DECISIONS THAT MAKE THINGS WORK BETTER

AN ANALYSIS OF THE QUALITY CONCEPT

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Abstract

The present thesis is aimed at analyzing the concept of quality and at discussing, in a unified manner, its role not only in operations management but also in strategic thinking. It criticizes the widespread view that quality is meeting the client's needs and expectations in such a way that the gap between perceptions and expectations is minimized. Essentially it develops a systematic proposal in order to understand the concept on the intuitive basis that quality is tantamount to how well something works for a given purpose.

The analysis is based on the fact that anytime that the quality concept is used there are actors that carry out an action with the help of a means—thus quality is a particular sort of means-ends fitness. Roughly speaking, the quality of a means is its capability to improve the expected consequences of the action. The analysis shows under which conditions this conclusion can be understood in terms of multi-attribute preference orderings under uncertainty—some ideas from decision theory, which are required in order to do that, are presented. In short, whether the expected consequences improve or not depends on an assumed preference ordering that has to be correct given the actors' circumstances and purposes—but it may be distinct from the actual preferences of many individual actors. Quality is neither subjective (it does not change depending on the psychological processes of any particular individual) nor objective (in a sense, it depends on action and cognition), but it is relative to a given set of reference preferences.

Some conditions apply to what it counts as a means, how it relates to an end, which attributes are relevant to assess consequences, or which reference preferences are well-formed. In particular, I discuss to which kind of means the concept is properly applied. As a complement, a basic model of means-ends relationships (built on several properties of Boolean functions) is presented. At a slightly more technical level, it shows relevant insights, but strictly speaking it is not required in order to understand the rest of the thesis.

Quality appears in management under two interrelated forms: (a) organizations' interventions in the quality of what they use and provide and (b) organizations' initiatives to compete through quality.

(a) The basic structure behind quality management is examined under the lens of the quality concept's analysis. The following issues are dis-

cussed: setting quality criteria, product design, process design, onsite planning, onsite control, standardization, product improvement, process improvement and rethinking reference preferences.

(b) The role of quality on competitive advantage and sustainable profitability depends on how quality relates to entry barriers. I show different ways in which quality can interact (if it does) with product differentiation, experience effects, scope economies, reputation, capital requirements, access to distribution channels, switching costs, legal barriers or scale economies. The strength of quality as a driver of profitability is discussed—the conclusion is that it is not easy to build sustainable competitive advantages on the basis of quality alone and that its complementary role in competition has several aspects that are needed to be taken into account.

Finally, the particular example of how the quality concept works in relation to information flows is treated in some detail. Information flows are processes that move information from the firm's inner or outer environment to actions. Decisive factors of its quality (basically, information asymmetries and coherence) are discussed. Two actual case studies are presented. The example of information flows is aimed at showing the motivation for a general analysis of the quality concept beyond slogan-like statements about clients, products, perceptions and expectations.

Preface

This thesis cannot be properly understood unless the fact that it carries out a conceptual analysis is taken into account—namely, an analysis of the quality concept. The term 'analysis' should not be taken here too narrowly. It means breaking down the concept into parts but also re-gluing some of them in different manners. Surely it involves a preliminary task of isolating the concept from other related concepts that, strictly speaking, are not essential to a proper usage of it. In addition, the analysis should show arguments to justify what constitutes a proper usage of the quality concept, what does not, and why.

Despite the thesis is a conceptual analysis in a broad sense, it is strictly speaking nothing more than that. There are no empirical statements (at least in a usual sense), empirical research methodologies, development of practical techniques or similar things. This does not necessarily mean that the research is useless. The alleged distinction between practical matters (applied, concrete in a sense) and conceptual matters (theoretical, abstract in a sense) should not be taken too far. It is not just that we cannot do most of the things we do without using concepts, but that we do not know in advance which concepts we may need (or in which level of sharpness), especially in creative tasks. Theoretical inquiries about concepts focused on practice (and many others that perhaps do not have that focus in an obvious way) can be as useful as any recipe to solve a particular problem.

There is some trend of thought that establishes that a well-founded research should have as many references as possible, all of them recent, functioning as a complement to a perfectly structured empirical work—in terms of objectives and methodology. This is not, quite clearly, the case of this research. Actually, the described format may be obviously desirable in many cases but clearly unsuited to many others.[1]

It doesn't mean that there are theses (this one among them) that cannot be critically examined in a structured way. It simply means that there

[1] To my mind, the literature of quality management consists of plenty of empirical studies that measure things without being actually sure of the concept which underlies the measurements; e.g., typical examples can range from psychometric measurements (Zeithaml, Berry and Parasuraman 1993a), to internal detected defects and external service call rates (Garvin 1983). In the case of perceived quality there are underlying assumptions concerning what quality is (that is, *what* people allegedly perceives). I do not suggest that research in quality management should not be empirical; indeed, it should, but using well-founded concepts.

are different correctness criteria for different kinds of research—in architecture, computational linguistics, fine arts, law, chemistry, economics, optometry, literature or whatever. In the present case, there are some constraints to what constitutes a suitable correctness criterion:

(1) As noted, a mainly conceptual inquiry is proposed.

(2) This inquiry (at least as it is carried out) is not based on an existing significant line of research in the field of quality management.

(3) There are few recent references that are explicitly aligned with the defended perspective, and almost any other reference takes some variant of the criticized view—namely, that quality is meeting the client's needs and expectations in such a way that the gap between perceptions and expectations is minimized.

(4) Most of the research tools that are proposed in the thesis are not considered in the available literature in quality management.

Taking these constraints into account, probably the main correctness criterion is the arguments' suitability. I have tried to make my arguments clearly explicit. References are useful just as illustrations of some premises in these arguments—some of them are recent, others are not. Correctness comes from how well the premises are explained, illustrated, discussed and justified—and of course from making reasonable inferences from the adopted premises.

Since one of the present dissertation's primary objectives is to suggest a much more rigorous way to think about the concept of quality, any review concerning any mistake in the present arguments would be entirely welcome. It would mean that a better reasoned understanding of the quality concept is moving on.

I would like to make a personal comment on the tools used in the analysis. According to the previous remarks, this thesis is a piece of basic research in the applied field of quality and process improvement. I might look at my academic background as more or less dedicated to this theme:

- On Improvement Decisions (UPC*)
  - PhD candidate, Statistics and Operations Research (UPC)
  - Master, Business Administration (UPC)
  - Master, Quality Management (UPC)
  - Degree, Statistics (UPC)
- BA, Philosophy (UAB**); with honors ("premi extraordinari de llicenciatura")

(*) UPC: Universitat Politècnica de Catalunya
(**) UAB: Universitat Autònoma de Barcelona

My professional experience, after a period as statistician and before I became assistant professor of quality management and applied statistics at

UPC, is in overall organizational improvement in SMEs—first as hired professional with managerial responsibilities and later in consulting. The point is that my research approach cannot be isolated from my practical experience and education.

For instance, when I am asked for the change from philosophy to statistics, I explain that my interest in the philosophy of action led me to decision theory, and decision theory to statistics and management. Of course this is partial, but true. As it will become clear later on, my understanding of the quality concept strongly depends on the concepts of action and decision.

Accordingly, the present thesis makes use of some concepts and tools from analytic philosophy, decision theory and similars. Of course they are not usual in quality management. They have been greatly simplified and I have tried to adapt them and put them in the appropriate context. As a side effect, some developments can appear too rough, simplistic and approximate to readers who are more versed in philosophy or decision theory. Likewise, the use of some results from industrial organization and business economics can be interesting from the viewpoint of quality management, but it may seem too much schematic from the point of view of a versed specialist.[2]

Therefore, the reader should take into account that this thesis perhaps relies in an unstable equilibrium. What has been simplified or taken as a mere sketchy indication may seem inviolable to some readers. What has been systematically analyzed in some detail and some degree of abstraction may appear as a pretentious unnecessary digression to other readers. The extent to which a reasonable equilibrium has been achieved depends on whether the arguments hit the spot. I accept the risk because I believe that, beyond its potential defects and limitations, this thesis poses (in a serious and systematic way) relevant and interesting basic research questions.

[2] I do not claim to be an expert in any of these fields (actually I am not)—but I do claim to be acquainted enough with these disciplines (along with having some formal education about them) to use them properly in my research on quality and improvement decisions. In particular, this thesis does not use philosophy in an amateur way to complement or contextualize an otherwise autonomous research; conceptual analysis plays *the* key role in the dissertation.

Dedico la tesi a la meva família, i especialment a la meva mare, a la meva àvia i a la Laia.

En Xavier i tots els companys de la secció de Tècniques Quantitatives de Gestió a l'ETSEIB mereixen un agraïment especial pel suport i l'ambient de treball que han proporcionat.

Oriol Camps Lorente
Barcelona, 15 de maig, 2012

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1

Introduction

Quality and Differentiation

Lancaster (1966) noted that consumer theory in microeconomics assumes that preferences and utility derive from goods *per se*. Goods are simply what consumers would like more of, thus this seems to be a reasonable starting point to describe consumer's choices in the economy. Lancaster suggested a quite different view based on the idea that goods are nothing more than bundles of characteristics and the consumers have preferences over characteristics—as Tirole (1988) put it. Lancaster used three statements to summarize his approach:

(1) The good, *per se*, does not give utility to the consumer; it possesses characteristics, and these characteristics give rise to utility.

(2) In general, a good will possess more than one characteristic, and many characteristics will be shared by more than one good.

(3) Goods in combination may possess different characteristics from those pertaining to the goods which are studied separately.

Lancaster's approach is particularly interesting to model product differentiation, a topic to which Lancaster himself made significant contributions (Lancaster 1980, 1990).

Products are different between them. Perfect competition (almost infinitely many suppliers providing undifferentiated products with price depending only on quantity) barely occur in actual economies. Firms want to differentiate their products because this allows them to make different pricing choices depending precisely on how and how much their products and services are different from the rest. A significant part of the product market's game consists in differentiation.

What differentiate products are the characteristics that they possess. When a set of differentiated products share the same characteristics but in different degrees, we speak of vertical differentiation; this is the case of products differentiated by their quality, thus the kind of differentiation in which we are mostly interested in this thesis. When a set of differentiated products are differentiated precisely because they do not share the same characteristics, we speak of horizontal differentiation; perhaps the para-

digm is the fashion market, where quality and durability is sometimes an unwanted waste because large segments of consumers (e.g., young people) want different clothing at least one time each year. In general, vertical and horizontal differentiation can be combined in different proportions (Beath and Katsoulacos 1991).

One way to express the distinction is saying that for some characteristics such as sweetness or crunchiness, preferences can be extremely different among consumers. As Cabral (2000) points out, differences in this sort of characteristics generate horizontal differentiation—more crunchiness, so to speak, can make a product truly different (not necessarily better or worse). For other characteristics such as reliability or durability, preferences are (with all other factors held constant) perfectly equal among consumers—more reliability, so to speak, does not make a product truly different, but simply better. Differences in this second sort of characteristics generate vertical differentiation.

To be sure, for most products there is a universal agreement that more reliability or durability is better; a consumer may give a lot of importance to them, while other may be quite indifferent, but both consumers agree in their improvement direction. Clothes' durability is not a problem by itself for young people—they agree that, with all other factors held constant, it would be better; it is just that all other factors are not constant, and they are not willing to pay more money for an advantage they do not want.

Cabral's introductory formulation of vertical and horizontal differentiation is perfectly correct to explain the distinction. Nonetheless, as we will see, strictly speaking it will not be well-suited to what we want to do:

Remark (1.1)

Given certain purposes and circumstances, if more reliability of a device is better for an actor then it is so, independently of his appreciation and opinions about the device's reliability.

In other words, with all other factors held constant, the reason that a more reliable device is a better means to achieve an end under certain circumstances is absolutely independent of the actor's desires and beliefs. Precisely, it only depends on his circumstances and his general purposes—usually implicit in what he does and not always consciously stated.

Moreover, we will see that actually cognitive biases lead us to prefer things that may play against our actual purposes in some circumstances. Note that, by contrast, if more sweetness or crunchiness is better for an actor then it is so in strict dependence of his taste. We can only say that it is better if the actor likes it. If not, it is not.

The idea of characteristics that are drivers of vertical differentiation and of better or worse quality somehow relates to the well-known notion of quality attribute in quality management. In this thesis, I will link the concept of quality attribute with the notion of preference defined over characteristics.

RESEARCH TOPIC AND BASIC ASSUMPTION

This thesis contains an analysis of the quality concept and a discussion of its role in different managerial issues, both in the field of operations management and fields related to strategic analysis. The present thesis is aimed at a unified treatment of several aspects of quality and its impact on firms' activities, usually spread throughout economics, industrial organization, quality management and other fields in business administration. Such a unified treatment requires a more or less systematic, well-founded definition of the concept—this is the aim of the theory of quality in Chapter 4.

In this sense, the thesis is an in-depth conceptual inquiry about a unique theme.

The analysis builds on the following basic informal assumption:

Supposition (1.2)

Quality is tantamount to how well something works for a given purpose.

This is not a quality definition, just an intuitive minimal principle that any quality definition has to account for—by all means, it also has to account for other aspects. No inquiry can start from nowhere: this informal principle is the starting point of this thesis.

I have no objections if somebody believes that how well something works for a given purpose has little to do with its quality. In that case I would consider (let us say, *ex hypothesi*) that simply he or she refers to a different concept from the one that is studied in this thesis.

THE MYTH OF OBJECTIVE AND SUBJECTIVE QUALITY

To my mind, the most interesting, rigorous and creative author in the field of quality has been W. A. Shewhart (1891–1967). In 1931, he wrote: "Enough has been said to indicate that there are two common aspects of quality. One of these has to do with the consideration of the quality of a thing as an *objective* reality independent of the existence of man. The other

has to do with what we think, feel, or sense as a result of the objective quality. In other words, there is a *subjective* side of quality." (Shewhart 1931). Shewhart thought of quality in terms of characteristics or, as he would put it, of quality characteristics with operational meaning (Shewhart 1939). Accordingly, quantitative standards should be expressed, "insofar as possible, in terms of quantitatively measurable physical properties. This does not mean, however, that the subjective measure of quality is not of interest. On the contrary, it is the subjective measure that is of commercial interest." (Shewhart 1931)

Most of the difficulties and conceptual dangers to properly understand the quality concept are already contained in these quotations. The history of the quality definitions consists of endless variations of the "puzzle" that Shewhart (perhaps unconsciously) pointed out: the puzzle of the objective – subjective duality of the quality concept. On the one hand, the quality of a product does not change depending on our perceptions—this will be one of the major themes of this thesis. On the other hand, it seems that quality only can be understood on the basis of what matters to people and what happens to them. Even if Shewhart probably did not consider it a puzzle, I will argue that this duality is the main problem when analyzing the quality concept.

Since it is the subjective aspect that is of commercial interest, when the duality was expressed in terms of perceived quality versus objective quality, it was the perceived quality that gained notoriety (Zeithaml, Parasuraman and Berry 1988a, 1988b, 1990; Zeithaml 1988). As noted in the Preface, the concept of perceived quality should make it clear enough *what* is supposed that the individuals perceive—that is, it also involves some conception of what quality is when nobody perceives it.

However, the idea of perceived quality has depredated the quality concept to a large extent. A well-known paper by Garvin (1987) suggested eight dimensions of quality:

(a) Performance

(b) Features

(c) Reliability

(d) Conformance

(e) Durability

(f) Serviceability

(g) Aesthetics

(h) Perceived quality

Among the aspects that I believe that can be criticized of Garvin's approach, I will focus on the fact that, as it is now common wisdom, better perceived quality (with all other dimensions held constant) implies better quality. To be sure, this is coherent with the decision to include as a quality dimension the very same perception of quality. I guess that better perceived quality does not increase quality in the same sense that better reliability does—otherwise we could have an infinite regress.

At any rate, Garvin's list mixes *performance* ("the product's primary operating characteristics") and *aesthetics* ("how the product looks, feels, sounds, tastes or smells").

Remark (1.3)

The problem is the attempt to mix the so-called objective dimension and the subjective dimension. As I will argue in Chapters 1 to 4, quality is neither objective nor subjective. The alleged objective – subjective duality of the quality concept is a major conceptual confusion.

This thesis is aimed at presenting a systematic conception according to which (i) quality is not modified depending on what we perceive but even so it is not objective; and (ii) quality can be understood on the basis of what people do and what happens to them but even so it is not subjective.

Together with perceived quality and perhaps serviceability ("the speed, courtesy, competence and ease of repair"), the inclusion of the aesthetic dimension is aimed at covering the alleged subjective aspect. In Chapter 4, I will argue that aesthetic criteria have nothing to do with quality—as better perceptions have nothing to do with it either.

That's not to say that aesthetic issues are not important in product design, service management, workplace design or whatever. I have no doubt that better products from an aesthetic viewpoint (whatever it means) are more saleable. It seems reasonable to me that they can be more usable when users like them. Therefore, aesthetic issues are relevant in some aspects of management. It is just that they do not define the quality concept—for the arguments discussed further along.

Of course, if quality means anything good for the client, then aesthetic value could be an aspect of quality. Nevertheless, a better price is something good for the client but better price does not imply better quality. Plainly and simply, quality is not anything good for the client. We will be able to better manage it if we become able to discriminate the proper usages of the quality concept from the spurious ones.

SOME CONCEPTIONS OF QUALITY

Usual Definitions

The following statements are coherent with Supposition (1.2) and are reasonably descriptive about some aspects of the quality concept:

(1) Quality is meeting clients' needs and expectations.

(2) Quality is fitness to use.

(3) Quality is conformance to requirements.

(4) Quality is conformance to specifications.

(5) Quality is being free of deficiencies. Quality is minimizing the number of defects per opportunity.

I take as a reference the statement about meeting clients' needs and expectations. The other definitions in the list are somehow reducible to it: use, requirements, specifications, or admissible amounts of deficiencies can be regarded as determined by needs and expectations. For the sake of simplicity, we shall consider the last four conceptions as particular instances of the first one—it is not necessary to do that, it is merely convenient to the exposition; for instance, Crosby would consider that (3) has a broader scope than (1), but he is mainly concerned with "eliminating hassle" by setting requirements (Crosby 1984).[3]

Despite the fact that these statements are basically correct, there are some aspects of the concept that they do not capture and there are other aspects that they add to our basic assumption. I comment on some of them later on. One of the most important ones was already noticed by W. Edwards Deming (1994): "The customer's expectations. There is much talk

[3] I don't take these statements as research results (even if they are so) but as influential conceptions in practice. The statement (1) is implicit in ISO (2005), since it defines requirements in terms of needs and expectations; (2) can be found in Juran (1992) and other Juran's previous works; (3) is discussed in Crosby (1979, 1984) and, actually, it is adopted in a slightly different sense in ISO (2005); for (4) and (5) see the comments by Juran and Godfrey (1999); (6, below) is loosely speaking the "gap 5" in Zeithaml, Parasuraman and Berry (1988, 1990); the Kano model implicit in (7) was published in Japanese in 1984, see Kondo and Kano's chapter (number 41) in Juran and Godfrey (1999); the statement (8) appears in Taguchi (1986).

The beginning phrase of the ASQ's definition is based on the lack of definition: "A subjective term for which each person or sector has its own definition. In technical usage, quality can have two meanings: 1. the characteristics of a product or service that bear on its ability to satisfy stated or implied needs; 2. a product or service free of deficiencies" (*http://asq.org/glossary/q.html*; 25 January, 2012).

about the customer's expectations. Meet the customer's expectations. The fact is that the customer expects only what you and your competitor have led him to expect. He is a rapid learner." According to Deming's remark, people's expectations probably are not an infallible indicator of how well something works for a given purpose, since customer's expectations are conditioned by what the market has led him to expect.

Prior to explore in some detail the idea of meeting needs and expectations I highlight three additional conceptions, also coherent with the basic assumption:

(6) Quality is minimizing the gap between expectations and perceptions.

(7) Meeting clients' needs and expectations is must-be quality. Attractive quality is exceeding clients' needs and expectations (Kano).

(8) Poor quality is the loss a product causes to society after being shipped, other than any losses caused by its intrinsic functions (Taguchi).

The next section explains some arguments so as to avoid focusing in the conception based on the gap between perceptions and expectations if we force ourselves to strictly observe the basic assumption. By virtue of statement (6), the quality concept is depredated by an alleged notion of perceived quality. The problem is not so much about Zeithaml, Berry and Parasuraman's works on perceived quality, but about its impact in the accepted wisdom (the received wisdom, the conventional wisdom) in practice and some research. At least in the usage I am going to analyze, quality does not consist in meeting needs and expectations if this means minimizing the gap between perceptions and expectations.[4]

Concepts behind the Kano model (attractive and must-be quality) also focus on perceptions and expectations. Thus they will be subject to the same objections. Nonetheless, the Kano model does not have to be interpreted as a quality definition. Setting aside how we conceive quality, users have perceptions about quality attributes: the fact that such perceptions do not define quality does not mean that they are not important to man-

[4] Strictly speaking, Zeithaml, Berry and Parasuraman exploit the fact that they focus on perceived quality in order to avoid any systematic analysis of quality *tout court*; albeit that, as noted, any conception of perceived quality involves a notion of what quality is. Considering their approach, from the claim that empathy, assurance, responsiveness, reliability and tangibles are aspects that explain perceived quality, there is no need to infer that more empathy (as more aesthetic value, for that matter) generates more quality. However, many professionals and non-scholar authors (and perhaps Zeithaml, Berry and Parasuraman themselves at some points) have inferred similar conclusions—the reader can try to google 'quality gap perceptions expectations' or 'quality needs expectations'.

agement purposes. Therefore, nothing in the theory about quality in Chapter 4 is especially against the Kano model.

