou d'être travailleur indépendant dans un avenir proche ou lointain après l'obtention de votre diplôme
29. Vous avez déjà des idées que vous aimeriez voir se développer à l'avenir.
30. Vous avez déjà des projets en cours que vous aimeriez concrétiser à l'avenir.
31. Vous avez déjà acquis de l'expérience dans l'entrepreneuriat.

C.5. Optimisme (*Optimism score* – OPT) [FR] [249] [250]

Veuillez fournir votre degré d'accord sur les affirmations suivantes à l'aide de l'échelle ci-dessous :

[1] - Totalement en désaccord
[2] - Plutôt en désaccord
[3] - Neutre
[4] - Plutôt d'accord
[5] - Totalement d'accord

1. Dans les moments d'incertitude, je m'attends habituellement au mieux
2. J'ai de la facilité à relaxer
3. S'il y a des chances que ça aille mal pour moi, ça ira mal
4. Je suis toujours optimiste face à mon avenir
5. J'apprécie beaucoup mes amis(es)
6. C'est important pour moi de me tenir occupé(e)
7. Je ne m'attends presque jamais à ce que les choses aillent comme je le voudrais
8. Je ne me fâche pas très facilement
9. Je m'attends rarement à ce que de bonnes choses m'arrivent
10. Dans l'ensemble, je m'attends à ce que plus de bonnes choses m'arrivent que de mauvaises

C.6 Novelty-seeking (NS) [EN] [251] [252]

Please indicate your level of agreement on the following statements by using the scale below :

[1] - Strictly disagreeing

[2] - Rather disagreeing

[3] - Neutral

[4] - Rather agreeing

[5] - Strictly agreeing

Please choose the appropriate response for each item:

1. You prefer variety to routine.
2. You love to think up new ways of doing things.
3. You are open to change.
4. You enjoy hearing new ideas.
5. You seek adventure.
6. You like to begin new things.
7. You like to visit new places.
8. You don't like the idea of change.
9. You dislike changes.
10. You prefer to stick with things that I know.
11. You jump into things without thinking.
12. You rush into things.
13. You like to act on a whim.
14. You make rash decisions.
15. You like to sleep on things before acting.
16. You think twice before doing something.
17. You take precautions.
18. You have an eye for detail.
19. You reflect on things before acting.
20. You investigate all possibilities.
21. You spend more money than you have.
22. You overuse your credit.
23. You never spend more than you can afford.

24. You never abuse your credit.
25. You break rules.
26. You know how to get around the rules.
27. You enjoy crude jokes.
28. You use swear swords.
29. You cheat to get ahead.
30. You resist authority.
31. You would never cheat on your taxes.
32. You try to follow the rules.
33. You stick to the rules.
34. You respect authority.

C.7 Réserve-inhibition (*Harm-avoidance* – HA), IPIP [FR] [251] [252]

Veuillez fournir votre degré d'accord sur les affirmations suivantes à l'aide de l'échelle ci-dessous :

[1] - Totalement en désaccord
[2] - Plutôt en désaccord
[3] - Neutre
[4] - Plutôt d'accord
[5] - Totalement d'accord

1. J'ai souvent le cafard
2. J'ai tendance à craindre le pire
3. Je n'ai pas une grande estime de moi
4. Je suis souvent de mauvaise humeur
5. Je suis facilement stressé(e)
6. Je suis à l'aise avec moi-même
7. Je suis détendu(e) la plupart du temps
8. J'ai rarement le moral au plus bas
9. Je ne suis pas facilement préoccupé(e) par les choses de la vie
10. Je ne me préoccupe pas des choses qui sont déjà passées
11. Jamais je ne pourrais faire des choses comme du deltaplane ou du saut à l'élastique (bungee)
12. Jamais je ne ferai d'investissement à haut risque