Taguchi's definition is interesting. He differentiates quality from value. Value (in the economic sense of willingness to pay or willingness to accept costs, which is different from price) is subjective, quality is not. I agree with Taguchi (1986) in that determining subjective value "is a marketing and product planning problem of vital importance for a company, but it is not an engineering problem". Implicitly there is the claim that quality is an engineering problem. I don't believe it is. However, at the end of Chapter 4 it will be clear why I think that it is a perhaps unfortunate way to express a great amount of truth. Taguchi's viewpoint significantly opposes to a quality notion based on gaps between expectations and perceptions.

EXPECTATIONS, PERCEPTIONS AND NEEDS

Comparison between Expectations and Perceptions

It is reasonable to think that if a product is of a good quality then customers' perceptions will be similar to their expectations.[5] The idea that quality is minimizing gaps between perceptions and expectations is an incorrect swapping of the antecedent and consequent of this conditional: from the statement that when there is good quality perceptions will be similar to expectations, we cannot infer that if perceptions are similar to expectations then there is good quality.

It is necessary to look a little bit closer to understand some additional disadvantages of the initial supposition. Let us consider an individual customer and a concrete product unit consumed by the customer at a given time. We people tend to believe that:

(*) If the product unit is good quality, then the customer's perceptions at the time of its consumption are sufficiently close (whatever it means) to the expectations before that time.

Notice that (*) assumes many things:

(a) The customer is of the adequate segment,

(b) The customer has made a proper use of the product.

Both (a) and (b) are very reasonable assumptions. However, the most important suppositions for the intelligibility of (*) are:

[5] For a detailed analysis on the concept of expectation, see Zeithaml, Berry and Parasuraman (1993b).

(c) The customer's expectations are reasonable regarding the available information, and his perceptions sufficiently fit with what he should have perceived. That is, the customer has not too many cognitive biases.

(d) Everything that is perceived and expected by the customer about the product is relevant to the quality concept. That is, unfulfilled expectations about price, emotions, feelings, aesthetic tastes, ideological connotations or ethical implications, are relevant to quality.

Despite that (a) and (b) are very reasonable suppositions, I will argue that (c) and (d) are wrong assumptions. In particular, cognitive psychologists caution us against (c) because experimental data show that often people have rare expectations and misperceptions.

In addition, in Chapter 2 I will argue that quality has nothing to do with what happens to concrete product units—of course, (*) is entirely about a concrete unit and a particular individual.

Meeting Needs and Expectations

On the one hand, the idea that quality is meeting needs and expectations is close to the definition about gaps between perceptions and expectations, and the main objection is also valid: maybe it is the case that if a product is good quality, then it meets clients' needs and expectations, but from that we cannot infer that if the product meets needs and expectations then it is of a good quality.

On the other hand, the notion of meeting needs and expectations is ambiguous. 'Needs' and 'expectations' may be synonyms of 'desires' and 'beliefs' (respectively) or not. The way to talk based on customer perceptions, perceived quality, and gaps between perceptions and expectations adopts the psychological meaning: the term 'needs' means individual desires and 'expectations' means individual beliefs.

The psychological version is subject to criticisms equivalent to those sketched in the previous section. Incoherent desires and absurd expectations do not change a good product into a bad one. Moreover, clients have needs and expectations, for instance, in relation to price, emotions, feelings, aesthetic tastes, ideological connotations or ethical implications—but it is highly dubious that these factors are relevant to quality; an argument about this matter can be found in Chapter 4.

A non-psychological version can be founded on the fact that needs can be taken to be independent of actors' conscience about those needs. Taking into account our circumstances, constraints and given purposes, we may need something without realizing that we need it. The important point is what we *should* want according to our purposes and circumstances.

In the same vein, expectations in a non-psychological sense are what we should expect according to our actions, environment and circums-

tances. Let us assume that 10% of flights of airline A arrive almost on time, 30% with a delay of 8-25 minutes, and 60% with a delay of more than 25 minutes. Now assume that 60% of flights of airline B arrive almost on time, 30% with a delay of 8-10 minutes, and 10% of a delay with more than 10 minutes. Obviously company B provides a better expected arrival time.

Now assume that Mr. Smith, a customer, believes that choosing airline A he has a probability to arrive on-time of about a 0.9 and that choosing airline B this probability is of about a 0.2. Mr. Smith is badly misinformed, but obviously his belief does not change which company actually provides a better expected arrival time. This is true even if all customers, without exception, would have such misguided beliefs.

Remark (1.4)

The non-psychological version is quite widespread and commonsensical: considering all other factors held constant, the service of airline B is better than the service of airline A. The reason is not (in this example as in any other possible example) that people acknowledge B's overperformance. The reason is that passengers need to arrive on time, not due to their mental states (namely, beliefs and desires), but to what can be taken to be their reference circumstances and purposes.

Any sound understanding of the quality concept coherent with our basic assumption has to be built on the non-psychological version. The following chapters provide some developments about how to do that.

If quality consists in meeting client's needs and expectations in such a way that gaps between expectations and perceptions are minimized, then quality is tantamount to client satisfaction. If your needs and expectations are met, then almost surely you are satisfied—this is what 'satisfaction' means in this context. Here I will take a quite different view: quality is a raw material for building customer satisfaction, and hence different from it.

Thus I am going to separate both notions: customer satisfaction can be more or less correlated to quality but there are other factors that can help in order to create satisfaction from quality. Actually, we are willing to admit that it is possible (although perhaps not frequent) that a product A can satisfy customers more than a product B but B can have better quality than A. In fact, this is a consequence of our basic assumption: that something works well for a given purpose does not necessarily imply that it is favorably perceived by nobody. Quality is a contributory cause to satisfaction: neither a necessary nor a sufficient cause.

SUMMARY OF CHAPTERS

The thesis comes roughly in two parts. The first part (Chapters 1 to 4) explains the analysis of the quality concept; the second part (Chapters 5 to 8) studies how the concept appears and how it can be used in managerial situations.

Chapter 1 has introduced and contextualized the discussion. Chapter 2 frames the quality concept in terms of means-ends fitness and studies to which kind of means the concept is properly applied.

Chapter 3 builds on the idea that quality depends on preference relations (thus hypothetical choices) on sets of alternative means to carry out actions: such preferences do not correspond to what an actor prefers but to what he should prefer given his circumstances and purposes. It proposes to understand quality measures in terms of multi-attribute ordinal utility functions representing suitable reference preferences. Arrow's impossibility theorem shows that given a series of preference orderings based on univariate attributes we cannot build a preference ordering according to quality unless some reasonable conditions are violated. Cognitive biases in decision making are examined in order to show why quality cannot depend on individual needs, perceptions and expectations.

The thesis hinges upon the theory of quality presented in Chapter 4. It can be regarded as a summary and structured development of the ideas studied in the entire first part of the dissertation.

The second part begins with Chapter 5. It studies the bases of quality management under the lens of the previous part. Chapter 6 analyzes how quality impacts on competition, particularly how it interacts with entry barriers. Its role as a driver of profitability is critically considered. Chapter 7 studies information flows' quality as a useful case to illustrate several aspects of the previous discussions. Two actual case studies are presented: the complaints management in a city council and the hiring needs analysis in a university. Finally, Chapter 8 ends the thesis with some conclusions on the economic significance of intervening on quality and competing through it.

As a complement to Chapter 2, Appendix 1 presents a model of means-ends relationships built on several properties of Boolean functions; it shows relevant insights, but strictly speaking it is not required in order to understand the rest of the thesis.

Appendix 2 somehow criticizes the view that quality management should use the scientific method. It contains a critical discussion on the role of quantitative evidence in management thinking.

Even though "type talk is pandemic [;] it is not occasional; it is not unusual; it is the norm" (Wetzl 2009), Appendix 3 tries to prevent some po-

tential philosophical objections to the use of “type-talk” in the first part of the thesis.

2

Means to Do Things

In the first chapter I have stated the following basic minimal assumption:

Supposition (1.2)

Quality is tantamount to how well something works for a given purpose.

The objective is to build an analysis of the quality concept observing this basic assumption as well as the intuition that quality can be understood in terms of multi-attribute preference orderings under uncertainty—as Lancaster would put it, in terms of preferences and utilities over characteristics. This chapter presents some necessary concepts so as to do that.

QUALITY AND MEANS TO CARRY OUT ACTIONS

A Key Assumption

I will use the following second critical assumption, which, in practice, is even more important than Supposition (1.2):

Supposition (2.1)

Anytime we use the quality concept there is an actor that carries out an action with the help of a means. Quality is said of means to carry out actions.

I take this statement as self-evident—as a supposition it could be beaten by any correct counterexample (at least one correct use of the quality concept such that in no way it could be formulated in terms of actors that carry out actions using means). I believe that counterexamples (if they exist) would be rare enough to do not subtract explanatory power to the analysis.

Supposition (2.1) will be used in many occasions throughout the thesis: any situation in which the quality concept is used will be analyzed in terms of actors, actions and means. It may be better understood looking at some simple examples:

(a) Climbers use ropes to climb mountains. Climbers are actors. Climbing mountains is an action. Using ropes is a means to do that action. Quality is said of ropes: if a type of rope A has better properties than a type of rope B to climb mountains, climbers should say that rope A has a better quality.

(b) Cooks use knives for cutting food. Cooks are actors. Cutting food is an action. Using knives is a means to do that action. Quality is said of knives: if a model of knife A has better properties than a model of knife B for cutting food, cooks should say that knife A is of a better quality.

(c) Patients use hospitals' services to obtain cures. Patients are actors. Obtaining cures is an action.[6] Using hospitals' services is a means to do that action. Quality is said of hospitals' services: if the service of hospital A has better properties than service of hospital B to obtain a cure, patients should say that hospital A is of a higher quality.

This is the case even if climbers, cooks and patients do not actually acknowledge the better performance of such types of ropes, knives and hospital services, respectively. Suppositions (1.2) and (2.1) lead to an initial idea that is worth bearing in mind:

Remark (2.2)

Quality is a particular sort of means-ends fitness.
The question is: which conditions define this particular sort by contrast to other sorts of means-ends fitness? This is what Chapters 2 to 4 are about.

To describe such conditions, I will begin by giving a working definition of 'end' and 'means'. The way in which this has been done is a little indirect (a simplified discussion about the concept of intentional action), but it will provide additional concepts that will be useful later on.

Intentional Actions

An action is something we do—in contrast to happenings, that just happen to us. Playing backgammon is something we do; having an accident is something that happens to us. However, actions can be intentional or not: putting a book down on the table normally is an intentional action. Putting the book down on a puddle of ink quite probably is a non-intentional action. Since both descriptions may refer to the same concrete

[6] This statement may sound suspicious—at least to readers with some acquaintance with the philosophy of action. It can be replaced by something like 'going to somewhere looking for a cure' that quite clearly refers to an action according to the ensuing subsection. In this case as in many others (but not all the cases), I do not intend to be very rigorous in all the details.

action, an action may be intentional under a description but non-intentional under another one (Anscombe 1957).

A plausible condition for actions' intentionality is the existence of reasons to perform them. Reasons seem to relate (causally or not) to beliefs and desires. For example, let us consider the action of pressing a button to launch a missile. If I want to launch the missile (desire) and I believe that pressing the button I will launch it (belief), then such belief and desire are the reasons for pressing the button. The action is intentional under the description 'to launch the missile', but maybe not under the description 'to launch the nuclear missile', for my set of beliefs may not include that the missile was a nuclear one. 'Desires' and 'beliefs' are synonyms of 'needs' and 'expectations' when the latter are taken in their psychological meaning.

Roughly speaking, actions are movements, and intentional actions are movements performed according to beliefs and desires. However, the type of movement one makes when raising the arm has different results in different circumstances: in the street near a taxi it will cause it to stop; in a talk will cause the presenter to stop and wait for a question. The movement is the same, but its meaning is quite different depending on the circumstances. Stopping a taxi and stopping a presenter to make a question involve quite similar movements but different results. In general terms, actions can be conceived in terms of what it is done or in terms of how it is done: stopping a presenter and stopping a taxi are two different types of actions in terms of what is done but they share the way in which it is done at a large extent.

In accordance, an action's specification can include purposes (desires), beliefs about circumstances, beliefs about what has to be done (what-beliefs), and beliefs about how it has to be done (how-beliefs).[7]

Ends and Means

Using these ideas I will adopt some informal definitions of 'end' and 'partial end'; from the definition of partial end we can define what a means is. Though informal and not pretty accurate, the following definitions will

[7] These last two paragraphs of the subsection are a very strong, crude simplification of some points in Israel, Perry and Tutiya (1991, 1993); see Israel, Perry and Macken (1999) for a summary focused on applications. Their approach to action theory from situation theory had some importance in my research process. In fact, K. Jon Barwise's works on situation theory (e.g., Barwise and Perry 1983, Barwise 1989, and particularly Barwise and Seligman 1997) have had a remarkable influence upon me—partly because the entire research actually began with the concept of information (see Chapter 7). There are no explicit signals of this influence in the final version, but many implicit imprints.

suffice to most of our purposes (Appendix 1 suggests one step further, which is based on the same ideas):

Definition (2.3) [End]

An end is what an action purports to achieve. So to speak, an end is an action conceived in terms of what to do.

Definition (2.4) [Partial end]

A partial end is simply an end to be achieved as a part of a primary end's achievement.

Definition (2.5) [Action]

An action is defined by an end plus the way to achieve it.

Definition (2.6) [Means]

A means is an action such that its end is a partial end to a primary action.

Supposition (2.7)

In principle, a means could be used in many partial ends to the same primary action. For the sake of simplicity, in most occasions I will assume that a means is associated to only one partial end to the primary action.

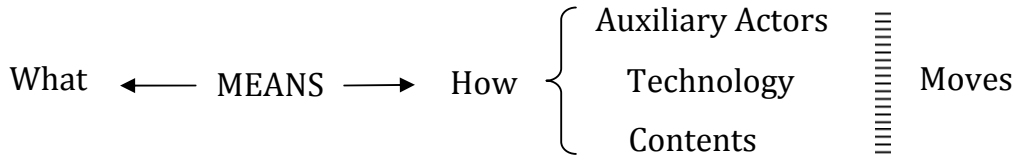
COMPONENTS OF MEANS

The next step is to identify a structure behind what I have generically called 'how to perform an action'. The objective is to identify some regular components of any means that are inherent to its character of auxiliary action used to carry out a primary action.

Basically, any auxiliary action is performed by someone (perhaps distinct from the actor who performs the primary action), it requires some technology or physical structure, and some contents (informative or not) may appear in its performance. Auxiliary actors, technology in a broad sense, and contents bring into play according to different kinds of moves.[8]

Therefore, setting aside the "what" that is implicit in the partial end which is associated to it, I will consider four basic components involved in the "how" part of a means: (1) moves, (2) auxiliary actors, (3) technology, and (4) contents.

[8] I use the term 'move' in a broad sense, perhaps closer to 'game move' than to 'physical movement'. Note that the first one would include the second.



Notice that significant differences in every component (even with all other components held constant) can constitute a different means—e.g., the same partial end performed by the same auxiliary actors using the same technology carrying the same contents can generate several types of means according to significantly different responses to which moves can be used (how actors, things and contents bring into play). I present some examples to illustrate each kind of component:

(a) *Moves*. There are several possible ways to make a courtesy communication within 48 hours from the reception of a complaint—each one constituting a means to make a person aware that his/her complaint is being managed. Likewise, there are several possible ways in order to request a form to somebody—each one constituting a means to collect all the information on time.

(b) *Technology* and *physical structures*. The use of a hammer is a means to drive a nail; the use of a pen is a means to write a letter. Hammers and pens are objects and thus components of using a hammer or using a pen. Setting aside tools and technology, surfaces, spaces or any physical structure can be components of a means to do something.

(c) *Contents* and *informative contents*. The informative content 'the complaint you communicated 48 hours ago is being managed by now' can be a component of a means to make a person aware that his complaint is being managed. The content 'please send the form back, completely filled out' can be a component of a means to collect on time all the information required for an issue.

(d) *Auxiliary actors*. The employee who makes a courtesy call within 48 hours is a component of a means to make a person aware that his complaint is being managed. The person who sends an e-mail requesting the form is also a component of a means to collect all the information on time.

From Devices to Actions

These examples show that ordinary language admits speaking of means as auxiliary actions—e.g., 'making the budget is a means to avoid lack of control'. However, in our everyday language we also speak of means as if they were what we have just called 'components'.

The clearest example is the case of devices—physical objects that are taken to be means to make different things.

Objects are means to do something to the extent that they imply some kind of action to be performed with them. Actually, when we speak of the iPhone's quality, we are not referring only to the device. We refer to the device and some other aspects that it involves: things it allows the user to do, instructions, indications, and so on. We speak of the iPhone's quality, but in a quite obvious sense we are talking about the things we do with it—or, if you want, about the device in the context of what we do with it.

Therefore, we have to bear in mind the following terminological annotation:

Remark (2.8)

At first sight, the word 'means' sometimes seems to be used to refer to objects. This does not contradict our definition of means as actions: concerning quality, an object matters only in relation to what can be done with it.

Examples at the beginning of this chapter can also illustrate this point:

(a) Using ropes is a means to climb mountains. Of course we could say that ropes are means; however, regarding the quality concept the means is *using ropes*.

(b) Using knives is a means for cutting food. Likewise, we could say that knives are means, but regarding the quality concept the means is *using knives*.

TYPES VS. TOKENS

The initial examples about ropes, knives and hospital services give us the occasion to note that quality refers to models, not to product units or service occasions. We said that if a model of rope A has better properties than a type of rope B to climb mountains, climbers should say that (the type of) rope A has a better quality. If a model of knife A has better properties than a model of knife B for cutting food, cooks should say that (the type of) knife A is of a better quality. Likewise, if the service of hospital A has better properties than service of hospital B to obtain a cure, patients should say that hospital A (its type of service) is of a better quality.

Quality does not refer to particular pieces of rope, to particular knifes, to particular cures performed in a given time in a certain hospital; quality refers to models of ropes, models of knives and types of services provided

in a given hospital or in several hospitals. This is the theme of the following sections.

Nobody doubts that there is some difference in the meaning of 'the iPhone' in the following sentences:

(1) The iPhone has had a sales increase of 68% between the third and the fourth quarter of 2010.

(2) The iPhone fell from the third floor to the street and was completely destroyed.

Of course, in (1), 'the iPhone' denotes a type; in (2) it denotes a token. Tokens are usually located in space and time; types never are.[9] Notice that things that can happen to tokens are different from things that can happen to types, and vice versa: an iPhone token can only appear once in the sales numbers of Apple Inc.; the iPhone type cannot fall from a third floor to the street.

Tokens can be of more than one type—point that we may forget if we simply identify types with models and tokens with units (or occasions). For example, an iPhone token is a token of iPhone, mobile phone, or wireless device, among many other types. The assignment of tokens to certain types and not to others is a key element of our cognitive life, not only concerning physical objects but also activities or whatever:

(3) Preparation of the budget is the critical phase of the economic management of any of our projects.

(4) Preparation of the budget was 2.5 hours of work.

In (3), the preparation of the budget is an activity type. In (4), it is an activity token.

Many things that can be said of types cannot be said of tokens, and vice versa. For example, in industrial reliability the concept of MTTF or mean time to failure is used. Look at the ceiling, locate a light bulb in use, a concrete one, and ask yourself what is its MTTF. Token light bulbs do not have MTTF; each one will have a lasting life, but no MTTF. The concept of mean

[9] We shall not dwell on the philosophical details of the distinction between types and tokens. My use of the distinction is influenced by the works of K. Jon Barwise, particularly Barwise and Seligman (1997). They make a pretty free use of the distinction—for instance they allow non-physical tokens and the type-token duality (tokens classifying their types); I have tried to maintain a more standard usage. Despite the "type-talk" is widespread in ordinary language, science and technology, the distinction has many ontological implications (Wetzl 2009). Here this is unimportant. I make some remarks about it in Appendix 3.

time to failure is applied to types of light bulbs, that is, models of which all its tokens share the same design and production process.

Remark (2.9)

This is the reason for which statistics is useful in quality improvement: because it makes it possible to get information about tokens and draw out knowledge about types.

Don't get confused between types and sets of tokens. The set of available drugs that enlarge life to 120 years and the set of brain implants that increase IQ in 50 points is exactly the same: the empty set. However, the type of drugs that enlarge life to 120 years is different than the type of brain implants that increase IQ in 50 points; both types have no tokens at this time, but they are different. This is obvious if we assume that tokens of these types might appear in the future. In addition, the set of all humans without me is not the set of all humans, because I am human. However, the type of humans does not change depending on my existence.

In the ensuing sections I am going to provide additional arguments and remarks to the claim that quality refers to types and not to tokens.

QUALITY CRITERIA VS. DEFECTIVENESS CRITERIA

Product models are not defective—only concrete units can have a defect when they don't fit with the type in some feature. When we say that, with all other factors held constant, better quality models have less defective units and worse quality models have more defective units, we associate the expression 'better or worse quality' with 'models' and the expression 'less or more defective' with 'units'. In accordance, it is quite reasonable to think that quality refers to types and defectiveness to tokens.

The iPhone model can have better or worse quality, but it cannot be defective; an iPhone unit can be defective if it has significant deviations from the designed model—and if we admit to say that it is good quality, this only means that it is a non-defective token of a good quality type.

Remark (2.10)

In quality control, strictly speaking, we do not control the "units' quality": we control some aspects of the model's quality looking at whether some units are defective or not.

The case of services provides a strong argument for this intuition. Obviously, service quality is something that can be (in principle) improved:

airline A in the example in Chapter 1 could think of measures to achieve a 90% of flights on-time, a 9% with a delay of 4-6 minutes and 1% of more than 6 minutes—of course, considering all other factors held constant, this would be an improvement in service quality. However, concrete service occasions can hardly be improved. When something goes wrong in a service occasion, the only thing that can be truly improved is the model behind the next service occasions. If a flight is delayed, there is no possible improvement in this occasion—maybe compensations, but not improvements. In fact, it doesn't make any sense to speak of improvements. If quality would refer to concrete things such as service occasions, then the concept of quality improvement would not make sense.

Therefore, quality criteria and defectiveness criteria are different kinds of criteria:

(i) Quality criteria implicitly or explicitly define the conditions for a type to fulfill some conditions. What defines these specific conditions related to quality criteria is the theme of the dissertation up to Chapter 4.

(ii) Defectiveness criteria define the requirements for a unit (or occasion) to fulfill the characteristics of the type. In general terms, these characteristics are defined in an explicit or implicit design process.

A defect is a violation of a defectiveness criterion. Although 'deficiency' is often used as a synonym of 'defect', in this thesis I will call 'deficiencies' (or 'quality deficiencies') only to the violations of quality criteria. I never say that a model (or type) has a defect; likewise, I never say that a unit violates a quality criterion (despite this can be a reasonable usage in ordinary language)—quality criteria are violated by types.[10]

Nonetheless, a type can have an *expected* number of defects, since it has associated probability distributions of the characteristics; accordingly, the expected value of the distribution of defects is a property of types or models.

Definition (2.11) [Defect]

A defect in a means-token occurs when at least one of its characteristics doesn't fit well with how it should be according to the type's (explicit or implicit) design.

[10] Namely, in ordinary language we would say that a unit violates a quality criterion if its defect is associated to a quality deficiency of its model. It can be a way of highlighting the token's defect or the type's deficiency.

Definition (2.12) [Deficiency]

A deficiency in a means-type occurs when its design is not adequate given the available information about the actor's circumstances and purposes.

In general, the relation between quality and defectiveness can be summarized with the following statements:

(iii) With all other factors held constant, the lower (greater) the expected number of defects in a product model, the better (worse) its quality.

(iv) Better (worse) quality of a model does not necessarily imply a lower (greater) expected number of defects in it.

(v) With all other factors held constant, the lowest (highest) expected number of defects in a model implies its best (worst) possible quality conditioned to the constant factors.

(vi) The previous statement (v) without the *caeteris paribus* clause is false. Without restricting the behavior of other factors, the lowest (highest) expected number of defects in a model does not imply its best (worst) possible quality in absolute terms.

(vii) The best (worst) possible quality in a model implies the lowest (highest) expected number of defects in it.

Remark (2.13)

In accordance, the definition of quality that claims that "quality is minimizing the expected number of defects per opportunity" is false in a literal sense or, at best, just a rough partial approximation.

REPRODUCIBLE VS. NON-REPRODUCIBLE MEANS

Means Relevant as Type or Relevant as Token

The Normandy Landings were a (complex) means to do something, namely to invade the occupied continental Europe in World War II. The iPhone is also a means to do many things, namely to do wireless communication tasks—from phone talks to reading a digital newspaper. However, there is a radical difference between both means: the Normandy Landings were relevant as concrete events located in space and time (that is, as a token); the iPhone is relevant as a reproducible (mass-producible, actually) type of wireless device. The Normandy Landings were not relevant because of their being a reproducible type of event. A concrete token of an

iPhone is not especially relevant because of its uniqueness in space and time, but (rather the contrary) because of sharing the distinctive features of its design.

I will name means such as the iPhone (that is, relevant-as-type means) 'reproducible means'. In contrast, I will name means such as the Normandy Landings (that is, relevant-as-token means) 'non-reproducible means'. That is:

Definition (2.14) [Reproducible means]

A reproducible means is a means relevant as type. In general, any reproducible means has an associated way to generate tokens of it according to its type.

Definition (2.15) [Non-reproducible means]

A non-reproducible means is a means that is relevant as a token. Of course they may have an associated way to generate tokens according to some type of object, but the token's relevance does not come from being a mere token of that type—e.g., Kate Middleton's wedding dress of course is a token of many types (dress, wedding dress) but its relevance does not come from being a mere token of a wedding dress.[11]

We do not require a sharp distinction between both kinds of mean. The distinction is founded on the idea of relevance, so it is a pragmatic, contextual distinction. Some cases are clear in usual contexts (Normandy Landings vs. iPhone) and some other cases can have distinct interpretations depending on the context.[12]

Now we can state the idea that quality refers to types and defectiveness refers to tokens in a more rigorous way:

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[11] According to Wikipedia (21 January 2012), "replicas of the garment were produced and sold, and the original dress is on display at Buckingham Palace." (Entry: Wedding dress of Kate Middleton). The example is useful to make clear our terminology: the replicas are not the Kate Middleton's wedding dress (she did not dress a replica)—thus the original is relevant-as-token and it has no quality. The replicas (not the original) may be reproducible means. By the way, note that the replicas perhaps may have quality, but not (or not only) as mere wedding dresses but as better or worse replicas of a particular dress.

[12] I shall not dwell on that, but there are many suggestive cases and interesting questions—e.g., can be buildings relevant-as-type? Which sorts of building would be non-reproducible means and which others could be considered as reproducible (although almost surely never reproduced)? Remark 2.18 points to this kind of question; for the interested reader, it is worth it to mention that the distinction explained in this section is somehow related to the distinction between *allographic* and *autographic* art forms in Goodman (1976).

Remark (2.16)

Only types of reproducible means have better or worse quality. Only tokens of reproducible means can be defective or not.

Remark (2.17)

Since the distinction between reproducible and non-reproducible means is mainly contextual, we can apply the quality concept to the extent that a means admits a characterization as a reproducible one.
That is, a given use of the quality concept will be more or less doubtful according to whether the characterization of a means as a reproducible one is more or less clear. (Of course, additional conditions discussed in the following chapters have to be fulfilled as well.)

Tokens of non-reproducible means can be successful or not, useful or not, but neither have quality nor are defective. Types of non-reproducible means can be, for instance, original or not, interesting or not; but they do not have better or worse quality. Some examples to illustrate the point:

(i) The iPhone type can have better or worse quality.

(ii) An iPhone token can be defective—e.g., if its battery dies in 7 minutes.

(iii) The concrete events we know as Normandy Landings were successful from the point of view of allies. Nonetheless, it does not make sense to say that they were a "non-defective" means to retake Europe.

(iv) The concrete events in April 1961 we know as Bay of Pigs Invasion were not successful from the point of view of US government. However, they were not "defective" in the same sense that an iPhone can be defective.

(v) The planning of the Normandy Landings was strategically and tactically interesting—for instance, for the use of a deception operation to persuade the Germans that the invasion would take place in Pas de Calais. This doesn't make it a "good quality" means to retake Europe either.

(vi) The planning of Bay of Pigs Invasion was not realistic; for instance, forces were insufficient, internal resistance in Cuba was not organized, and knowledge about Cuban defenses was deficient. Nonetheless, this doesn't make it a "poor quality" means to invade Cuba.

Notice the following pattern of singular, somehow deviated cases:

Remark (2.18)

A means token can be a token of a reproducible means for certain purposes and a token of a non-reproducible means for other purposes. It

has no quality, but it may be defective or not as token of the reproducible means—of course, not as token of the non-reproducible means. The type of the reproducible means can be of a good quality or not.[13]

What is a Process?

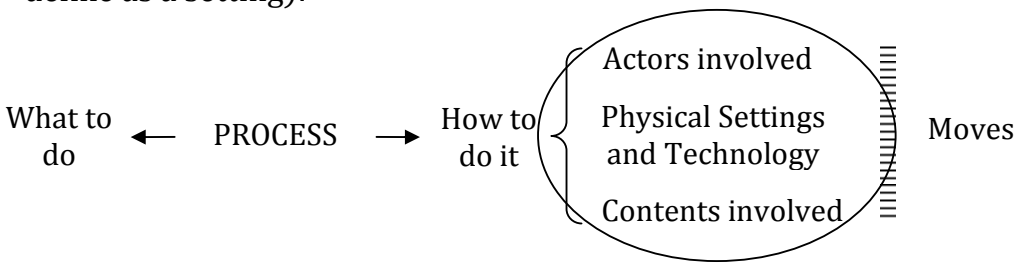
In a quite obvious sense, processes are reproducible means to do things—namely, to produce or generate their outputs. They are reproducible because what differentiates a process and a relevant-as-token activity is that typically processes can be executed many times: each execution is an occasion or token that precisely matters as a token of the type defined by the process. Moreover, processes will be a salient example of reproducible means in this thesis because we want to speak of process improvement, how processes fulfill quality criteria, or how processes' correctness determines the quality of what they produce.

In general terms, the conception of processes as sequences of interrelated activities that transform inputs into outputs is mostly correct. However, it does not ensure that a process is a reproducible means. According to the definition, concrete and unrepeated chains of activities count as much as accurately designed models of processes that generate thousands of executions in different factories—e.g., a patented packaging process.

I will define a process in terms of physical settings (including actors) that generate discrete or continuous executions in a predetermined way. This is the general idea of the following two definitions:

Definition (2.19) [Setting]

A setting is an arrangement of means' components (actors, physical objects, and contents) that is able to perform complex moves adequate to achieve pre-defined ends. Since a process is just a particular sort of means, we can depict it in the same way (a circular shape shows what I define as a setting):



[13] Examples may arise when a token of a reproducible means gains a particular significance of any kind—i.e., a Marilyn Monroe's X-ray radiograph of her chest cavity from 1954, now a collector's object; an US Department of Defense identification card that Monroe used when she performed for the troops in Korea in 1954 and while she was on her honeymoon with Joe DiMaggio (it was sold for $57,000 in 2008).

Definition (2.20) [Process]

A process is the set of phenomena which makes a particular setting to generate concrete executions of a certain type.[14]

Designing a process implies to design settings and how they generate executions. Likewise, improving a process implies to improve settings and/or how they generate executions. Executions imply outputs and settings generate executions using inputs. Therefore, it is true that processes turn inputs into outputs. The notion of process as a black box between inputs and outputs is complementary (not contrary) to the definition I use here.

MEANS TO USE VS. MEANS TO PROVIDE

In the previous sections I have discussed to which objects the quality concept is applied: types of reproducible means used as helps to carry out actions. To do that, I have presented the basic notions of means, type and reproducibility. The negative result is that the quality concept is neither applied to types or tokens of non-reproducible means nor to tokens of reproducible means.

In this last section I present a different kind of distinction. It does not focus on what is essential to the quality concept but on two different kinds of means to which the concept can be potentially applied. It is a simple, pragmatic distinction that has a remarkable importance to assess the scope of intervening on quality.

The Contextual Distinction

Any organization that provides means to do things also uses other means in order to provide them. Recalling Supposition (2.1) (anytime we use the quality concept there is an actor that carries out an action with the help of a means), in the first case (*means to provide*) the actor is outside of the organization and the action he carries out has normally nothing to do with the organization's activities. In the second case (*means to use*) the actor is the organization itself and the action belongs to the organization's operational or managerial activities. Thus:

[14] The ascendancy of this definition in my research can be traced through a reflection about Barwise and Seligman's (1997) concept of *channel*—that is, a classification of connections between tokens with constraints between types. Actually, I simply conceive processes as channels in Barwise and Seligman's sense. As in other cases, here I simplify my exposition.

Definition (2.21) [Means to provide]

We speak of means to provide when who generates (perhaps merely acquiring it) the reproducible means is not the same actor who is going to use it.

Definition (2.22) [Means to use]

We speak of means to use when who generates (perhaps merely acquiring it) the reproducible means is the same actor who is going to use it.

Again, this is a mainly pragmatic, contextual distinction: the same type of process or physical object can be used or provided depending on the context. It is a matter of fixing a viewpoint.

As I will discuss in the ensuing chapters, the adoption of a certain perspective is essential to make a quality attribution—i.e., an ordering of several alternative means according to their quality. We will see that quality is not subjective but relative to some assumptions, which of course should be correct. The distinction between means to provide and means to use implies a key decision concerning such quality attributions—namely, whether the actor that generates the reproducible means is considered as the same actor that carries out the action that the means helps to carry out.

Means Other Than Sold Products and Services

The distinction is also important because in Chapter 5 I will argue that the generic activity of intervening on quality is independent of (but of course can be applied to) the field of business administration. Such an activity makes sense beyond the context of clients and products sold. It has a "proper core" that can be applied (and it is applied, actually) beyond market contexts. Additionally, I will argue against taking the market case as a model to understand the role of quality in non-market contexts.

However, this has been a traditional strategy to think of quality, mainly due to historical reasons:

Remark (2.23)

The traditional approach in thinking of quality has been, in general, to take the *means to provide in market contexts* as a reference model: means *to use* in business processes have been understood according to that model. For instance, the concept of *internal client*, as it is used in quality management, allows analyzing agents in an organization in the same terms that external clients to the organization are analyzed—so to speak, the conceptual tools to think of quality are transferred from

the external market environment to the internal organizational environment.

Moreover, the same thing occurs concerning used means (and some provided) in *non-market* contexts—e.g., in public policy or scientific research contexts. For instance, in order to analyze the data quality in a clinical trial we would think of the data user as a client with needs and expectations—thus data quality would depend on meeting the user's needs, expectations and requirements (Lee, Pipino, Funk and Wang 2006). By the way, this is Wang's (1998) "Information Product perspective" to manage data quality (mostly data not sold to third parties), that gives a noteworthy importance to "understand data consumer's needs" (Wang, Allen, Harris and Madnick 2003).

In fact, means to provide not only include means sold, and means to use not only include raw materials and capital goods to produce means sold. Business organizations provide means other than those that they sell, mainly things they need to provide in order to obtain further sales: from documents for legal requirements to annual reports to investors. Of course such means to provide are used by the organization to achieve some ends (as products sold are used to obtain revenues), but some actor which is external to the organization use them to achieve an end of his own.

If means that are provided but not sold are *reproducible* means, they have quality. Furthermore, there can be *non-reproducible* means that are provided but not sold—which would not be of interest to quality management but obviously they may have an impact on the organization's performance or public image; e.g., an endowment for cultural sponsorship as a means to fund an artistic project.

According to our terminology, raw materials and capital goods are physical components of processes. Processes (including outsourced processes) are the means typically used by organizations to provide other means.

Remark (2.24)

Processes will be our most important case of reproducible means to use. It doesn't mean that processes cannot be provided—this is the case of most (but not all) services.[15]

[15] Most services are reproducible means to provide, but some occasional services could be better classed as *non*-reproducible. Examples could include occasional tasks contracted to somebody who does not perform them in a reproducible way—nothing prevents the service to be performed in a reproducible basis subsequently; e.g., a football stadium rents facilities to host a wedding.

Again, there are *non-reproducible* means *to use*, which are not object of interest of quality management but can have an occasional impact on performance or public image; e.g., a plan to resolve a scandal (for instance, the case of the HP spying scandal in 2006).

Means Provided in Business Contexts

It will be useful to define four usual kinds of means to provide in business contexts, taken to be reproducible means. I do not suggest they cannot be non-reproducible; it is just that our focus on quality makes the non-reproducible case uninteresting for us. I link each kind of means with what we could call as its distinguished components:

(a) Services—i.e., auxiliary actions performed by auxiliary actors using technology and contents. A service is a process or a set of processes (that is, of settings generating continuous or discrete executions in a particular way) aimed at being performed by a supplier A as exchangeable element of an economic exchange with a client B.

(b) Products—i.e., objects. A product is an object obtained as a result of some kind of process (not necessarily a production process in an industrial sense) aimed at being provided by a supplier A as exchangeable element of an economic exchange with a client B. In general, also physical things and structures can be classed as products: materials, chemical substances, animals, buildings, and so on.

(c) Product-service systems—i.e., a product with a set of services that are associated to its use. A product-service system is complex of objects and processes which are aimed at being provided and performed (respectively) by a supplier A as exchangeable element of an economic exchange with a client B. Processes are somehow associated to the use of the object.

(d) Data, edited contents (or "information goods")—i.e., contents in some physical carrier or technology. An edited content or "information good" (including datasets, documents, films, music and the like) is a set of contents (generated as a result of a process) in some device or physical carrier aimed at being provided by a supplier A as an exchangeable element of an economic exchange with a client B. The physical object or carrier is needed in order to enable the content's use, but usually (with some exceptions) it is not the relevant exchangeable element—at least in comparison with the content. The means consists in using the contents to do something, from informing to lying or convincing.

3

Preference, Choice and Quality Measures

In the previous chapter we have studied the idea of means as the sort of object to which the quality concept is properly applied. From now on I will consider means as alternatives to choose—strictly speaking, as alternatives to order from a set of means according to some criteria (i.e., in which order they should be chosen according to those criteria). The definition of such criteria is, in broad terms, the main theme of the next chapter.

THE BASIC SETTING

Under Which Interpretation We Are Going to Use Decision Theory

The basic paradigm in decision theory is that there is an actor (the decision maker) that has preferences over a set of alternatives. Decision theory strictly observes the maxim that it must not be disputed regarding tastes: what makes an ordering correct is not what is preferred but the preference's coherence. From the set of alternatives {$1, $200,000, $200,001} (i.e., amounts of costless money to receive) the following preference is perfectly admissible:

$1 is strictly preferred to $200,000
$1 is strictly preferred to $200,001
$200,000 is indifferent from $200,001

However, the following one would not be correct:

$200,001 is strictly preferred to $200,000
$200,000 is strictly preferred to $1
$1 is strictly preferred to $200,001

The reason for its incorrectness is not that \$1 is preferred to \$200,001; the problem is the ordering's coherence—the infinite cycle \$200,001 → \$200,000 → \$1 → \$200,001 → \$200,000 → \$1 → \$200,001 →...

Preferences are assumed to be psychological, a subjective state of the decision maker that guides its choices. Decision theory makes some coherence assumptions, but it does not legislate about tastes. Given certain tastes, it studies how the decision maker should ideally choose.

In order to model the quality concept, I am going to use (normative) decision theory in a quite different way. Roughly speaking, I am going to move the focus from what an actor decides to what an actor *should* decide given certain circumstances and purposes.

Let us recall the Supposition (2.1):

Supposition (2.1)

Anytime we use the quality concept there is an actor that carries out an action with the help of a means. Quality is said in relation to means to carry out actions.

Of course, the actor the supposition speaks of is not a concrete individual; it is a type of actor. Specifically:

Definition (3.1) [Actor]

An actor is a type defined by a set of circumstances and purposes—or, better, by a set of propositions about circumstances and propositions about purposes. A token is of that type if some conditions on the propositions are fulfilled—e.g., if all of them are true of the token.

We focus on which (type of) means from a set of alternative means should be chosen given the circumstances and purposes that define the actor. Recall that each means is constituted by a partial end and a way to achieve it (in terms of moves, technology, contents and auxiliary actors); the means purports to achieve a primary end associated to the action mentioned in Supposition (2.1).

Let us assume that there is somebody (whom I will call 'the analyst') that gathers information and makes judgments about the previous aspects. The analyst's objective is to make a quality attribution:

Definition (3.2) [Quality attribution]

A quality attribution is an ordering of a set of alternative means according to their quality. Making a quality attribution is tantamount to figure out which alternative means in the set should be preferred by an actor according to its circumstances and purposes.

I do not assume that the analyst is omniscient; it is a normal person with bounded cognitive capabilities. Of course, if needed, I can assume that the analyst is right, simply by hypothesis—but this is not a rule of our setting. He (or she) has to order the set of alternatives according to some available information on the abovementioned elements which is relevant in order to make the quality attribution.

Let us call this collection of elements 'a problem'. One result of this thesis is that quality is not subjective (it does not depend on the actor's beliefs and desires), but it is relative to a problem. The same means (the same product or service) analyzed under the perspective of two different problems may have different quality. As a summary:

Definition (3.3) [Problem for a quality attribution]

A problem is determined by:

(a) An actor defined by circumstances and purposes.
(b) A primary end.
(c) A partial end to the primary end.
(d) A set of alternative means that have the partial end in common but differ in the ways to achieve it.

In Chapter 4 we shall see that the means in the set of alternative means have to be comparable. In fact, in practical situations some means in the set can be useful to other relevant ends (e.g., a smartphone can be compared with a cell phone in relation to the phone call function and some other features, but it helps to make much more things); we will see that how such kinds of complexities are managed in a quality attribution entirely depends on how the problem is defined.