13. J’évite les situations dangereuses
14. J’ai tendance à prendre des risques
15. Je suis du genre à rechercher le danger
16. J’ai envie de tout essayer au moins une fois
17. J’aime être téméraire
18. Je fais des choses considérées comme dangereuses
19. Je ne connais pas de limite
20. Je me laisse aller
21. Je me sens mal à l’aise lorsque je suis entouré(e)
22. Je trouve cela difficile d’approcher d’autres personnes
23. Je ne me sens à l’aise qu’avec mes amis
24. Autour de personnes qui me sont étrangères, je suis en retrait et ne me fais pas remarquer
25. J’appréhende les nouvelles rencontres
26. Je me sens bien lorsque je suis entouré(e) d’autres personnes
27. Je parle beaucoup et à beaucoup de monde lors des soirées
28. Je ne suis pas dérangé(e) par les situations sociales difficiles
29. J’agis avec assurance lorsque je suis avec d’autres personnes
30. Sorti(e) de ma zone de confort, je me sens à l’aise
31. Je suis facilement accablé(e) par les évènements
32. Je suis souvent déprimé(e)
33. Il m’arrive de me sentir impuissant(e) dans certaines situations
34. De façon générale, je sens que je manque de confiance en moi
35. J’ai besoin d’assurance
36. Je fais facilement face aux déboires
37. Je sais gérer plusieurs choses à la fois
38. Je peux m’occuper de tout, m’attaquer à tout
39. Je réfléchis vite

C.8 Risk compensation (RC) score (developed for the study) [EN]

Please indicate your level of agreement on the following statements by using the scale below:

[1] - Strictly disagreeing

[2] - Rather disagreeing

[3] - Neutral

[4] - Rather agreeing

[5] - Strictly agreeing

Please choose the appropriate response for each item:

1. When you drive, you always strictly respect speed limits.
2. In a car, as the driver or a passenger, you always fasten your seat belt (however long or short the ride is).
3. On a bike, you always wear a cycling helmet (however long or short the ride is).
4. You know the date of validity of your vaccines.
5. The booster shot of your vaccines that are not up-to-date is scheduled.
6. You practice sports and/or activities usually considered as extreme or dangerous, as a hobby or to challenge yourself.
7. You have knowledge and understanding, or you've had training, regarding finance and investment.
8. You have experience in the field of finance and investment.
9. You are used to play the lottery or to bet money.
10. In general, you use your credit card rather than your debit card.
11. You pay your credit card balance at the end of each month.
12. When you withdraw money from an ATM, you withdraw only the amount you need in the moment.
13. You use direct debits and automatic bank transfers to pay your bills (phone, electricity...).
14. You're protected and warned against overdraft on your banking account.
15. You have an important tobacco consumption.
16. You have a high excessive alcohol consumption frequency.

APPENDIX D – INFORM AND CONSENT FORM [EN]

Title of the research project:

Defining and measuring risky behaviour: a comparative study of the notions and measurements tools tackling decision-making and entrepreneurship.

Research team:

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Master Research candidate in industrial engineering

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Preamble:

We hereby request your participation in an exploratory research project aimed at studying the behaviour facing risk in certain situations. We use and compare different measurement tools

stemming from several disciplines (neurology, psychology, economy, finance), and we are particularly interested in entrepreneurship decision among students.

You have been selected for this project because you are a current student from Polytechnique Montréal-Université de Montréal-HEC Montréal, or have graduated recently.

However, before accepting to participate in this project and before signing this form, please take the time to read, understand and carefully consider the information provided below. We invite you to ask any question you might have to the researcher in charge of the project or the other members of the research team and to ask them to explain to you any word or information that is not clear.

Presentation of the research project and its objectives:

Comparing those tools will enable us to better understand the links between the different disciplines and the multiple aspects of behaviour facing risk. By combining such information with entrepreneurship, it will enable us to better understand why some students choose this path. In this context, the involvement of students from different backgrounds (courses, training) is precious.

Nature and duration of your participation in this research project:

Your participation within the scope of this project will consist in a series of questions, organized in several independent sections, to which you will be asked to answer based on your self-knowledge and experience. **The online form is entirely anonymous.** All the answers you will provide will remain confidential. Completing the questionnaire will take approximately between 20 and 30 minutes. If you accept to participate in this project, simply fill out the questionnaire.