Notation

In this chapter we study several sorts of preferences concerning means to do things—i.e., from preference relations on the bare set of alternative means to preference relations on multivariate probability distributions associated to each means. I use a simplified notation which is intended to be easily adapted to each case—mathematical rigor and generality have been partly sacrificed to flexibility and suitability to our particular purposes.

I describe the notation for the most general case (preference relations over joint multivariate probability distributions associated to each means); the more basic cases are straightforward simplifications of this one:

(i) [Set of means $\mathcal{M}$] Preference relations will be initially defined on a set $\mathcal{M} = \{x, y, \dots, x', y', \dots\}$ of alternative means to carry out an action. If not specified otherwise, the set of means can be taken to be finite in most occasions.

(ii) [Set of multivariate consequences $\boldsymbol{Z} = Z_1 \times \ldots \times Z_n$] A multivariate consequence $(z_1, \ldots, z_n) = \boldsymbol{z} \in \boldsymbol{Z}$ occurs when a means $x \in \mathcal{M}$ is used, in some fixed circumstances, to carry out a given action.

(iii) [Attribute] Each set $Z_1, \ldots, Z_1$ is an attribute used to assess an aspect of a multivariate consequence. Each attribute Z_i takes values $z_i, z_i', z_i'' \ldots$ Attributes can be uncountable sets.

(iv) [Simple probability distributions p_i] A simple probability distribution is a function $p: Z \to [0,1]$ such that $p(z) \neq 0$ for *at most* finitely many $z \in Z$ and $\sum_{z \in Z} p(z) = 1$. Simple probability distributions concentrate mass on a finite subset of Z (Kreps 1988). Actually, we consider n simple probability distributions p_i defined on Z_i such that conditional probabilities like $p_i(z_i|z_1, \ldots, z_{i-1,}z_{i+1,} \ldots, z_n)$ are defined. Notation $p_i(z_i)$ is taken to be an abbreviation (of a sum of conditional probabilities) according to the calculus of probability.

(v) [Joint probability distribution $\boldsymbol{p}$] A joint (multivariate) probability distribution is a function $\boldsymbol{p}: \boldsymbol{Z} \to [0,1]$ with $\boldsymbol{Z} = Z_1 \times \ldots \times Z_n$ such that $\boldsymbol{p}$ depends on each simple probability distribution p_i defined on $Z_i, i = 1, \ldots, n$, according to the calculus of probabilities—chain rule and factorization from the definition of conditional probability. Joint probability distributions are defined on the basis of conditional probabilities like $p_i(z_i|z_1, \ldots, z_{i-1,}z_{i+1,} \ldots, z_n)$; by contrast, simple distributions conceived on the basis of non-conditional probabilities $p_i(z_i)$ (sums of conditional probabilities, actually) will be interpreted as marginal distributions.

(vi) [Set of joint probability distributions $\boldsymbol{P}$ for a set of multivariate consequences $\boldsymbol{Z}$] Let $\boldsymbol{P}$ be the set of all the joint probability distributions given $\boldsymbol{Z} = Z_1 \times \ldots \times Z_n$. Thus for any $\boldsymbol{p}: \boldsymbol{Z} \to [0,1]$ we have that $\boldsymbol{p} \in \boldsymbol{P}$.

(vii) [Set of simple probability distributions P_i for an attribute Z_i] Let P_i be the set of all the simple probability distributions for an attribute Z_i. That is, for any $p_i: Z_i \to [0,1]$ we have that $p_i \in P_i$.

(viii) $p_i(z_i)$ is a probability; namely the probability that the attribute Z_i takes the value z_i.

(ix) $\boldsymbol{p}(z_1, \ldots, z_n)$ or $\boldsymbol{p}(\boldsymbol{z})$ is also a probability; namely the probability that the multivariate consequence $\boldsymbol{Z}$ is $\boldsymbol{z} = (z_1, \ldots, z_n)$.

We shall begin with a generic case (choices on an arbitrary set $\mathcal{M}$ of alternatives); then we will turn to consider univariate consequences Z of elements in $\mathcal{M}$ and (simple) probability distributions over these consequences. Later on we shall consider the multivariate case: multivariate consequences $\boldsymbol{Z} = Z_1 \times \ldots \times Z_n$ with n attributes and joint multidimensional distributions on these attributes, taken as belonging to $\boldsymbol{P}$.

In summary, the issue in this chapter is how to order different sorts of sets—namely $\mathcal{M}$, P, and $\boldsymbol{P}$. Ultimately, each means in $\mathcal{M}$ will be mapped to a joint distribution in $\boldsymbol{P}$, thus preference relations over $\mathcal{M}$ will depend on preference relations over $\boldsymbol{P}$. Therefore, the multidimensional case will be our default case in the analysis of the quality concept in Chapter 4.

PREFERENCE ORDERINGS AND CHOICE FUNCTIONS

Preferences

Now we are going to study the main concept behind the analyst's task: what a preference relation on a set of means is. The concept of preference relation presented here is quite standard; formally, it makes no difference whether the relation orders $\mathcal{M}$ according to what a decision maker prefers or according to what it should prefer. Of course, later I shall interpret this ordering as '--- has better quality than ---', but for the time it is not necessary to dwell on that. Apart from the standard definition, below I also consider an alternative formalization by Ariel Rubinstein, which is interesting considering our purposes.

Definition (3.4) [Preference relation]

A preference relation on $\mathcal{M}$ is a binary relation $\succsim \subseteq \mathcal{M} \times \mathcal{M}$ satisfying the following two conditions:

(1) Completeness. For any $x, y \in \mathcal{M}$, $x \succsim y$ or $y \succsim x$. That is, any element of $\mathcal{M}$ relates to, at least, another element.

(2) Transitivity. For any $x, y, z \in \mathcal{M}$, if $x \succsim y$ and $y \succsim z$, then $x \succsim z$.

Strict preference is commonly written $x \succ y$ and corresponds to the case in which $x \succsim y$ and not $y \succsim x$. Indifference is commonly written $x \sim y$ and corresponds to the case in which $x \succsim y$ and $y \succsim x$.

If $\succsim$ is complete and transitive then other elementary properties hold for $\succ$ and $\sim$ (Mas-Colell, Winston and Green 1995):

(3) $\succ$ is irreflexive and transitive, that is, it is never the case that $x \succ x$ and if $x \succ y$ and $y \succ z$, then $x \succ z$.

(4) $\sim$ is reflexive, symmetric and transitive (and hence it is an equivalence relation; we can build equivalence classes on the basis of indifference). That is, it is always the case that $x \sim x$ (reflexivity), if $x \sim y$ then $y \sim x$ (symmetry) and if $x \sim y$ and $y \sim z$, then $x \sim z$.

(5) If $x \succ y$ and $y \succsim z$, then $x \succ z$.

A preference relation is non-satiated if there is not any element $x \in \mathcal{M}$ such that for any $y \in \mathcal{M}, x \succsim y$. Otherwise it is satiated and x is a satiation point.

Since in most cases we consider that $\mathcal{M}$ is finite, in principle we assume that the preference relation $\succsim$ ('the actor should prefer x to y or be indifferent between them') is satiated, so there is one or more means that are the best choice for the actor. Quite arbitrarily, in general I shall assume that at least two means in $\mathcal{M}$ are not indifferent.

An alternative formalization of the preference concept is interesting to our purposes. Rubinstein (2006) defines a preference on a set $\mathcal{M}$ as a function $f(\cdot)$ that assigns to any pair (x, y) of distinct elements of $\mathcal{M}$ one of the three "values" $x \succ y$, $y \succ x$, or I, in such a way that the following two conditions hold:

(6) No order effect. $f(x, y) = f(y, x)$.

(7) Transitivity. If $f(x, y) = x \succ y$ and $f(y, z) = y \succ z$, then $f(x, z) = x \succ z$, and if $f(x, y) = I$ and $f(y, z) = I$, then $f(x, z) = I$

The alternative formalization, as Rubinstein demonstrates, is equivalent to the previous one if I is interpreted as indifference. In some sense, this formalization moves the emphasis from an intrinsic relation between elements of $\mathcal{M}$ (somehow similar to an intrinsic structure of $\mathcal{M}$) to an external judgment about any two pairs of elements in $\mathcal{M}$.

In accordance, in our interpretation of the quality concept in terms of preference orderings on a set of alternatives, there is no need to assume that quality is something inherent to the set of alternatives independently of any contextual factor. We are more interested in ordering the set of alternatives on the basis of an external judgment (that of the analyst) built on contextual elements defined in a problem.

Choice Functions and Revealed Orderings

The induced choice function by a preference relation $\succsim$ on $\mathcal{M}$ is a function $C_{\succsim}$ (or simply C if there is no confusion) that assigns to every nonempty set $A \in \mathcal{P}(\mathcal{M})$, where $\mathcal{P}(\mathcal{M})$ is the power set of $\mathcal{M}$, the elements of A that should be preferred by the actor according to $\succsim$. A choice function is actually a correspondence: it is a rule defined on a set of sets that returns a set. The set $C(A)$ is not necessarily a singleton (a set with only one element), since there can be many elements that are indifferent from a satiation point.

For any $x \in \mathcal{M}$, if $x \in C(A)$, we say that x is chosen from A. In general, of any element $y \in A$ we say that y could have been chosen from A. Now I am going to build two relations upon these concepts. The first relation is

written xVy and can be read 'x is revealed to be at least as good as y'; it is defined as follows:

$$xVy \Leftrightarrow \text{there is an existing } A \in \mathcal{P}(\mathcal{M}) \text{ such that } y \in A \text{ and } x \in C(A)$$

That is, x is revealed to be at least as good as y if and only if y could have been chosen from A and x is chosen from A. Notice than in the relation V it is possible for element y to belong also to $C(A)$. The second relation is written xSy and can be read 'x is revealed to be strictly better than y'; it is defined as follows:

$$xSy \Leftrightarrow \text{there is an existing } A \in \mathcal{P}(\mathcal{M}) \text{ such that } y \in A \text{ and } x \in C(A) \text{ and } y \notin C(A)$$

That is, x is revealed to be strictly better than y if and only if x is chosen from A and y could have been chosen from A but it has not been chosen.

Given the relations V and S, we can define two indirect relations V^* and S^* in the following way:

$$x\ V^* y \Leftrightarrow x\ V z_1\ V\ z_2\ V\ \ldots\ V\ z_k\ V\ y$$
$$x\ S^* y \Leftrightarrow x\ S\ z_1\ S\ z_2\ S\ \ldots\ S\ z_k\ S\ y$$

for $x, y, z_1, \ldots, z_k \in A$. We say that x is indirectly revealed to be at least as good as y and that x is indirectly revealed to be strictly better than y, respectively. Each one of the following two statements is equivalent to the claim that $C(\cdot)$ is induced by a complete and transitive reference relation (Border 2011):

(a) [V^*-axiom] For every $A \in \mathcal{P}(\mathcal{M})$, if $x \in A$ and for all $y \in A$ it is the case that $x\ V^* y$, then $x \in C(A)$

(b) [Congruence axiom] For every $A \in \mathcal{P}(\mathcal{M})$ and every $x, y \in A$, if $y \in C(A)$ and $x\ V^* y$ then $x \in C(A)$

The choice function $C(\cdot)$ is said to satisfy the weak axiom of revealed preference if and only if the relations V and S that have been defined with it satisfy:

$$\text{For } x, y \in \mathcal{M}, \text{ if } xVy \text{ then it is not the case that } ySx$$

That is, the condition says that if x is revealed to be at least as good as y, then y is not revealed to be strictly better than x. An equivalent formulation says that for $x', y' \in \mathcal{M}$, if $x'Sy'$ then it is not the case that $y'Vx'$ (in order to see it, just consider $x' = y$ and $y' = x$ in the previous formulation). The equivalent condition says that if x' is revealed to be strictly better than y', then y' is not revealed to be at least as good as x'.

The choice function $C(\cdot)$ satisfies the strong axiom of revealed preference if and only if:

For $x, y \in \mathcal{M}$, if xS^*y then it is not the case that yS^*x

That is, the condition says that if x is indirectly revealed to be strictly better than y, then y is not indirectly revealed to be strictly better than x (Border 2011).

The usual interpretation of revealed preferences is that they allow inferring the decision maker's preference ordering on the basis of his actual choices. I interpret choice functions and revealed preferences not as indications of what an actor prefers, but as a way to infer, from the analyst's external judgments about what the actor should do, which alternative can be considered better given certain circumstances and purposes.

That is, if we assume that the analyst has enough information, his judgments that given two means $x, y \in \mathcal{M}$, x reveals to be at least as good as y given the problem posed, lead us to infer (under certain conditions) that x has the same or greater quality than y. Again, the point is that quality is not an intrinsic property of the means in $\mathcal{M}$, but the result of an external judgment (taking a problem into account) that *reveals* a quality attribution.

In a sense, the most intuitive formulation of the decision-theoretic aspects of the quality concept perhaps would be in terms of choice functions, not of utility functions—the most developed approach in decision theory. The V^*-axiom, the congruence axiom, and the weak and strong axioms of revealed preferences are examples of conditions that choice functions should fulfill in order to adequately model *correct* quality attributions—that is, not any arbitrary preference ordering would be valid, even when it is actually hold by a consumer.

UTILITY REPRESENTATIONS AND EXPECTED UTILITY

Utility Representations

A function $u: \mathcal{M} \to \mathbb{R}$ is a utility function representing a preference relation $\succsim$ if, for any $x, y \in \mathcal{M}$, $x \succsim y$ if and only if $u(x) \geq u(y)$. As we are going to see, a preference relation can be represented by a utility function only if it is complete and transitive, but the converse is not true: in general, not all complete and transitive preference relation can be represented by a utility function (Mas-Colell, Winston and Green 1995). Simplifying the question, basically it depends on the character of the set $\mathcal{M}$ on which the relation is defined—whether it is finite, infinite countable, or uncountable (Kreps 1988).

Let **u** be the following condition:

For any $x, y \in \mathcal{M}$, $x \succsim y$ if and only if $u(x) \geq u(y)$ $(\mathbf{u})$

(a) $\mathcal{M}$ is a finite set. A binary relation is a preference relation if and only if there is a function $u: \mathcal{M} \to \mathbb{R}$ such that condition $\mathbf{u}$ holds.

(b) $\mathcal{M}$ is an infinite countable set. A binary relation is a preference relation if and only if there is a function $u: \mathcal{M} \to \mathbb{R}$ such that condition $\mathbf{u}$ holds.

(c) $\mathcal{M}$ is an uncountable set. If there is a function $u: \mathcal{M} \to \mathbb{R}$ such that condition $\mathbf{u}$ holds then $\succsim$ is a preference relation. The reverse is not true.

If they exist, utility functions (functions for which condition $\mathbf{u}$ holds) are unique up to strictly increasing transformations. That is, if $f(\cdot)$ is a strictly increasing function, then $f\big(u(x)\big)$ is also a new utility function representing the same preference relation as $u(x)$ (Mas-Colell, Whinston and Green 1995).

A counter-example for the hypothetical reverse implication of case (c) is provided by the lexicographic preference relation. Let $\succ$ be a preference relation on an uncountable set X with a total order $(X, >)$. Relation $\succ$ is defined by:

$$(x', y') \succ (x, y) \text{ if and only if } [x' > x \text{ or } (x' = x \text{ and } y' > y)]$$

The principle behind lexicographic preferences is straightforward: the first coordinates are decisive unless they are equal; in such case the second coordinate becomes decisive. That is, the first letter of two words is decisive to order them alphabetically, unless it is the same letter; in this case the second letter becomes decisive—hence the name 'lexicographic preferences'. A simple proof that lexicographic preferences (despite being generated by a quite common and familiar procedure) do not have a utility representation can be found in Rubinstein (2006) or, for a more detailed proof (but based on similar ideas), Kreps (1988).

Even though in most case we assume $\mathcal{M}$ to be finite, let us briefly explain the uncountable case. For the sake of simplicity, in order to explain the concept of continuity in an intuitive way, let us assume that each element in $\mathcal{M}$ can be associated to a real number. We say that a preference relation $\succsim$ on $\mathbb{R}$ is continuous if for any sequence of pairs (x_n, y_n) such that $x_n \succsim y_n$ (with $x_n, y_n \in \mathbb{R}$ for $n = 1, \ldots, \infty$), then for

$$x = \lim_{n \to \infty} x_n \text{ and } y = \lim_{i \to \infty} y_n$$

we have $x \succsim y$.

An alternative but equivalent definition of continuity says that a preference relation $\succsim$ on $\mathcal{M}$ is continuous if for all $x \in \mathcal{M}$ the set $\{y \in \mathcal{M} \mid y \succsim$

$x\}$ includes its boundaries, and the set $\{y \in \mathcal{M} | \, x \succsim y\}$ also includes its boundaries (Debreu 1959). (Note that, strictly speaking, this implies some topological properties of $\mathcal{M}$; the reader can think of consequences assessed using real numbers).

Now we can complete the uncountable case:

(d) $\mathcal{M}$ is an uncountable set. Existence theorem (Debreu's theorem): if a binary relation is a continuous preference relation on $\mathcal{M}$ then there is an existing continuous function $u: \mathcal{M} \to \mathbb{R}$ such that condition $\mathfrak{u}$ holds.

A proof can be found in any introductory text, for instance Mas-Colell, Whinston and Green (1995), Kreps (1988) or Rubinstein (2006).

Non-continuous preference relations on uncountable sets of alternatives can barely be the case in the context of quality: non-continuity implies "jumps" in the preference relation. A simple example in the quality context will help us illustrate this point.

Let X (a set of alternatives) be the set of ways in which a very simple pastry with flour, salt and water can be cooked. Each element of the set of alternatives can be designated by a pair (x, y) where x is the proportion of flour and y the proportion of salt—the proportion of water is the rest. Strictly speaking, X is an uncountable set, since $X = \{(x, y) | x, y \in (0,1), x + y < 1\}$. Let us assume that quality is dependent only of the two attributes x and y—setting aside factors such as components' temperature, components' quality, mixing technique, mixing time, and so on.

A non-continuous preference relation would mean, for instance, that there is at least one combination of ingredients $(a, b) \in X$ such that given any other combination $(s, t) \in X$ we have that $(a, b) \succ (s, t)$ and for some real numbers $\varepsilon, \varepsilon' \in \mathbb{R}$ as small as we want, we also have that $(a + \varepsilon, b + \varepsilon') \succ (s, t)$, but:

$$(s, t) \succ \left(a + \frac{\varepsilon}{2}, b + \frac{\varepsilon'}{2} \right)$$

If this happens, then the preference relation $\succ$ would be non-continuous.

Of course, this sort of situations is highly implausible for most cases of quality attributes. Therefore, we can assume that utility functions over means to carry out actions exist in any or almost any relevant case—even when consequences in $\mathbb{R}$ or $\mathbb{R}^n$ are taken into account. However, such utility representations would exist only if a suitable preference relation on the set of means actually existed. We will see (in the discussion of Arrow's impossibility theorem found below), that there are strong arguments to defend that, given partial preferences on attributes, an aggregated preference relation cannot be built unless some sacrifices are made.

Probability Distributions and Lotteries

Up to now, consequences were deterministic and implicit in the choice of each $x \in \mathcal{M}$. In this subsection, preference relations are defined on a choice set P of probability distributions defined on a set of consequences Z. In Chapter 4 we will need a way to link probability distributions with the alternative means. For the moment, the simple intuition that the use of each means in $\mathcal{M}$ involves some consequences that are subject to variability will suffice.

Each probability distribution in P is a function $p: Z \to [0,1]$ such that $\sum_{z \in Z} p(z) = 1$. If Z is finite or countable infinite, P will be considered the set of all the probability distributions in Z. When Z is uncountable, we will take P as the set of all simple probability distributions on Z. Recall that a simple probability distribution in Z is a function $p: Z \to [0,1]$ such that $p(z) \neq 0$ for at most finitely many z and $\sum_{z \in Z} p(z) = 1$.

In the context of decision theory probability distributions are oftentimes called 'lotteries' and consequences are called 'prizes'. In the rest of the thesis we will only use 'probability distribution' and 'consequence'. Adopting Rubinstein's (2006) notation (similar to Varian 1992), lotteries are usually taken to have the form

$$\alpha z \oplus (1 - \alpha) z'$$

where the prize $z \in Z$ is realized with probability α and prize z' with probability $(1 - \alpha)$. Given a L -tuple of lotteries $(p_l)_{l=1,\dots,L}$ and a L -tuple of non-negative real numbers $(\alpha_l)_{l=1,\dots,L}$ that sum up to 1,

$$\bigoplus_{l=1}^{L} \alpha_l p_l$$

is the lottery for which $(\bigoplus_{l=1}^{L} \alpha_l p_l)(z) = \sum_{l=1}^{L} \alpha_l p_l(z)$. As a particular case, we can write

$$\alpha p \oplus (1 - \alpha) p'$$

for $p, p' \in P$; that is, for lotteries instead of values in Z.

A degenerated lottery is a probability distribution that assigns probability 1 to a unique prize $z \in Z$; to denote this lottery we write $[z]$. That is, $[z](x) = 0$ for any value $x \in Z$ other than z; accordingly, $[z](z) = 1$.