Inclusion and exclusion criteria:

All of the participants in this study must be adults. We are mainly aiming at current students or recent graduates from Quebec academic institutions and more specifically Montreal. Students may have gone back to university studies and already have acquired a working or entrepreneurial experience, which would be relevant for our project.

Benefits resulting from your participation in the research project:

You will not derive any personal benefit from your participation in this research project. However, the knowledge acquired through your participation will help advance the state of knowledge on risk and entrepreneurship.

Once the data is collected, compiled and analyzed, and the results presented in the master's thesis, the conclusions of the study could be transmitted to you. The whole study and its conclusions will be available publicly (http://publications.polymtl.ca/theses.html).

Disadvantages resulting from your participation in the research project:

The disadvantages are limited to the time required to fill out the online form: between 20 and 30 minutes.

Risks that may results from your involvement in the research project:

This research project will not subject you to any additional risk than those you are subject to in your regular daily activities. You could potentially find it difficult to answer some questions. If so, feel free not to answer these questions.

Financial compensation:

You will not receive any financial compensation for your participation in this study.

Voluntary participation and withdrawal right:

Your participation in this research project is voluntary. You can therefore refuse to participate in it by not answering the questions of the following survey, and you can decide at any moment to withdraw from the project without having to motivate your decision, and without any risk to suffer any prejudice. In the event of your early withdrawal of the study (meaning, before the online form has been completely filled out), the data that has collected to this point will not be kept.

Participants may be withdrawn without their consent by the researchers or the Research Ethics Board of Polytechnique Montréal should they not follow the instructions provided or should there be some administrative reasons to abandon the project, notably for safety or feasibility reasons.

Compensation in case of prejudice and rights of the participant:

Should you suffer any prejudice as a result of your participation in this project, be informed that you are not giving up any of your rights nor discharging the researchers, or the institution from their legal and professional duties.

Confidentiality:

You shall feel free to answer frankly to the questions you will be asked. The researcher, as well as any other member of the research team, is committed to protecting the data collected by ensuring the security of all the information, by keeping every record in a secure location, and by discussing about the data collected solely with the other members of the research team.

The only people that will have access to the data are the following:

- Christophe Mondin (M.A.Sc. candidate, in charge of the project, Polytechnique Montréal);
- Nathalie De Marcellis-Warin (Research supervisor, Polytechnique Montréal & CIRANO);
- Thierry Warin (Research co-supervisor, HEC Montréal & CIRANO);
- Carl St-Pierre (Research associate, Polytechnique Montréal).

Upon receipt of the survey duly filled out, the researcher in charge of the project will compile the answers to the questions asked. Only the information that is needed for the safe execution of the research project will be collected.

All the information collected within the framework of this study will remain strictly confidential within the legal limits. **The online form is entirely anonymous.** In order to preserve your identity and the confidentiality of the information you will provide us with, your answers will only be identified by a code.

The data collected by the researcher will be stored in a computer protected by a password and with limited access. The data will also be stored on the servers of the CIRANO research centre 1130, Sherbrooke O., Montreal H3A 2M8, Canada). Data will be stored for analysis purposes for 10 years (standard period for any master or doctorate research project in engineering), after which it will be destroyed.

For monitoring or control purposes the research data could be consulted by a person mandated by the Research Ethics Board of Polytechnique Montréal or by a person mandated by the research councils. All these individuals adhere to strict confidentiality policies.

Protection of personal information during the circulation of the study's results:

The researcher in charge of the project will use all the data for the sole objectives of the research project briefly described above. The data collected within the framework of the project could be published in scientific papers or be shared with other people during scientific conferences. However, because of the anonymous nature of your participation to the research project, **no information that could lead to your identification will be contained in these publications or scientific communications**.

The whole study and its conclusions will be available publicly (http://publications.polymtl.ca/theses.html).