Expected Utility Representations

We want a representation of a preference relation $\succsim$ on P in a similar way that when alternatives were not specifically probability distributions. By a von Neumann – Morgenstern expected utility representation I mean a function $u: Z \to \mathbb{R}$ such that:

$$p \succsim p' \text{ if and only if } \sum_{z \in Z} p(z) u(z) \geq \sum_{z \in Z} p'(z) u(z)$$

Remember that even when Z is uncountable, we assume that $p(z) \neq 0$ for at most finitely many $z \in Z$; thus the cardinality of Z can be taken to be finite in this context.

Following Rubinstein (2006), I present the von Neumann – Morgenstern expected utility theorem on the basis of two conditions:

(e) Independence. For any $p, p', p'' \in P$ and $\alpha \in (0,1)$,

$$p \gtrsim p' \text{ if and only if } \alpha p \oplus (1-\alpha)p'' \gtrsim \alpha p' \oplus (1-\alpha)p''$$

(f) Continuity (for the case of lotteries). Let us consider $p, q \in P$ as vectors in $[0,1]^{|Z|} \subset \mathbb{R}_+^{|Z|}$, where $|Z|$ is the cardinality of Z. As in the case of $\mathcal{M}$ or the consequences in Z, if $p \succ q$, then there are neighborhoods $B(p)$ of p and $B(q)$ of q such that:

$$\text{For all } p' \in B(p) \text{ and } q' \in B(q),\ p' \succ q'$$

Remark (3.5) [Von Neumann – Morgenstern expected utility theorem]

Let $\gtrsim$ be a preference relation on **P** satisfying the conditions of independence and continuity. There are numbers $(v(z))_{z \in Z}$ such that

$$p \gtrsim p' \text{ if and only if } U(p) = \sum_{z \in Z} p(z)\, v(z) \geq U(p') = \sum_{z \in Z} p'(z) v(z)$$

In the context of expected utility theory, I will call functions $v(\cdot)$ 'von Neumann – Morgenstern utility functions', and functions such as $U(\cdot)$ 'expected utility functions'. Notice that functions $v(\cdot)$ represent preference relations on Z, but functions $U(\cdot)$ represent preference relations on P. That is, $v(\cdot)$ order prizes or consequences while $U(\cdot)$ order probability distributions. The proof can also be found in Rubinstein (2006), but it is a core result of decision theory and can be found in most texts about expected utility theory.

As von Neumann – Morgenstern utility functions on prizes are unique up to strictly increasing transformations, expected utility representations are unique up to positive affine transformations—any function consisting in multiplying by a positive number and adding any scalar. Let $\gtrsim$ be the preference relation on P and numbers $(v(z))_{z \in Z}$ as in the expected utility theorem. Defining $w(z) = \alpha v(z) + \beta$ for all $z \in Z$, $\alpha > 0$ and $\alpha, \beta \in \mathbb{R}$, the utility function $W(p) = \sum_{z \in Z} p(z)\, w(z)$ also represents the preference relation $\gtrsim$.

For the analysis of the quality concept, the idea of preference relations defined over probability distributions will be central. Choices between alternative means have to be made on the basis of the consequences of its use. In almost all the interesting cases, consequences have a non-degenerated probability distribution—thus they have variability. There-

fore, choices between means depend on their distributions. In Chapter 4 we will assign a multi-dimensional probability distribution over a set of suitable attributes to each alternative means.

MULTI-ATTRIBUTE DECISIONS AND QUALITY MEASURES

Rationale

Let us assume that a friend of yours, Mr. Smith, wants to give you away an apple tree for your garden—Mr. Smith owns an apple tree planting. You can choose between three different varieties. How would you decide between them? Probably you will ask Mr. Smith about how good are the apples that each variety gives, how much quantity they give, how much irrigation they need, how vulnerable are they to pests and diseases, and so on. Obviously, each one of these decision attributes is subject to uncertainty: each particular tree may show some variability and you do not know how the tree will behave in the future. At any rate, given the attributes of the three varieties you can make your decision, since you have preferences over the multi-dimensional alternatives—that is, given a pair of varieties you should be able to say whether you strictly prefer one of them or you are indifferent.

Now assume that you are Mr. Smith and you want to improve the quality of the apple tree varieties you sell. How would you do that? Probably you will try to find out how good each of the varieties' apples are, how much quantity they give, how much irrigation they need, how vulnerable they are to pests and diseases, and so on. Each one of these attributes is subject to uncertainty and it has, in principle, an improvement direction—in short: more apples, tastier, less irrigation, and less vulnerability. Of course, they will have a joint probability distribution—which will almost surely be quite different to the simple aggregation of their marginal distributions, since attributes almost surely will not be independent. If you obtain varieties with better joint distributions of the attributes (normally, 'better' will also mean with less variability in the marginal distributions), you will obtain better quality varieties.

Intuitively, quality attributions can be understood in terms of multi-attribute decisions under uncertainty. In some sense, they are two sides of the same coin. Of course, that's not to say that any multi-attribute decision under uncertainty can be understood in terms of quality attributions. This thesis is a discussion about the several conditions that must hold to identify quality orderings to multi-attribute preferences under uncertainty.

Let $\succsim$ be a preference relation on $\boldsymbol{P}$. Of course, previous developments are useful in order to think of a utility function that represents $\succsim$. In particular:

(a) Provided that for any $\boldsymbol{p}, \boldsymbol{p}' \in \boldsymbol{P}$, $\boldsymbol{p} \succsim \boldsymbol{p}'$ if and only if $U(\boldsymbol{p}) \geq U(\boldsymbol{p}')$, we know that $U(\cdot)$ is a utility representation of $\succsim$.

(b) There are $(u(\boldsymbol{z}))_{\boldsymbol{z}\in\boldsymbol{Z}}$ such that

$$\boldsymbol{p} \succsim \boldsymbol{p}' \text{ if and only if } U(\boldsymbol{p}) = \sum_{z\in Z} \boldsymbol{p}(\boldsymbol{z})\, u(\boldsymbol{z}) \geq U(\boldsymbol{p}') = \sum_{z\in Z} \boldsymbol{p}'(\boldsymbol{z}) u(\boldsymbol{z})$$

We will assume that the theorem is valid under similar conditions that in the unidimensional case (as it is, actually); the proof and other details are not relevant to our discussion—a summary can be found in Fishburn (1968, 1970).

The main problem we explore in this section is how to express the utility functions $u(\boldsymbol{z})$ (for any $\boldsymbol{z} \in \boldsymbol{Z}$) as functions of the attributes in which is $\boldsymbol{z} \in \boldsymbol{Z}$ is assessed. Therefore, we want to find $f, u_1(\cdot), \dots, u_n(\cdot)$ such that:

$$u(\boldsymbol{z}) = u(z_1, \dots, z_n) = f[u_1(z_1), \dots, u_n(z_n)\,]$$

Note that I have perpetrated a serious abuse of notation, since I have used the same symbol '$\succsim$' for three different preference relations, defined in different sets. From now on I will distinguish between a preference relation defined on multi-dimensional joint probability distributions ($\succsim_Q$), a preference relation defined on consequences (or n-tuples of attributes; $\succsim_q$), and a preference relation defined on unidimensional attributes attributes ($\succsim_i$).

Preferences over multivariate probability distributions	$\boldsymbol{p} \succsim_Q \boldsymbol{p}'$	$\boldsymbol{p}, \boldsymbol{p}' \in \boldsymbol{P}$
Preferences over (multidimensional) consequences	$\boldsymbol{z} \succsim_q \boldsymbol{z}'$	$\boldsymbol{z}, \boldsymbol{z}' \in \boldsymbol{Z}$
Preferences over attributes	$z_i \succsim_i z_i'$	$z_i, z_i' \in Z_i, i \in \{1, \dots, n\}$

Independence Concepts and Multi-Attribute Utility Functions

I am going to review three kinds of independence conditions between attributes: additive (or value) independence, preferential independence and utility independence (Keeney 1992).

(1) Preferential independence. A pair of attributes $\{Z_1, Z_2\}$ is preferentially independent of other attributes $Z_3, \dots, Z_n$ if the preference relation between $\boldsymbol{z}, \boldsymbol{z}' \in \boldsymbol{Z}$ only depends on changes in the levels of Z_1 and Z_2 and does not depend on the levels at which $Z_3, \dots, Z_n$ are fixed.

(2) Utility independence. Attribute Z_1 is utility independent of attributes $Z_2, \dots, Z_n$ if the preference relation for $\boldsymbol{p}, \boldsymbol{p}' \in \boldsymbol{Z}$ is such that only depends on changes in the level of Z_1 (taking its probability into account) and does not depend on the levels at which $Z_2, \dots, Z_n$ are fixed.

(3) Additive independence. Attributes $Z_1, \dots, Z_n$ are additive independent if the preference relation on $\boldsymbol{P}$ does not depend on the joint distributions but only on their marginal probability distributions $p_i \in P_i$. That is, for $\boldsymbol{p}, \boldsymbol{p}' \in \boldsymbol{P}$, if $\boldsymbol{p} \succsim_Q \boldsymbol{p}'$ only in virtue of the marginal distributions $p_1, \dots, p_n, p_1', \dots, p_n'$ then attributes $Z_1, \dots, Z_n$ are additive independent. In this case we interpret each p_i as a marginal distribution, in the sense of a sum of conditional probabilities like $p_i(z_i|z_1, \dots, z_{i-1,} z_{i+1,} \dots, z_n)$.

With these independence concepts, we can present some results on the existence of mathematically treatable utility functions expressed in terms of partial utility functions on attributes.

Given attributes $Z_1, \dots, Z_n$, $n \geq 2$, the following function (called 'multilinear utility function')

$$\begin{aligned} u(z_1, \dots, z_n) = & \sum_{i=1}^{n} k_i\, u_i(z_i) \\ & + \sum_{i=1}^{n} \sum_{j>i}^{n} k_{ij}\, u_i(z_i) u_j(z_j) \\ & + \sum_{i=1}^{n} \sum_{j>i}^{n} \sum_{h>j}^{n} k_{ijh}\, u_i(z_i) u_j(z_j) u_h(z_h) + \cdots \\ & + k_{1\cdots n} u_1(z_1) \dots u_n(z_n) \end{aligned}$$

exists if and only if each Z_i, $i \in \{1, \dots, n\}$ is utility independent of other attributes, where $u_i(\cdot)$ is a utility function on Z_i and the values k are scaling constants (Keeney 1992).

Given attributes $Z_1, \dots, Z_n$, $n \geq 2$, the following function (called 'additive utility function')

$$u(z_1, \dots, z_n) = \sum_{i=1}^{n} k_i\, u_i(z_i)$$

exists if and only if the attributes are additive independent, where $u_i(\cdot)$ is a utility function on Z_i and the values k are a scaling constants (Keeney 1992).

Given attributes $Z_1, \dots, Z_n$, $n \geq 3$, the following function (‡)

$$\begin{aligned} u(z_1, \dots, z_n) = & \sum_{i=1}^{n} k_i\, u_i(z_i) \\ & + k \sum_{i=1}^{n} \sum_{j>i}^{n} k_i\, k_j u_i(z_i) u_j(z_j) \\ & + k^2 \sum_{i=1}^{n} \sum_{j>i}^{n} \sum_{h>j}^{n} k_i k_j k_h\, u_i(z_i) u_j(z_j) u_h(z_h) + \cdots \\ & + k^{n-1} k_1 \dots k_n u_1(z_1) \dots u_n(z_n) \end{aligned}$$

exists if and only if $\{Z_1, Z_i\}$, $i \in \{2, \dots, n\}$ is preferentially independent of the other attributes, and if Z_1 is utility independent of the other attributes,

where $u_i(\cdot)$ is a utility function on Z_i, $i \in \{1, \dots, n\}$, and the values k are scaling constants (Keeney 1992). The constant k in the function (‡) can be calculated: if $\sum_{i=1}^{n} k_i = 1$ then $k = 0$; if $\sum_{i=1}^{n} k_i \neq 1$ then $k \neq 0$.

When $k = 0$, function (‡) is the additive utility function. When $k \neq 0$, the function (‡) is the following one (called 'multiplicative utility function'):

$$ku(z_1, \dots, z_n) + 1 = \prod_{i=1}^{n} [kk_i u_i(z_i)]$$

Notice that the result based on the existence of (‡) only can be applied if $n \geq 3$. For $n = 2$ there is the following case: given two mutually utility independent attributes Z_1, Z_2 then

$$u(z_1, z_2) = k_1 u_1(z_1) + k_2 u_2(z_2) + (1 - k_1 - k_2) u_1(z_1) u_2(z_2)$$

where $u_i(\cdot)$ is a utility function on Z_i and the values k are scaling constants (Keeney 1992).

At first sight, independence assumptions seem quite implausible in the contexts that are relevant to this thesis. In actual cases, attributes almost never will be independent. This is not good for any independence assumption, but clearly for the most basic one, additive independence. Nonetheless, notice that the lack of independence does not necessarily cause orderings to change—the correlation can be not high enough to change preferences. The plausibility of independence assumptions should be assessed for each case, but it cannot be automatically discarded from the existence of dependence between attributes.

Nonetheless, two problems arise: (1) independence assumptions are not guaranteed in general, thus (relatively) mathematically treatable utility functions are not guaranteed either; (2) even though multilinear, additive or multiplicative functions could be obtained, they are treatable in a rather relative sense—i.e., the scaling constants can be hard to establish in most complex cases. In the next subsection, we see that utility functions could be used in principle to represent quality attributions; however, as a practical project this seems to be arduous: in actual cases there would be a large number of highly correlated quality attributes with relative weights difficult to assess.

The Notion of a Quality Measure

Let us assume that there is a set of means and a preference relation on the set of joint probability distributions assigned to each means. If this preference relation $\succsim_Q$ on $\boldsymbol{P}$ admits a utility representation, I am going to interpret such utility function as a quality measure. That is, for any $\boldsymbol{p}, \boldsymbol{p}' \in \boldsymbol{P}$ and any two means

$x, y \in \mathcal{M}$ such that $\boldsymbol{p}$ is the probability distribution for the attributes of x and $\boldsymbol{p}'$ is the probability distribution for the attributes of y, I interpret $\succsim_Q$ and the two relations $\succ_Q$ and $\sim_Q$ (defined in the usual way), in the following manner:

x has equal or higher quality than x if and only if $\boldsymbol{p} \succsim_Q \boldsymbol{p}'$
x has strictly better quality than y if and only if $\boldsymbol{p} \succ_Q \boldsymbol{p}'$
x has the same quality than x if and only if $\boldsymbol{p} \sim_Q \boldsymbol{p}'$

We say that the function $Q(\cdot)$ is a quality measure of $\succsim_Q$ if the following condition holds:

$$\text{for any } \boldsymbol{p}, \boldsymbol{p}' \in \boldsymbol{P}, \boldsymbol{p} \succsim_Q \boldsymbol{p}' \text{ if and only if } Q(\boldsymbol{p}) \geq Q(\boldsymbol{p}') \qquad (1)$$

Therefore, a quality measure is a utility function representing reference preferences.

Under convenient conditions of the von Neumann – Morgenstern expected utility theorem, the quality measure $Q(\cdot)$ is defined in the following way:

$$Q(\boldsymbol{p}) = \sum_{\boldsymbol{z} \in \boldsymbol{Z}} \boldsymbol{p}(\boldsymbol{z}) q(\boldsymbol{z})$$

where $q(\cdot)$ is an utility function representing a preference relation $\succsim_q$ defined on $\boldsymbol{Z}$.

Therefore, the condition (1) can be written:

$$\boldsymbol{p} \succsim_Q \boldsymbol{p}' \text{ if and only if}$$
$$Q(\boldsymbol{p}) = \sum_{\boldsymbol{z} \in \boldsymbol{Z}} \boldsymbol{p}(\boldsymbol{z}) q(\boldsymbol{z}) \geq \sum_{\boldsymbol{z} \in \boldsymbol{Z}} \boldsymbol{p}'(\boldsymbol{z})\, q(\boldsymbol{z}) = Q(\boldsymbol{p}')$$

Our characterization of a quality measure implies a central principle that shall be highlighted:

Supposition (3.6)

Any quality measure has to be a function of attributes—in particular, it has to be a function of quality-related attributes which are relevant to a given quality attribution (see later in Chapter 4).

Supposition (3.6) forces us to express the functions $q(\boldsymbol{z})$ (for any $\boldsymbol{z} \in \boldsymbol{Z}$) as functions of the attributes in which $\boldsymbol{z} \in \boldsymbol{Z}$ is assessed. Thus we want to find $f, u_1(\cdot), \ldots, u_n(\cdot)$ such that:

$$q(\boldsymbol{z}) = q(z_1, \ldots, z_n) = f[q_1(z_1), \ldots, q_n(z_n)]$$

Each function $q_i(\cdot)$ is a utility function that represents a preference relation $\succsim_i$ on each attribute $i \in \{1, \ldots, n\}$. This will be the starting point of our discussion of Arrow's impossibility theorem applied to the quality con-

cept. To be sure, any quality measure $Q(\cdot)$ implies three preference relations and three kinds of functions representing them:

Preferences over multivariate probability distributions	$Q(\boldsymbol{p})$	$\boldsymbol{p} \in \boldsymbol{P}$	$\succsim_Q$
Preferences over (multidimensional) consequences	$q(\boldsymbol{z})$	$\boldsymbol{z} \in \boldsymbol{Z}$	$\succsim_q$
Preferences over attributes	$q_i(z_i)$	$z_i \in Z_i, i \in \{1, \ldots, n\}$	$\succsim_i$

Risk Aversion and the Concavity of Quality Measures

The preference relation $\succsim$ is risk averse if for any probability distribution $p \in P$, it is the case that $[Ep] \succsim p$. Remember that single values are taken as degenerated lotteries $[z]$ in which $[z](z) = 1$. Therefore, $\succsim$ is risk averse if for any probability distribution p the degenerated distribution $[Ep]$ of its expected value is preferred to p.

A preference relation $\succsim$ on P represented by a utility function $u(\cdot)$ is risk averse if and only if $u(\cdot)$ is concave.[16] That is, the implicit risk aversion in a preference relation is closely related to the concavity of the utility function used to compute the expected utility of the distributions it orders. A proof can be found in any textbook in decision theory or microeconomics.

The Jensen inequality says that if $u(\cdot)$ is concave, then for any K-tuple of non-negative real numbers $(\alpha_k)_{k=1,\ldots,K}$ that sum up to 1 it is the case that

$$u\left(\sum_{k=1}^{K} \alpha_k x_k\right) \geq \sum_{k=1}^{K} \alpha_k u(x_k)$$

By the Jensen inequality, for any lottery $p \in P$, the preference relation $\succsim$ on P represented by a utility function $u(\cdot)$ is risk averse if and only if $u(Ep) \geq Eu(p)$, where $E\cdot$ denotes expected values. Notice that from the definition of utility function it immediately follows that $[Ep] \succsim p$.

Thus, for instance, any preference relation that considers the expected value of any lottery (x_1 with probability .5, x_2 with probability .5) as preferable to the lottery itself, it is risk averse (Raiffa and Keeney 1993). Of course, it follows that $u(.5x_1 + .5x_2) \geq .5u(x_1) + .5u(x_2)$ whenever $x_1 \neq x_2$ (in such case the lottery would be degenerated). Therefore, $u(\cdot)$ is concave.

[16] Let us remember that a function $f(\cdot)$ is said to be concave if for any x, y in its domain and a real number t in [0,1], it is the case that $f(tx + (1-t)y) \geq tf(x) + (1-t)f(y)$. A function $f(\cdot)$ is convex if for any x, y in its domain and a real number t in [0,1], it is the case that $f(tx + (1-t)y) \leq tf(x) + (1-t)f(y)$.

Conversely, a preference relation $\succsim$ on P represented by a utility function $u(\cdot)$ is risk prone if and only if $u(\cdot)$ is convex.

Given a preference relation $\succsim$ on P, the set of certainty equivalents of the lottery p is the set of prizes (degenerated lotteries) indifferent from p:

$$\mathcal{C}(p) = \{z \in Z | [z](z) \sim p\}$$

A certainty $c(p) \in \mathcal{C}(p)$ equivalent is a "for certain" prize as preferable as p.

Let Ep be the expected value of a probability distribution $p \in P$, that is $Ep = \sum_{z \in Z} p(z)\, z$. The risk premium which is associated to p is

$$rp(p) = Ep - c(p)$$

The term 'risk premium' makes sense because $rp(p)$ could be regarded as the amount that an actor with preferences $\succsim$ would pay to replace p by its expected value (Kreps 1988).

We say that a preference relation $\succsim_1$ on P is more risk averse than a preference relation $\succsim_2$ on P for any lottery $p \in P$ and any degenerate lottery $[Ep] \in P$ (Rubinstein 2006),

$$p \succsim_1 [Ep] \text{ implies that } p \succsim_2 [Ep]$$

If $u_1(\cdot)$ and $u_2(\cdot)$ are von Neumann – Morgenstern utility functions representing $\succsim_1$ and $\succsim_2$, an alternative definition says that the preference relation $\succsim_1$ is more risk averse than $\succsim_2$ if the function $\varphi(\cdot)$ is such that $u_1(t) = \varphi\big(u_2(t)\big)$ is concave, for any $t \in Z$. An even more restrictive definition (if $u_1(\cdot)$ and $u_2(\cdot)$ are twice differentiable von Neumann – Morgenstern utility functions) says that the preference relation $\succsim_1$ is more risk averse than $\succsim_2$ if, for all $z \in Z$,

$$r_1(z) = -\frac{u_1''(z)}{u_1'(z)} \geq -\frac{u_2''(z)}{u_2'(z)} = r_2(z)$$

This is the most widely used version in microeconomics, where models generally assume utility functions with convenient mathematical properties.

Remark (3.7)

Risk aversion is a property of preference orderings. A preference ordering can be more or less risk averse than another. This property is inherited by utility functions representing preference relations.

Accordingly, there is no need to speak of risk averse individuals. The concept of risk aversion makes sense even though we do not focus on what individual actors actually prefer but rather on what they should prefer given their circumstances and purposes.

Since quality measures are utility functions, it makes sense to discuss how the notion of risk aversion has to be interpreted concerning quality. The statement that variability is the worst quality enemy implies that for any distribution $\boldsymbol{p}$ associated to a means, the degenerated distribution of its expected value $[E\boldsymbol{p}]$ should always be preferred. This is exactly the definition of risk averse preference relation.

Quality attributes are such that their lack of variability always will be advisable. Since a reproducible type of means is used to carry out an action, it is normally advisable that its consequences can be foreseen as accurately as possible. Therefore, the attribute's expected value will be always preferable to any amount of uncertainty. This is a consequence of the particular sort of means-ends fitness that quality is. Thus:

Remark (3.8) [Conclusion on quality measures]

Quality-driven preferences should be always risk averse.

As a consequence, any quality measure has to be a concave function on the attributes.

ARROW'S IMPOSSIBILITY THEOREM (VERSION ON QUALITY)

Duality between Group and Multi-Attribute Decisions

Kenneth May (1954) argued that, where choice depends on multiple perhaps conflicting criteria (the multi-attribute case discussed in the last section), preference patterns may be intransitive unless one criterion dominates. His argument partly relied on the fact that choice between multi-attribute alternatives can be seen as equivalent to voting situations as studied by Kenneth J. Arrow (1951), and particularly to the Condorcet paradox. Let us assume three candidates x, y and z. Three voters have the following preferences: xyz, yzx, and zxy. If a fourth voter uses the majority rule (to establish his preferences on the basis of candidates voted by the majority in each pairwise comparison), his preferences will be intransitive ($xyzx$), since x is preferred to y in two of three orderings, y is preferred to z in other two orderings, and so on.

Provided that we are comparing three candidates on the basis of three attributes (the votes of each one of the three voters), May noted that the multi-attribute problem can be interpreted as a voting problem. One of May's conclusions was that preferring the best alternative in a majority of attributes in pairwise comparisons may generate intransitive preferences.

In this section I study a well-known result by Arrow (1951) about voting and group decision making, but interpreting it under the lens of our multi-attribute approach to the quality concept. In the first place, I present

the version focused on the quality concept. Secondly I present Arrow's original version.

Our exposition is indebted to Mas-Colell, Whinston and Green (1995). They break down the exposition into two parts (as I do in the ensuing subsection); most expositions focus on the second case, to which the most important result of Arrow (1951) is focused. The source Arrow (1951) has been used as well as complementary material from Fishburn (1968), Luce and Raiffa (1957), Keeney and Raiffa (1993) and Geanakoplos (2005).

Arrow's Theorem: Quality Version

Let $\boldsymbol{Z}$ be a set a set of multidimensional consequences of choice alternatives; the reader can think of them as products or services to use or compare. Let $\{Z_1, \dots, Z_n\}$ be a set of n attributes to assess the consequences; the reader can think of attributes as product features useful to compare them. Consequently, consider $\boldsymbol{Z} = Z_1 \times \dots \times Z_n$. By analogy to the previous section, let us assume that there are preferences associated to each attribute and preferences over alternatives to choose:

Preferences over (multidimensional) consequences	$\boldsymbol{z} \in \boldsymbol{Z}$	$\succsim_q$
Preferences over attributes	$z_i \in Z_i, i \in \{1, \dots, n\}$	$\succsim_i$

Let us assume that we do not know $\succsim_q$ and that we want to define it on the basis of the aggregation of all $\succsim_i$. The aggregation should fulfil certain conditions in order to be satisfactory. This is the basic statement of the problem we will face in this section.

Let us break down the exposition in two different cases: firstly when the set $\boldsymbol{Z}$ has two members, $|\boldsymbol{Z}| = 2$, and we have more than one attribute, $n \geq 2$; secondly when $|\boldsymbol{Z}| \geq 3$ and $n \geq 2$. The simplest case will be useful to understand the problem and implications in the general case.

Case A. $|\boldsymbol{Z}| = 2$ and $n \geq 2$

Let $\boldsymbol{Z} = \{\boldsymbol{z}, \boldsymbol{z}'\}$. Each preference relation $\succsim_i$ orders $\boldsymbol{z}$ and $\boldsymbol{z}'$ according to their values in the respective attribute: $\succsim_1$ for Z_1, $\succsim_2$ for Z_2, ..., $\succsim_n$ for Z_n. Actually, according to each attribute we are able to write whether $\boldsymbol{z} \succsim_i \boldsymbol{z}'$, $\boldsymbol{z} \succ_i \boldsymbol{z}'$, or $\boldsymbol{z} \sim_i \boldsymbol{z}'$, with the relations $\succ_i$ and $\sim_i$ defined as it is usual from $\succsim_i$.

A profile is the n-tuple with the preference according to each one of the n attributes:

$$(\alpha_1, \dots, \alpha_n) \in \{-1,0,1\}^n$$

where:

$$\alpha_i = \begin{cases} -1 \text{ if (according to attribute } i) \ \boldsymbol{z} \text{ is strictly preferred to } \boldsymbol{z}' \\ 0 \text{ if (according to attribute } i) \ \boldsymbol{z} \text{ is indifferent from } \boldsymbol{z}' \\ 1 \text{ if (according to attribute } i) \ \boldsymbol{z}' \text{ is strictly preferred to } \boldsymbol{z} \end{cases}$$

In order to define $\succsim_q$ from preferences $\succsim_i$ we want to find a function $F(\cdot)$ that assigns an overall preference to every possible profile $(\alpha_1, \dots, \alpha_n) \in \{-1,0,1\}^n$ based on attributes.

The most important discussion will be (here and in the general case) about the desirable properties of such function $F(\cdot)$. Let us consider some possible properties of $F(\cdot)$:

(a) $F(\cdot)$ fulfils the *condition of no preeminent attribute* if there is no attribute h such that for any profile $(\alpha_1, \dots, \alpha_n)$, $\alpha_h = 1$ implies $F(\alpha_1, \dots, \alpha_n) = 1$ irrespective of values $\alpha_1, \dots, \alpha_n$ other than α_h; or, likewise, if $\alpha_h = -1$ implies $F(\alpha_1, \dots, \alpha_n) = -1$ irrespective of values $\alpha_1, \dots, \alpha_n$ other than α_h.

(b) $F(\cdot)$ fulfils the *Pareto condition* if it respects equal strict preferences among attributes: $F(1, \dots, 1) = 1$ and $F(-1, \dots, -1) = -1$.

Now notice that the majority criterion (choosing the alternative preferable according to the highest number of attributes) implies a function $F(\cdot)$ that fulfils the Pareto condition and, with only one exception, the condition of no preeminent attribute. The exception occurs when $n - 1$ attributes dictate indifference and the remaining attribute dictates strict preference to one alternative.

Since we take attributes as a guide to choose between $\boldsymbol{z}$ and $\boldsymbol{z}'$, no intransitive preferences can appear. Of course, the majority rule can lead to intransitive orderings if $n \geq 3$—this is the Condorcet paradox, which has already been explained. The associated function to choose the preferable alternative according to the highest number of attributes fulfils other conditions:

(c) $F(\cdot)$ fulfils the *condition of unweighted attributes* (or condition of equally weighted attributes) if positions of α_i in $F(\alpha_1, \dots, \alpha_n)$ can be interchanged and the function's value doesn't change. That is, for any surjective function $\pi: \{1, \dots, n\} \to \{-1,0,1\}$ (surjective means that any i has an h such that $\pi(h) = i$) and any profile $(\alpha_1, \dots, \alpha_n)$ we have that $F(\alpha_1, \dots, \alpha_n) = F\left(\alpha_{\pi(1)}, \dots, \alpha_{\pi(n)}\right)$.

(d) If $F(\alpha_1, \dots, \alpha_n) = F(-\alpha_1, \dots, -\alpha_n)$ then $F(\cdot)$ fulfils the *condition of neutrality*.

(e) $F(\cdot)$ fulfils the *condition of updating* if, whenever $(\alpha_1, \dots, \alpha_n) \geq (\alpha_1', \dots, \alpha_n')$, $(\alpha_1, \dots, \alpha_n) \neq (\alpha_1', \dots, \alpha_n')$ and $F(\alpha_1', \dots, \alpha_n') \geq 0$, we have $F(\alpha_1, \dots, \alpha_n) = +1$. If in a certain moment t' the function $F(\cdot)$ dictates a as preferable or indifferent from b (that is, $F(\alpha_1', \dots, \alpha_n') \geq 0$), and in a mo-

ment $t > t'$ the value of some attributes change in such a way that a becomes more preferable to b (that is, $(\alpha_1, \dots, \alpha_n) \geq (\alpha'_1, \dots, \alpha'_n)$ and $(\alpha_1, \dots, \alpha_n) \neq (\alpha'_1, \dots, \alpha'_n)$), then the overall relation $\succsim_q$ has to take this into account and consider a as strictly preferable to b.

Remark (3.9)

The function that corresponds to the majority rule fulfils the unweighted attributes, neutrality and updating conditions.

In addition, any function that fulfils these three conditions corresponds to the majority rule—see Mas-Colell, Whinston and Green (1995).

One may think that the Condorcet paradox (intransitive preferences as result of the majority criteria when $|\boldsymbol{Z}| \geq 3$), is due to some violation of some of these three conditions in the case of more than two alternatives to choose. Nonetheless, Arrow (1951) demonstrated a result that implies that this is not the cause; hence the Condorcet paradox has nothing to do with unweighted attributes, neutrality or updating conditions. This is important to our purposes, because it means that the result explained in Case B (Arrow's main negative result) holds independently that whether attributes are equally weighted or not—obviously, in the context of quality, attributes are not equally weighted.

Case B. $|\boldsymbol{Z}| \geq 3$ and $n \geq 2$

In the general case, profiles cannot be regarded anymore as members of $\{-1,0,1\}^n$, because preferences over $|\boldsymbol{Z}| \geq 3$ alternatives have much more than the 3 possibilities with 2 alternatives ($a \succ b$, $b \succ a$ or $a \sim b$). Let $\boldsymbol{\mathcal{R}}$ be the set of all possible complete and transitive preference relations on Z. In this notation (similar to that of Mas-Colell,Whinston and Green 1995) profiles are taken as being elements of some set $\boldsymbol{\mathcal{A}} \subset \boldsymbol{\mathcal{R}}^n$, that is, n-tuples of complete and transitive preference relations on Z. Profiles can be denoted by $(\succsim_1, \dots, \succsim_n) \in \boldsymbol{\mathcal{R}}^n$.

As before, in order to define $\succsim_q$ from preferences $\succsim_i$, we need a function $F(\cdot)$ that assigns an overall preference $F(\succsim_1, \dots, \succsim_n) \in \boldsymbol{\mathcal{R}}$ to every possible profile $(\succsim_1, \dots, \succsim_n) \in \boldsymbol{\mathcal{R}}^n$ based on attributes. The most important discussion is about the desirable properties of the function $F(\cdot)$.

We need the concept of strict preference relation derived from $F(\succsim_1, \dots, \succsim_n)$, denoted by $F_p(\succsim_1, \dots, \succsim_n)$. In the same sense that $F(\cdot)$ leads to $\succsim_q$, the function $F_p(\cdot)$ leads to $\succ_q$. That is, for any $\boldsymbol{z}, \boldsymbol{z}' \in \boldsymbol{Z}$, we have:

$\boldsymbol{z} F_p(\succsim_1, \dots, \succsim_n) \boldsymbol{z}'$ if and only if $\boldsymbol{z} F(\succsim_1, \dots, \succsim_n) \boldsymbol{z}'$ but not $\boldsymbol{z}' F(\succsim_1, \dots, \succsim_n) \boldsymbol{z}$

Let us now consider some reasonable properties that $F(\cdot)$ should fulfill.

(f) $F(\cdot)$ fulfils the *condition of no preeminent attribute* if there is no attribute h such that for any two alternatives $\{\boldsymbol{z}, \boldsymbol{z}'\} \subset \boldsymbol{Z}$ and any prefe-

rence profile $(\succsim_1, \ldots, \succsim_n) \in \boldsymbol{\mathcal{A}} \subset \boldsymbol{\mathcal{R}}^n$, we have that $\boldsymbol{z} F_p(\succsim_1, \ldots, \succsim_n) \boldsymbol{z}'$ whenever $\boldsymbol{z} \succ_h \boldsymbol{z}'$. The condition simply says that the function does not consist in using the criteria of only one attribute.

(g) $F(\cdot)$ fulfils the *condition of independence of irrelevant alternatives* if the aggregate preference between any two alternatives $\{\boldsymbol{z}, \boldsymbol{z}'\} \subset \boldsymbol{Z}$ depends only on the preferences according to attributes between these two alternatives $\boldsymbol{z}$ and $\boldsymbol{z}'$, without regard of preferences involving any alternatives in $\boldsymbol{Z}$ other than $\boldsymbol{z}$ and $\boldsymbol{z}'$.

(h) $F(\cdot)$ fulfils the *Pareto condition* if, for any $\boldsymbol{z}, \boldsymbol{z}' \in \boldsymbol{Z}$ and any preference profile $(\succsim_1, \ldots, \succsim_n) \in \boldsymbol{\mathcal{A}} \subset \boldsymbol{\mathcal{R}}^n$, it is the case that $\boldsymbol{z} F_p(\succsim_1, \ldots, \succsim_n) \boldsymbol{z}'$ whenever $\boldsymbol{z} \succ_i \boldsymbol{z}'$ for every $i \in \{1, \ldots, n\}$. The condition simply says that if all the attributes coincide in a strict preference, the aggregate preference must respect it.

The main result we are interested in is the following one:

Remark (3.10) [Arrow's impossibility theorem, quality version]

With $|\boldsymbol{Z}| \geq 3$ and $n \geq 2$, there is no function $F: \boldsymbol{\mathcal{A}} \to \boldsymbol{\mathcal{R}}$ with $\boldsymbol{\mathcal{A}} \subset \boldsymbol{\mathcal{R}}^n$ such that it fulfils the three conditions: Pareto, independence of irrelevant alternatives, and no preeminent attribute.

The result says that there is no way to define $\succsim_q$ on the basis of the n preferences $\succsim_i$ whenever the following three conditions hold:

(1) There is not a preeminent attribute.

(2) Any attribute-based preference between two alternatives only takes these two alternatives into account.

(3) If attribute-based preferences coincide then the final relation preserves the coincidence.

Arguably, these conditions are quite reasonable. In fact, Arrow's theorem says that whenever the aggregated relation $\succsim_q$ satisfies 2 and 3, it has to satisfy 1—it takes one attribute as preeminent. Therefore, if we take for granted 2 and 3, Arrow's theorem does not demonstrate that reference preferences do not exist (and hence that quality measures do not exist), but that reference preferences or quality measures that don't make one attribute preeminent do not exist.

Remark (3.11)

If we are willing to admit the preeminence of only one attribute, this is tantamount to say that quality is not a truly multidimensional concept. This is against most of our intuitions about the quality concept.

Quality and the Hypothesis of Independence of Irrelevant Alternatives

At first sight, the independence of irrelevant alternatives condition seems the best place to conduct an attack—in order to show that Arrow's theorem has not so devastating consequences to the concept of *quality measure*. I use an example from Rubinstein (2006) that he borrows from Luce and Raiffa (1957). Let us consider the preferences in which an actor chooses chicken from the menu {steak tartare, chicken} but chooses steak tartare from the menu {steak tartare, chicken, frog legs}. This could be reasonable if the introduction of frog legs is taken as a signal of restaurant's quality. That is, steak tartare is the choice in a good restaurant; chicken is preferred to steak tartare in a bad restaurant. The hypothesis of independence of irrelevant alternatives is violated because the alternative frog legs indicate that the restaurant is a good one.

The counterexample is interesting because, in addition, it has somewhat to do with quality—quality uncertainty (and signals to reduce this uncertainty) will be an important theme later on, in Chapter 6. It seems that, in actual quality attributions, comparisons are not strictly pairwise, but pairwise with an eye in the rest of alternatives.

The hypothesis of the independence of irrelevant alternatives relates to Sen's α condition.

Definition (3.12) [Sen's α condition]

Let A, B be subsets of a choice set such that $A \subset B$. A choice function $C(\cdot)$ satisfies α condition when if $x \in B$ and $x \in C(A)$ then $x \in C(B)$.

The condition simply states that if an alternative is chosen from a list of alternatives, then it must be chosen from any partial list that has been elaborated from the original one. Thus the choice cannot depend on which alternatives appear in any sub-list.

Sen's α is usually regarded as a necessary condition of rationality. If you choose New York from the set of alternative cities to go on vacation {London, Paris, New York, Berlin, Singapore, Tokio}, it should not be admissible to choose Paris from the set {Paris, New York, Singapore, Tokio}.

To our purposes, the question is: can we think of a case in which the quality of something changes depending on whether there is or there is not another available alternative? It seems quite implausible, since quality is (according to our approach) what an actor should choose according to some suitable attributes. At best, any case of that phenomenon will be better explained by an ill specification of the problem than by a spontaneous change in the quality of something.

That is, probably we would choose chicken from the menu {steak tartare, chicken} and steak tartare from the menu {steak tartare, chicken, frog legs}, but this has nothing to do with the quality of the steak tartare or the chicken. This has to do with how we have posed the problem. Our standards about how to figure out what an actor should choose according to quality attributes and regarding his purposes and circumstances, do not allow (by hypothesis) such specifications.

That's not to say that ill specifications cannot occur in a quality attribution; it is just that they would lead to an incorrect quality attribution. Violations of the hypothesis of independence of irrelevant alternatives do not show a special property of the quality concept, but simply errors in its use.

Arrow's Original Voting Version

In the voting formulation we have $|\boldsymbol{Z}|$ candidates and n voters. If $\boldsymbol{\mathcal{R}}$ is the set of all possible complete and transitive preference relations on the list of $|\boldsymbol{Z}|$ candidates, a preference profile is an element of $\boldsymbol{\mathcal{R}}^n$, that is, an ordering of candidates dictated by each voter. The problem is to find a social choice function $F: \boldsymbol{\mathcal{A}} \to \boldsymbol{\mathcal{R}}$ with $\boldsymbol{\mathcal{A}} \subset \boldsymbol{\mathcal{R}}^n$ such that it returns an ordering between candidates from the preference profile of the n voters.

Three reasonable conditions for a social choice function $F(\cdot)$ are the following:

(i) $F(\cdot)$ fulfils the *condition of non-dictatorship* if there is no voter h such that the social choice function returns h's ordering without regard of other voters.

(j) $F(\cdot)$ fulfils the *condition of independence of irrelevant alternatives* if the social choice function orders two candidates x, y only on the basis of voters' preferences between these two candidates, setting aside preferences about candidates other than x and y.

(k) $F(\cdot)$ fulfils the *Pareto condition* if, whenever all voters coincide in the strict preference of one candidate against other candidate, the social choice function respects that preference.

Arrow's theorem says that, when there are three or more candidates and two or more voters, any social choice function that satisfies the conditions of Pareto and independence of irrelevant alternatives, it is a dictatorship—cannot satisfy non-dictatorship.

There are many proofs of the theorem, apart from Arrow's (1951). Since I've taken as main reference Mas-Colell ,Whinston and Green (1995), their proof can be closer to our exposition in terms of notation. Short and relatively intuitive proofs can be read in Geanakoplos (2005). Another short and intuitive proof appears in Luce and Raiffa (1957).

COGNITIVE BIASES

In the first chapter I have already pointed out some inconveniences of the assumption that if a product is of a good quality then the gap between perceptions and expectations is minimized. The assumption is false when the customer has cognitive biases. A good quality product may be not able to avoid the gap between perceptions and expectations if at least one of them (perceptions or expectations) is biased. Cognitive psychology and behavioral economics have collected large amounts of evidence which demonstrate that such biases are widespread in average population.

People hardly decide according to normative decision theory. People's preference orderings do not always fulfill normative coherence conditions which allow utility functions' definition. Even more evident is the fact that we people make systematic mistakes of probability assessment and belief revision. As Zoë Chance and Michael I. Norton (2009) pointed out in a Harvard Business School working paper entitled 'I read Playboy for the articles – Justifying and rationalizing questionable preferences', humans are masters of self-deception, so their preferences do not necessarily respond to what they should prefer.

I will focus my exposition on four examples which can compromise reasonable decision making: framing biases, conjunction fallacies, intransitivity of multi-attribute preferences, and memory biases. There are many others.

Framing Biases

A framing bias occurs when equal alternatives formulated in different but equivalent ways are evaluated differently. Let us assume two hospitals, A and B. Both institutions have equally competent physicians, procedures and technology. Particularly, both are aware of the best available treatments. In hospital A, doctors explain to people with lung cancer that they can choose between surgery and radiation therapy. They say:

(a) Of 100 people having surgery 90 live through the post-operative period, 68 are alive at the end of the first year and 34 are alive at the end of five years.