Contact information of resource person:

Should you have any questions pertaining to the research project, you can communicate with Christophe Mondin, researcher in charge of the project at: (514) 625-5090, or by e-mail at: christophe.mondin@polymtl.ca.

Other resource persons:

- Should you have any questions pertaining to the research project, you can communicate with Nathalie de Marcellis-Warin, research director of the project at: nathalie.demarcellis-warin@polymtl.ca;
- Should you have any questions pertaining to your participation in this research project, you can communicate with Ms. Delphine Périé, Chair of Polytechnique Montreal's Research Ethics Board at: (514) 340-4711, Ext. 4437 or by e-mail at: delphine.perie@polymtl.ca.

Consent:

By answering the questions in this online form, you agree to participate in this research project in accordance with the conditions set out in this document. Please keep a copy of this document.

Please click on the NEXT box at the bottom on this page to accept the terms of confidentiality, in order to access to the form.

APPENDIX E – ETHICS CONFORMITY CERTIFICATE

POLYTECHNIQUE MONTRÉAL
LE GÉNIE EN PREMIÈRE CLASSE

CERTIFICAT DE CONFORMITÉ ÉTHIQUE

Le 23 février 2016

M. Christophe Mondin
Mme Nathalie De Marcellis-Warin
Département de mathématiques et génie industriel
Polytechnique Montréal

N/Réf : Dossier CÉR-15/16-22 (projet non financé)

Madame, Monsieur,

J'ai le plaisir de vous informer que les membres du Comité d'éthique de la recherche (CÉR) ont procédé à l'évaluation en comité restreint du projet de recherche intitulé « *Définir et mesurer le comportement face au risque: une étude comparative sur la prise de décision en situation d'incertitude, ses notions et ses outils de mesure* ».

Les membres du CÉR ayant examiné votre projet en ont recommandé l'approbation sur la base de la documentation amendée que vous nous avez fait parvenir hier.

Veuillez noter que le présent certificat est valable pour une durée d'un an, soit du **23 février 2016 au 22 février 2017**, pour le projet tel que soumis au Comité d'éthique de la recherche avec des êtres humains.

Nous vous saurions gré de nous faire parvenir un bref **rapport annuel** (http://www.polymtl.ca/recherche/documents-officiels-et-formulaires) afin de renouveler votre certificat au moins un mois avant l'expiration du présent certificat. La secrétaire du Comité d'éthique de la recherche avec des sujets humains devra également être informée de toute modification qui pourrait être apportée ultérieurement au protocole expérimental, de même que de tout problème imprévu pouvant avoir une incidence sur la santé et la sécurité des personnes impliquées dans le projet de recherche (sujets, professionnels de recherche ou chercheurs).

Je vous souhaite bonne chance dans la poursuite de vos travaux,

Delphine Périé-Curnier, présidente
Comité d'éthique de la recherche avec des êtres humains

CC. Céline Roehrig (DRIAI), Olivier Grenier, Nathalie Daigle, Danielle Bilodeau (BRCDT), Brigitte Coté (Finances)

Comité d'éthique de la recherche avec des êtres humains
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APPENDIX F – PRINT SCREENS OF THE ONLINE SURVEY

Online Form - Decision-making, Entrepreneurial Orientation and Risk - Polytechnique Montreal, HEC Montreal & CIRANO

Load unfinished survey | Exit and clear survey

Please indicate your level of agreement on the following statements by using the scale below :
[1] - Strictly disagreeing
[2] - Rather disagreeing
[3] - Neutral
[4] - Rather agreeing
[5] - Strictly agreeing