(b) Of 100 people having radiation therapy all live through the treatment, 77 are alive at the end of one year and 22 are alive at the end of five years.

In hospital B, doctors inform people with lung cancer about the two available treatments, of course the same:

(c) Of 100 people having surgery 10 die through the post-operative period, 32 die by the end of the first year and 66 dye by the end of five years.

(d) Of 100 people having radiation therapy, none die during treatment, 23 die by the end of one year and 78 die by the end of five years.

There is no actual difference between hospital A and B in relation to treatments against lung cancer. However, significantly less people would choose radiation therapy in hospital A than in hospital B: people evaluate in different ways equal alternatives framed in terms of survival or framed in terms of mortality. Although I have adapted the formulation, choice's statements and general conclusions in this example are taken from Kahneman and Tversky (1986). They notice that "the framing effect was not smaller for experienced physicians or for statistically sophisticated business students than for a group of clinic patients". Statistical details and exact formulations can be found in their work or in McNeil, Pauker, Sox and Tversky (1982).

To provide an additional example, let us assume two web pages, again A and B. They are almost identical by hypothesis. Let us say that the unique difference is how a screen formulates an equivalent choice. In webpage A, the client initially gains $300 just to make the following decision between:

(e) A sure gain of $100.

(f) 50% chance to gain $200 and 50% to gain nothing.

Exactly the same choice is presented in webpage B. The screen says that the client initially gains $500 just to make the following choice:

(g) A sure loss of $100.

(h) 50% chance to lose nothing and 50% to lose $200.

Albeit web pages A and B are actually the same (both screens propose a choice between $400 for sure and an even chance of $300 or $500), users' perceptions are different. Users of webpage A consistently will do risk averse evaluations, while clients of webpage B consistently will do risk seeking evaluations. As before, I have adapted the example to choice's statements and conclusions from Kahneman and Tversky (1986). If the probability of winning or losing is not too small, choices framed in terms of gains are usually risk averse; choices framed in terms of losses are often risk seeking. We people see differences where they do not exist.

Remark (3.13)

Framing biases may cause that two equivalent products or services create different perceptions in the customer. However, nothing actually changes in them as means to achieve an end; both alternatives are actually the same one. In normal cases, they can hardly have different quality. Of course, it is advisable to deliver the product or service which causes most desirable perceptions according to the framing bias, i.e.,

under salability or profitability criteria. However, that's not to say that one alternative has better quality.

Conjunction Fallacies

If quality depends on the gap between perceptions and expectations, we should be sure that people expects reasonable events. If not, poor quality could be caused not by product features but by misguiding expectations. Nonetheless, evidence shows that we people do have misguiding expectations. For instance, the probability of the compound event $A \cap B$ has to be lower than the probability of A. However, in some circumstances people seem to evaluate $A \cap B$ as more likely than A. That is, people would expect $A \cap B$ in a greater degree than A.

Kahneman and Tversky reported a famous experiment in which they explained to the subjects: "Linda is 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations. Please rank the following statements by their probability, using 1 for the most probable and 8 for the least probable". From 8 statements, the best ranked (mean rank of 2.1) was 'Linda is active in the feminist movement'. The second worst ranked (mean rank of 6.2) was 'Linda is a bank teller', being second only to 'Linda is an insurance salesperson' (mean rank of 6.4). The statement 'Linda is a bank teller and is active in the feminist movement' had a mean rank of 4.1, just in the middle of the two components of its conjunction. Experimental details can be found in Kahneman and Tversky (1982).

This result has been replicated in many other experiments (Poulton 1994). Of course, if Linda is a bank teller and is active in the feminist movement, then she is a bank teller. Therefore, the event that Linda is a bank teller should have equal or greater probability than the conjunction. About 85% of students with some acquaintance with statistics commit the conjunction fallacy.

In another experiment, Kahneman and Tversky used a regular six-sided dice with two red faces and four green faces. Subjects were asked to select one from three sequences of reds (R) and greens (G). A reward of $25 (of 1983) was offered if the sequence appeared on 20 successive rolls of the dice. The sequences were: (1) RGRRR, (2) GRGRRR, and (3) GRRRRR. About 65% of the subjects choose (2), despite the fact that (1) is included in it. The sequence RGRRR cannot have lower probability than GRGRRR. Subjects were students of decision sciences at Stanford University and University of British Columbia (Kahneman and Tversky 1983).

Remark (3.14)

Conjunction fallacies occur when a compound event is judged as more probable than one of its component events. The conjunction fallacy is

quite incompatible with consistent expectations—i.e., to evaluate $A \cap B$ as more likely than A is inconsistent. However, experiments show that it is widespread even in people with knowledge of statistics. Good quality products or services may not be able to meet inconsistent expectations.

Intransitivity in Multi-Attribute Preference Orderings

The third case I want to discuss is preferences' intransitivity. In choosing between univariate consequences, normally preferences are transitive. The pioneer paper by Amos Tversky (1969) argued that intransitivity appears when people choose between simple lotteries on these univariate consequences. However, there is no complete agreement about that—see Birnbaum and Gutierrez (2007) for a summary.

Nonetheless, few authors doubt that intransitivity actually arises when alternatives are multivariate probability distributions on (multi-attribute) consequences. As early as in 1940, Kendall and Smith noticed the emergence of circular patterns in paired comparisons between several alternatives. The second experiment in Tversky (1969) showed regular intransitive preferences in choices between pairs of hypothetical college applicants according to three dimensions—percentiles in intellectual ability, emotional stability and social facility.

As remarked above, May (1954) argued that where choice depends on conflicting criteria, preference patterns may be intransitive unless one criterion dominates. The argument relied on the Condorcet paradox on voting and the majority rule. As preferring the best candidate for a majority of voters may yield intransitive preferences, preferring the best alternative in a majority of attributes may generate them as well.

Zhang, Hsee and Xiao (2006) studied the majority rule in individual decisions. They defend that the rule is more likely to be used in the choice of one among several alternatives than in rating each one of the alternatives—that is, in terms interesting to our purposes: heuristics for individuals' quality orderings may not coincide with heuristics for individuals' product choice.

In addition, the majority rule is more likely to be used if the information is displayed by attribute rather than by alternative. The format "the values of attributes X, Y and Z for the alternative A are 7.5, 9.0 and 8.0, for the alternative B are (…)" generate less use of the majority rule than the format "attribute X's values for alternatives A and B are 7.5 and 8.0, attribute Y's values for alternatives A and B are (…)". Again, psychological rules for quality orderings may not coincide with rules for product choice, because attributes are not necessarily considered in the same way in each

case—nonetheless, we would say that better products in a quality ordering should be the products chosen according to quality criteria.

In any way, experimental evidence suggests that the majority rule (to look at which option is best at most of the available attributes) is widely used as an intuitive choice criterion among multi-attribute alternatives. The rule may generate cycles even if preferences according to each separate attribute were transitive.

In addition, attributes' aggregation and unpacking significantly affects the use of the majority rule. There is a certain amount of evidence that shows that the weight that different attributes receive depends on how they are partitioned (Fischoff, Slovic and Lichtenstein 1978; Weber, Eisenführ and von Winterfeldt 1988; Martin and Norton 2009; Zhang, Hsee and Xiao 2006). Accordingly, changes in how judges categorize attributes (or changes on how attributes are considered) may yield cyclical preferences.

Remark (3.15)

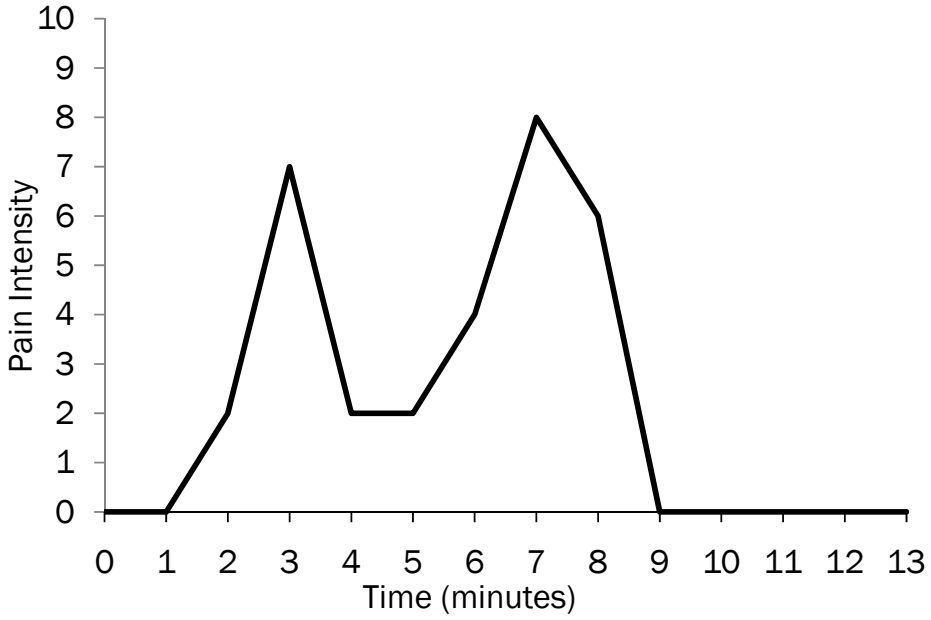
Quality depends on multiple attributes under uncertainty. In such settings, there is a wide agreement that people's actual preferences may be intransitive. If quality depends on individual's psychological preferences, it is possible for product A to have a strictly better quality than product B, product B to have strictly better quality than product C, but product C a strictly better quality than product A. Of course, this contradicts all our intuitions about the quality concept. Therefore, quality cannot depend on individual's psychological preferences.

Memories

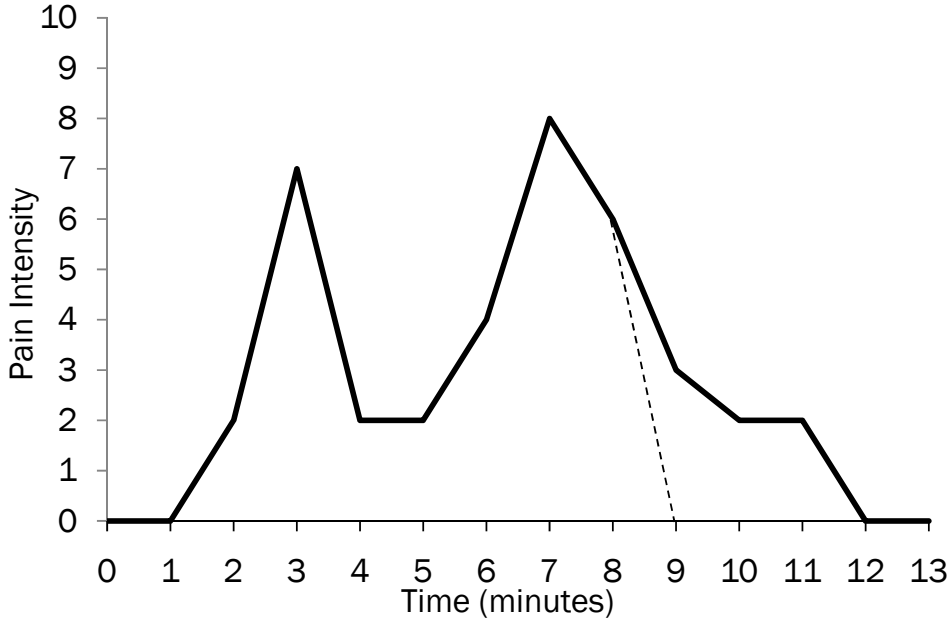
The last case of cognitive bias I want to discuss refers to memory. People's perceptions during an experience may not coincide with what they later remember to have experienced. Redelmeier, Katz and Kahneman (2002) show an illustrative case of a randomized trial about two procedures of colonoscopy. Kahneman talked about it in his Nobel lecture in economics (Kahneman 2003). I will present it as a simple puzzle to show my point, but design details of the experiment appear in Redelmeier, Katz and Kahneman's paper.

The normal procedure to do a colonoscopy requires passing a flexible tube through the anus. It was, at least at the time of the study, an unpleasant diagnostic procedure. When pain intensity is reported with a scale from 0 to 10, that procedure—I will name it 'procedure A'— may cause a hypothetical curve similar to that shown in the graph. Procedure B is exactly the same that procedure A, but extended in time. It provides 3 additional minutes of pain prior to colonoscope removal. It adds no additional medical information; the sole difference is that the colonoscope rests 3 more minutes in the rectum. The evolution of pain intensity may be similar

to the following hypothetical curve. A typical example of graph of each procedure would be:



Hypothetical case with procedure B
Freely adapted example based on Kahneman (2003)



Hypothetical case with procedure B
Freely adapted example based on Kahneman (2003)

The y-axis corresponds to pain intensity reported during the test. After the colonoscopy, retrospective evaluations were asked to the patients. The fact shown by Redelmeier, Katz and Kahneman is that patients who received procedure B reported significantly less pain in retrospective evalua-

tions after colonoscopy than patients who received procedure A. The reason seems to be that procedure B ends less abruptly. No pain is inflicted with the rapid removal, but the last memory is less negative if it is slower. However, patients of procedure B suffered more time, as themselves reported during the test. Memories are imperfect and susceptible to bias.

Now let me make a question to the reader: which procedure would you prefer? Do you want to suffer 12 minutes or 9 minutes? Another question: which procedure is better as a means to diagnose? Of course, procedure B is a worse (a poorer quality) diagnostic method: there is a trivial alternative equally effective and shorter. If the normal procedure were B and somebody discovered a way to shorten it to 3 minutes without actual loss of information, of course we would speak of a quality improvement.

A last question: which procedure would you recommend from the healthcare policy's viewpoint? Redelmeier, Katz and Kahneman show that it should be procedure B, the poorer quality diagnostic method. The reason is that patients' memories in the past influenced their decisions about future colonoscopies. Authors report significant relative increases in the odds of returning to a subsequent colonoscopy.

This example is aimed at showing three important points of this thesis. The first one is that quality is relative to a means-end relationship. Procedure B is worse as a means to the diagnostic end. For this reason nobody with all the information would choose it: he would suffer 3 more minutes without any increase of diagnostic efficacy. From the patients' point of view, it is poorer quality than procedure A, despite they have a better post-experience memory of it. The second point is that quality is almost *never* the only issue to be taken into account in actual situations. From healthcare policy's viewpoint, to adopt procedure B seems to be better.

A third point discussed in this thesis is that quality depends on reference attributes and preferences. We could consider that a diagnostic procedure is better if it maximizes the probability of return to subsequent colonoscopies. If the end is to maximize long-term, overall diagnostic efficacy, procedure B might be better, since it increases returns without additional drug use. However, this is not because patients would be willing to choose procedure B instead of procedure A, but because patients don't know the treatment that they have not received. In other words, it is advisable to cheat patients, given their own memory biases. This is the policy maker's viewpoint, not the patient's viewpoint.

Remark (3.16)

Anyway, the expression 'gap between perceptions and expectations' is ambiguous, since it does not make it clear whether it refers to actual perceptions or remembered perceptions. Actual perceptions and remembered perceptions do not necessarily coincide.

Gigerenzer vs. Kahneman and Tversky

I will make several remarks about Gerd Gigerenzer's criticisms of Kahneman and Tversky's approach on cognitive biases. I will spend some time to discuss the issue because a critical part of my argument is that (1) cognitive biases can systematically lead to error and that (2) abstract models of correctness (logic and decision theory in a broad sense) provide references to analyze such kinds of error. Gigerenzer criticize these views. Furthermore, the discussion may be useful to avoid misunderstandings of my own position.

Gigerenzer says that Kahneman and Tversky were centered on narrow norms and were wrongly focused to prove that judgment often deviates from those norms (Gigerenzer 1996). Such norms (mainly from basic probability theory and normative decision theory) are narrow in the sense that they are formal and neglect not only contents but also contextual information. Gigerenzer argues that human intelligence is powerful precisely because of its ability to deal with pragmatics, to discriminate relevance, to pay attention to contexts and to work with content-dependent reasoning. According to Gigerenzer, Linda's example (about whether it is more probable that she is a bank teller or it is more probable that she is a bank teller and is active in the feminist movement) is significant of Kahneman and Tversky's mistakes. Intelligent, content-focused adaptive minds take into account context and Linda's description to achieve a plausible judgment (Gigerenzer 1996; Gigerenzer and Gaissmaier 2011). Content-blind minds directed by formal probability theory only focus on the artificial issue that if Linda is a bank teller and is active in the feminist movement, then she is a bank teller. After hundreds of experiments confirming the conjunction fallacy "we have learned more about the limits of logic than about the workings of the mind" (Gigerenzer and Gaissmaier 2011).

As a consequence, Gigerenzer defends "good errors" which are typical of real intelligence and arise from the adaptation of mental heuristics to the structure of environments. At the same time, he condemns the negative vision of errors implied by the reliance on logical principles for the general definition of rational behavior (Gigerenzer and Gaissmaier 2011).

I don't interpret Kahneman and Tversky's work as actually supporting a negative vision of errors based on the reliance on logical principles. I believe this is an incorrect and misguiding interpretation. Gigerenzer's objections say more about his viewpoints than about Kahneman and Tversky's.

His criticisms mostly rely on the role of abstract models of reasoning. Kahneman and Tversky are quite neutral and pragmatic about these models. Gigerenzer's Frequentist claim against probabilities of single events is just an example (Gigerenzer 1996); Kahneman and Tversky are not particularly Bayesian, they just take as reference different models of reasoning

(Kahneman and Tversky 1996).

Of course intelligence is about context, relevance, content and adaptation. Nothing in Kahneman and Tversky's work denies it. The very idea behind the heuristics and biases program—that judgment under uncertainty often rests on a limited number of simplifying heuristics rather than extensive algorithmic processing, as Gilovich, Griffin and Kahneman (2002) summarize—is not particularly contrary to this view of intelligence, quite the opposite.

Gigerenzer says that biased minds make better inferences (Gigerenzer and Brighton 2009). He does not refer to an accuracy-effort trade-off. He claims that heuristics can be more accurate than complex strategies even though they process less information. Gigerenzer calls it the 'less-is-more effect' and shows several prediction studies were simple heuristics (such as "choose the alternative recognized in first place by not particularly well-informed average people") outperform sophisticated statistical models. Heuristics are not good or bad, rational or not; their accuracy depends on how they fit the environment. This is "ecological rationality" as opposed to logical rationality (Gigerenzer and Brighton 2009). With experience, people learn how to select proper heuristics. Gigerenzer's simple heuristics are interesting (see Todd, Gigerenzer and ABC Research Group 1999), but he does not focus on cases in which such heuristics get poor results in one-shot concrete problems. He is not interested in this—coherently with his interpretation of Frequentism.

In this sense, Gigerenzer is concerned with accounts of thought processes in the context of ecological rationality. Kahneman and Tversky were particularly interested neither in processes nor in ecological rationality (Kahneman and Tversky 1996)—I am not either. They looked for cases in which heuristics get poor results in concrete problems.

Intelligence can create models of correctness and error. When people systematically feel that in a fair lottery the ticket with 11111 is less likely than 69237, they are wrong. We are naturally inclined to expect less occurrences of the first number—it seems "less random". Obviously this is an absurd expectation. Of course, the heuristic process behind the error (perhaps aimed at recognizing non-random patterns) may be accurate and efficient in other contexts. Under the adequate circumstances, I suppose it may yield a less-is-more effect and outperform sophisticated statistical methods. However, there are many cases in which heuristics systematically yield to wrong conclusions.

The idea that if a customer uses a good quality product then the gap between perceptions and expectations is minimized, assumes that he has no cognitive biases that yield to misperceptions and absurd expectations. I suppose this can be translated into Gigerenzer's terms: the idea assumes that the customer has already discovered ecologically rational heuristics to

select a better product in a given context. There is no reason to accept such assumption in any of both formulations.[17]

ADDENDUM. ORDINAL VS. CARDINAL QUALITY MEASURES

Ordinal vs. Cardinal Utility

According to our definition of a utility function, if $u(x) - u(y) \leq u(x') - u(y')$ we cannot infer that the degree of preference of x to y is lower (or equal, at best) than the degree of preference of x' to y'. Utility functions do not carry information about the degree (or magnitude) of preference. In this sense, they are ordinal utilities.

It is possible to define other kinds of utility functions (namely, cardinal utility functions) that somehow measure the degree or magnitude of preference. With such measures $u_c(\cdot)$ we could infer from $u_c(x) - u_c(y) \leq u_c(x') - u_c(y')$ that the degree of preference of x to y is lower (or equal, at best) than the degree of preference of x' to y'. In the following subsection we will see a way to obtain a cardinal utility function, based on Debreu (1958). Fishburn (1970) has a chapter on this issue.

Of course, for cardinal utility functions the property of uniqueness up to strictly increasing transformations does not hold in general: if $u(\cdot)$ is a cardinal utility function and $f: \mathbb{R} \to \mathbb{R}$ is a strictly increasing function, $f\left(u(x)\right)$ is not necessarily a cardinal utility function representing the same degrees of preference as $u(\cdot)$. The fact that expected utility functions

[17] Provided we want to create and improve means to do things, the main question remains: which correctness criteria do we want to assume? Because of that I am interested in ways to explore and model correctness criteria.