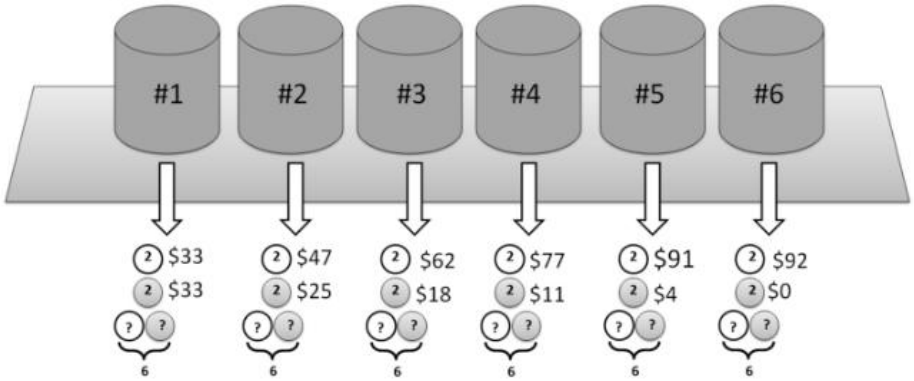
	[1] - Strictly disagreeing	[2] - Rather disagreeing	[3] - Neutral	[4] - Rather agreeing	[5] - Strictly agreeing	No answer
Over the last three years, you have personally committed much more change in your life than your friends.	○	○	○	○	○	
In dealing with other people you typically respond to actions the other people initiate.	○	○	○	○	○	
In your peer-group, you are very seldom the one that first begins using new products, services, etc.	○	○	○	○	○	
Entrepreneurship is for you the favourite career choice.	○	○	○	○	○	
During the last three years, changes you have committed in your life have generally been quite dramatic.	○	○	○	○	○	
In dealing with other people you typically initiate actions to which other people then respond.	○	○	○	○	○	
When confronted with decision-making situations involving uncertainty, you typically adopt a bold, aggressive posture in order to maximize the probability of exploiting potential opportunities.	○	○	○	○	○	
In general, you have a strong proclivity for low-risk projects.	○	○	○	○	○	
In your peer-group, you are typically the one that first begins using new products, services, etc.	○	○	○	○	○	
In a confrontational situation you typically seek to avoid clashes preferring live-and-let-live posture.	○	○	○	○	○	

Section 3-2 - Table number 2

Situation :

This time, the distribution of the black and white balls in every box is not known precisely. Every box still contains 10 balls, of which at minimum 2 of them are black and 2 of them are white. The distribution of colour of the six other balls is unknown and random (**it means that this distribution is not the same for all the boxes**).

For instance, the box #1 can contain 4 whites and 6 blacks, whereas the box #4 can contain 8 white.



Decision :

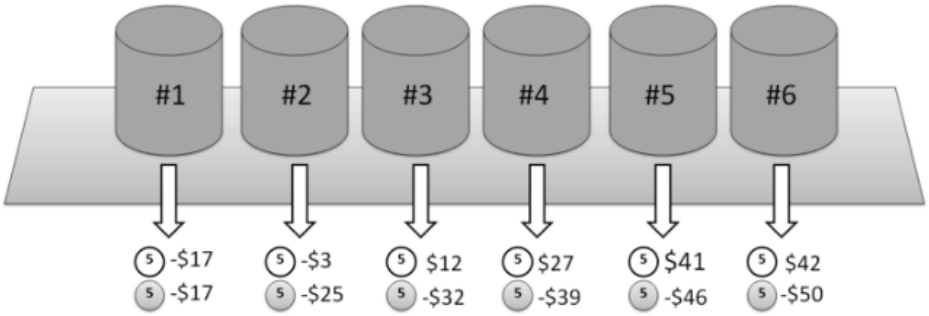
Please indicate in which box you'd like to pick a ball at random.

	Box #1	Box #2	Box #3	Box #4	Box #5	Box #6	No answer
Choice of box	○	○	○	○	○	○	

Section 3-3 - Table number 3

Situation :

Consider that you received $50. Be careful this time, several boxes are filled with balls linked to a negative gain. If you pick up a ball associated to a negative gain, the amount will be deduced from your initial $50.



Decision :

Please indicate in which box you'd like to pick a ball at random.

	Box #1	Box #2	Box #3	Box #4	Box #5	Box #6	No answer
Choice of box	○	○	○	○	○	○	