I am not actually interested in how we think or how we should think. To my mind, logic and decision theory in the widest sense are collections of formal and informal models of correctness, sometimes incompatible between them.

Creation and improvement depend on correctness criteria, but there is no need to have too many presuppositions about what correctness is. This is not such a strange idea: obviously (a) design choices depend on assumptions about what is correct and (b) it is advisable not to have a too closed mind to alternative correctness criteria.

I don't believe that logic and decision theory define rationality; I am not interested in what rationality is. My view is that they are aimed at conceptual analysis and problem types' analysis, not primarily at real-time practical reasoning. Of course they are not explanatory theories of thinking; they are ways to explore and model correctness criteria.

are not unique up to mere strictly increasing transformations does not mean that they are cardinal.[18]

The definition and assessment of cardinal utility functions is highly problematic. It is hard to figure out how we can measure whether somebody prefers x twice the degree of his preference to y. Why twice and not 3 times or 3.12 times or whatever? There is not any easy and reliable procedure to define and assess cardinal utilities. In microeconomics, where utility functions are used to describe consumer's preferences, the concept of utility function is invariably ordinal.

In this thesis, mostly concerned in describing what an actor should prefer assuming certain reference purposes and circumstances, cardinal utilities are even less adequate. Cardinal utility functions seem aimed at measuring the individual intensity of attraction or willingness to consume a good. Actually, the most plausible answer to the question 'why twice and not 3 times or 1.71 times or whatever?' is based on the criteria of whether the client is willing to pay for x 2, 3 or 1.71 times the price of y. But how we operationally define how many times the price of y somebody *should* be willing to pay for x, given certain circumstances and purposes?

The ultimate reason for our use of ordinal utilities against cardinal ones is that the degree of preference does not change choices—cardinal utilities look like a psychometric indicator rather than a tool to model decision-making. The choice function is independent of any utility representation of a preference relation. The set $C(A)$ of elements of $A \in \mathcal{P}(\mathcal{M})$ chosen according to a preference relation $\succsim$ on $\mathcal{M}$ does not change depending on any degree of preference. We are interested in what an actor should choose, thus we do not need to compare preference differences—this is also the basic intuition we want to capture: whether something works better that something else for a given purpose or not.

Moreover, I have already argued that the analysis of the quality concept does not need to assume that the set of alternatives has an intrinsic structure, as if quality were something objectively embedded in products or services. Quality depends on judgments (that have to be correct) about many contextual factors; which factors are considered as relevant depends

[18] However, expected utility functions $U(\cdot)$ seem to be "more than ordinal"—actually, it is true that to some authors they are cardinal (Machina 1987). In my opinion, and this will be the criterion used in this thesis, uniqueness up to positive affine transformations (and not merely to strictly increasing transformations) is a side consequence of the requirement to compute $U(\cdot)$ from $u(\cdot)$ and $p(\cdot)$. Functions $U(\cdot)$ are not cardinal in the proper sense that a cardinal representation measures a magnitude (Baumol 1958). The fact that due to their mathematical formulation they are not unique up to strictly increasing transformations has nothing to do with whether they represent some magnitude or not—and actually they don't. It is a side effect of a merely convenient formulation.

on each quality attribution. Quality is not subjective, but relative to a set of reference preferences which have to be correct taking into account actors' purposes and circumstances. This is against any conception implying measuring quality as a magnitude. Thus it engages us with the widespread (standard in microeconomics) ordinal conception of utility.[19]

On Survey-Based Quality Measures

One way to define cardinal utility functions is from the point of view of stochastic choice (Debreu 1958). Stochastic choice occurs when the choice function is non-deterministic. For instance, given a pair (x, y) with $x, y \in \mathcal{M}$ we could describe an actor's preferences by means of a probability $p(x, y)$ to choose x and a probability $p(y, x) = 1 - p(x, y)$ to choose y. A Frequentist interpretation would be that the actor chooses x against y one in $1/p(x, y)$ times he or she faces the decision, and chooses y against x one in $1/p(y, x)$ times—by the way, it doesn't look like a promising model to describe what an actor should prefer given certain purposes and circumstances.

For a set $\mathcal{M}$, $p(\cdot)$ is a function from $\mathcal{M} \times \mathcal{M}$ to [0,1] such that $p(x, y) + p(y, x) = 1$ for every $(x, y) \in \mathcal{M} \times \mathcal{M}$. A cardinal utility function for $(\mathcal{M}, p)$ is a real-valued function $u(\cdot)$ on $\mathcal{M}$ such that:

$$p(x, y) \geq p(x', y') \text{ if and only if } u(x) - u(y) \leq u(x') - u(y')$$

This definition provides a theoretically correct specification of cardinal utilities (Debreu 1958). The first appendix of Luce and Raiffa (1957) discusses and criticizes the probabilistic utility theory.

Actually, concerning quality, we could think of a "quality" measure $q(x, y)$ between elements x, y of a set of products as the proportion of people in a market segment that chooses x against y. To be sure, if $q(\cdot,\cdot)$ were a quality measure (actually, I will argue it is not), it would be a cardinal quality measure.

In fact, in order to be a quality measure it should rely on at least four assumptions:

(1) People in the segment only take attributes that are relevant to quality into account.

(2) They have correct assessments of multivariate joint probability distributions.

[19] This has been the reason to present in some detail the concept of choice function and some associated notions—revealed preferences and the like. The usual focus on utility functions can be misleading to some extent.

(3) Each person has well-formed (e.g., complete and transitive) preference orderings on these distributions.

(4) There is a way to aggregate each person's individual preferences into a unique well-formed preference ordering such that no unique individual determines the final ordering.

Notice that the survey-based procedure is tantamount to the majority voting rule.

The first assumption (1) is probably incorrect, since we people tend to mix impressions about price, emotions, feelings, aesthetic value, ideological connotations or ethical implications of products and services together with their quality-related attributes. This is what advertising in part is about: how to use signals (for instance of good quality) in order to attract or convince potential customers. Quality signals are typically based on price, emotional references, feelings, or aesthetic features of products and services. We customers mix quality attributes and quality signals—we have to deal with too many purchasing choices in order to do it in another way.

Suppositions (2) and (3) are highly dubious due to the evidence about cognitive biases in psychology and behavioral economics. Supposition (4) corresponds to the standard formulation of Arrow's impossibility theorem, which has already been explained.

4

A Theory of Quality

In this chapter, I formulate a theory of quality that observes our basic minimal assumption that quality is tantamount to how well something works for a given purpose. In order to do it, we shall consider preference orderings over types of means—actually, over joint probability distributions assigned to each alternative means.

ATTRIBUTES: RELEVANT AND QUALITY RELATED

Let us begin with the analyst facing a problem; recall the definition:

Definition (3.3) [Problem for a quality attribution]

A problem is determined by:

(a) An actor defined by circumstances and purposes.
(b) A primary end.
(c) A partial end to the primary end.
(d) A set of alternative means that have the partial end in common but differ in the ways to achieve it.

In order to make the quality attribution over the means, the analyst has to fix several quality attributes in order to assess the consequences of the action conditioned to the fact that a means has been used. Attributes have to fulfill two main conditions:

Supposition (4.1) [Condition 1 for quality attributes]

Attributes have to be adequate, relevant for a particular problem.

Supposition (4.2) [Condition 2 for quality attributes]

Attributes have to be quality-related, that is, attributes such that better or worse quality depends on.

In a sense, we will see that the second condition can be reduced to the first one—most, if not all, of the relevant attributes to a problem will be quality-related attributes. That is, the frame of a problem in terms of ac-

tions carried out by actors using means determines that attributes relevant to such a problem are quality-related.

Recall that we noticed that if a type of rope A has better properties to climb mountains, climbers should say that rope A is of a better quality. In the same sense, a model of knife A has a better quality if it has better properties for cutting food, and the service of hospital A is of a better quality if it has better properties to obtain cures. In order to set reference attributes we have to focus on differences between alternatives concerning climbing mountains, cutting food, or obtaining cures. Relevant differences are those in relation to the action that the actor carries out.

Price and Other Attributes Not Related to Quality

This is the exact reason to the fact that price has nothing to do with quality. Of course, people have needs and expectations in relation to price, and indeed price can cause dissatisfaction. But price differences are not differences in relation to the action that the actor carries out. Properties of a knife model for cutting food do not change with its price, as do not change properties of a model of rope to climb mountains or properties of a hospital service to provide cures. Not be confused with the fact that more expensive products tend to have better properties: fixing one model and two different prices for the same model, there is no change in the capability to carry out the action.

The same argument applies for expectations about emotions, feelings, aesthetic tastes, ideological connotations or ethical implications. They are very important to many issues, but not at all in relation to quality. Properties of a knife which are relevant for cutting food do not change if an individual is afraid of knives. Properties of a model of rope that are relevant for climbing do not change if an individual believes that the phosphorescent color of the rope is against good taste and aesthetics. Properties of a hospital service to provide cures do not change if an individual believes that doctors are dehumanized engineers of the human body. It may change the user's disposition when using the product (and this, of course, may well be important and interesting), but the product or service's properties to accomplish an end do not change. Psychological determinants of dispositions to use the means may be very important and have to be managed, but they have nothing to do with quality.

A Test to Check Quality Attributes

A suitable test to detect quality attributes is to figure out what happens if we fix one model of means and two different levels of the attribute for the same model; if there is no change in the capability to carry out the action, the attribute has noth-

ing to do with quality. On the contrary, if the capability to carry out the action changes, then the attribute is quality-related.

As said before, price does not pass the test: fixing one model and two different prices for the same model, there is no change in the capability to carry out the action. Emotions, feelings, aesthetic tastes, ideological connotations or ethical implications do not pass the test either: fixing one model and two different emotional reactions to the same model, there is no change in the means' capability to carry out the action—the test can be easily extended to the rest of cases.

Attributes that are typically related to quality pass the test even in generic problems. For instance, fixing one model and two different degrees of reliability for the same model, the highest degree of reliability provides an improved capability to carry out the action. Likewise, if a problem is formulated in terms of an action to be carried out in the long-run, fixing one model and two different degrees of durability, the higher degree of durability provides an improved capability to carry out the action as well—note that this is not necessarily true if the problem's definition does not take the long-run into account.

Let us now consider Condition 1 (adequacy to a problem); a problem's definition determines whether the capability of a means to carry out the action changes or not depending on different levels of an attribute:

Remark (4.3) [Relevance]

A complete description of the problem (in terms of actions, actors and means and thus of circumstances, purposes, ends, partial ends, and moves) contains all the relevant information so as to decide what is important and what is not in order to carry out the action. An attribute can be considered as not relevant to the problem (e.g., price in typical cases) when it is not taken into account in any partial end, it does not vary depending on how the means is carried out, it does not represent any significant aspect of the circumstances, and so on.

Likewise, an attribute can be considered as relevant to the problem (e.g., reliability in typical cases) when it varies depending on how the means is carried out, defines directly or indirectly some partial end, some aspect of the circumstances, and the like.

Accordingly, any attribute which is relevant to a problem could be considered as a quality relevant attribute in most cases.

Uncertainty

As discussed in Chapter 3, attributes have variability and can be associated with a probability distribution. In fact, we will link each alternative means to a particular probability distribution over the attributes used to assess its concequences.

Means can be regarded as types defined by the random behavior of a set of suitable quality-relevant attributes. In fact, if two different types of mean would have virtually indistinguishable joint probability distributions, then we would not be able to distinguish their respective quality. From the quality's viewpoint, a means is nothing more than a multivariate probability distribution that can be implemented using some technology (in the broad sense), auxiliary actors, contents and moves.

REFERENCE PREFERENCES

Reference Preference Relations

Probability distributions defined over quality-related and relevant attributes are useful to assess the consequences of the action given the use of some means. The quality concept depends on determining which joint probability distributions are more favorable to the actor given its circumstances and purposes.

Therefore, the quality concept depends on preference relations over the set of joint probability distributions of relevant and quality-related attributes. I name such preference relations 'reference preferences', because they are assumed as a reference in a quality attribution.

As argued in previous chapters, reference preferences should be well-formed. Requirements from normative decision theory can be a guide to adopt criteria on what is a well-formed reference preference. Transitivity seems to be critical in the quality case; saying that x has worse quality than z when x has better quality than y and y better quality than z contradicts all our intuitions about the quality concept.

Implicit Knowledge of Reference Preferences

People make quality attributions in their everyday life but do not explicitly define and assess joint probability distributions of relevant, quality-related attributes. Nonetheless, they do something similar in an implicit, unstructured manner—even though some of our actual quality attributions may be not really accurate or not well-formed.

People have a tacit (or implicit) knowledge of which attributes make something better or worse, which directions of improvement they have, or which correlations between attributes are plausible. A quality attribution builds upon this tacit knowledge.

Remark (4.4) [Reference preferences as tacit rules]

A reference preference can be regarded as a tacit rule to order joint probability distributions of relevant, quality-related attributes. Given

an alternative means, the rule returns which relative position would have according to its quality. According to this view, a reference preference is an implicit rule that can hardly be completely specified in an explicit way—but of course it can be partially and approximately described rather easily in many cases (choosing some key attributes and describing their behavior with standard probability models).

The case is similar to that of the maximization of utility in microeconomics. People do not compute utility functions. Likewise, people only make quality attributions in an unconscious manner. Nonetheless, utility functions can be a suitable conceptual device to model economic decisions.

Remark (4.5)

Given a problem, the analyst has to define the set of reference preferences according to the available information about the actor's purposes and circumstances. The analyst's quality attribution only will be correct if the reference preferences are correct—if the joint probability distributions that are more favorable to the actor given its purposes and circumstances are actually determined as preferable.

The role of the analyst is to make the tacit knowledge concerning reference preferences that we use in order to make judgments about quality explicit and systematic.

ALTERNATIVE MEANS: COMPARABILITY

In order to define preference orderings on sets of means, we have to assume that means can be compared to each other in relation to their quality. However, it makes no sense to ask what is higher quality, a Toyota Tundra or a Billy bookshelf from Ikea. I am not asking whether the quality of a Toyota Tundra in relation to the other vehicles of its type is of a higher quality than a Billy bookshelf in relation to other bookshelves. I am asking whether the quality of a Toyota Tundra is higher or lower than a Billy bookshelf.

It makes no sense because both the Toyota Tundra and Ikea's bookshelf are means to carry out quite different types of actions. There are few actions that are less alike than moving from one place to another and storing objects at home. This is what the condition that the set of alternatives has to contain alternatives suitable for a given problem means.

Remark (4.6)

Notice that if quality is meeting customer's wants and expectations, there is no reason to avoid comparing the Toyota Tundra and the Billy

bookshelf in relation to the degree in which they respectively minimize the gap between perceptions and expectations.
The same thing is true for many other quality definitions: conformance to requirements, fitness to use, conformance to specifications, or minimizing defects.

Of course, the sets of actions linked to different means are hardly ever identical. For instance, vinyl disc became obsolete after Compact Disc. Their quality was actually compared in terms of sound; in fact, vinyl discs perished among other reasons because CD's sound quality was better. Nonetheless, Compact Discs do many more things than to store sounds. Is the CD actually comparable with the vinyl disc? Yes, to the extent that it is also a means to reproduce sounds—that is, they are comparable to the extent that both are suitable for a problem.

At any rate, we do not need a categorical distinction: we can say that two means are more comparable to the extent that the actions that they help carry out are more similar. The lesser the degree of coincidence or overlap between sets of actions, the less we tend to compare the quality of means. If the actions are totally different, we say that the means' quality is not comparable. To the extent that we are able to say whether two actions coincide or look alike in a relevant way (and in general we know how to do it) we could say whether two means are sufficiently comparable or not.

ASSIGNMENT FUNCTIONS

Functions from Means to Distributions

Quality is defined on a set of multivariate probability distributions, but the choice that the analyst would advise is to make on a set of alternative means. In terms of the notation used in Chapter 3, we need a function $f: \mathcal{M} \rightarrow \boldsymbol{P}$ that assigns a probability distribution to every alternative means. Notice that $f(\cdot)$ is not necessarily injective (in principle, two means can have the same distribution associated to them) and it is not surjective (not any distribution has associated a means).

As noticed above, means can be identified with, or regarded as, joint probability distributions—different means with indistinguishable distributions would not differ in quality.

Remark (4.7)

This last step completes our analysis of the quality concept: quality depends on whether a joint distribution of (relevant and quality-related) attributes associated to a means is more or less preferable to the joint

distributions associated to other means according to a set of (correct, well-formed) reference preferences.

Implicit Knowledge of Assignment Functions

In order to make quality attributions people have to make implicit assignments of joint probability distributions to each alternative means they are considering in the quality attribution. Only after doing it people can assign a better quality level to means that have better expected consequences according to their purposes and circumstances, since the belief about expected consequences assumes some kind of implicit belief concerning probability distributions.

Note that, in principle, a quality attribution can fail (can be incorrect) for at least three main generic reasons. (1) If the implicit assignment fails, the actor would assign an incorrect probability distribution to the type of means—obtaining misleading conclusions. Furthermore, (2) reference preferences can be wrong if they don't respond to the assumed circumstances and purposes. Finally, (3) the circumstances and purposes that are assigned to a certain type of actor have to be correct—"target" actor tokens have to actually fulfill some conditions concerning the assumed set of circumstances and purposes.

SUMMARY AND CONCLUSION

Summary

Let us assume that the analyst has been capable to make correct judgments about the following points:

(1) An action which has been carried out by an actor with the help of a means. That is, the analyst has made correct judgments about the circumstances and purposes that define the actor, about a primary end, about partial ends, and about distinct ways to achieve such partial ends.

(2) Quality-related and relevant suitable attributes to the problem.

(3) The random joint behavior of such attributes (joint probability distributions on them).

(4) A well-formed preference relation over the joint distributions.

(5) How to assign a multivariate distribution to each means.

Then the quality of a means x is equal or greater to that of another means y if and only if the distribution associated to x is preferred to the distribution associated to y in the preference relation.

Taking up the notation used in Chapter 3, for two alternative means $x, y \in \mathcal{M}$, a correct assignment function $f: \mathcal{M} \to \boldsymbol{P}$ and an adequate and well-formed preference relation $\succsim_Q$ on $\boldsymbol{P}$, we have:

x has equal or higher quality than x if and only if $f(x) \succsim_Q f(y)$

With the usual notational conventions in microeconomics and decision theory we can also write:

x has strictly better quality than y if and only if $f(x) \succ_Q f(y)$
x has the same quality than x if and only if $f(x) \sim_Q f(y)$

A different problem with the same means but taking into account different actors (with other circumstances and purposes) would compel the analyst to gather new information and to make a different quality attribution explicit.

What Quality Is?

Quality is not subjective. It does not depend at all on the psychological processes or states of any particular individual, such as perceptions, expectations, beliefs or desires. It is not objective either—in the sense that it is not "independent of the existence of man" (Shewhart 1931).

Quality is relative, which is a very different thing that being subjective—e.g., GPS location results are relative to the geographic coordinate system, but are not subjective. Quality is relative to a problem and a set of reference preferences.

Provided that we understand that quality is relative to a certain context and references, and that people have an implicit knowledge of such references, the quality concept can be understood as follows:

Remark (4.8) [On what quality is]

Quality is the capability that the types of means have to improve the expected consequences of the action that they help to carry out; whether expected consequences have improved or not depends on actors' purposes and circumstances.

That is:

(1) Quality is the capability of means to improve the expected consequences of their ends.

(2) Products and services used to do something have better quality to the extent in which they provide better consequences.

(3) In this sense, quality is about how well a means works for a given purpose.

ADDENDUM. QUALITY VS. GRADE

The term 'grade' is usually used in quality management to refer to the difference between a BIC pen and a Montblanc pen, between a small family car and a Ferrari or a Porsche, between the cheapest simple hotel and a five star luxury hotel. The difference is not, properly speaking, in quality: they are pairs of different things, with different purposes and different requirements. According to the usual conception in quality management, including the ISO standards, grade is the category or rank given to different quality requirements for products having the same, or a very similar, functional use.

According to the theory of quality, the distinction refers to the non-comparability of otherwise very similar products and services. The point is that they look like comparable means to achieve a similar end, but actually they are not: the fact that the requirements are different implies that quality criteria are different, some relevant attributes can be different, and reference preferences are substantially different. Comparability is only apparent because, in general, they are means that respond to different problems—that is, actor's purposes and circumstances are very different.

Therefore, the distinction is perfectly coherent under the theory of quality, and the theory can account for it adequately. Moreover, the theory also accounts for an aspect that the usual conceptions based in customer satisfaction can barely explain: in spite of the difference in grade, actually there is no reason to deny that there is *also* a difference in quality.

Quite intuitively, there is no reason to avoid comparing the BIC pen and the Montblanc pen according to their quality, since in a sense they are obviously comparable—in the final count, they can be used as alternative tools to do many things. Thus, they can be analyzed also as alternative means to achieve the same end under the same problem. Several quality-related attributes can be defined for both pens: ink fluidity, ink cartridge duration, and so on. For these attributes each one of these pens has a different joint distribution, and the respective distributions can be compared according to some reference criteria: optimal fluidity, as long as possible ink cartridge duration, and so on. In some sense, it is obvious that two pens can be compared in their quality.

That's not to say that there is not a difference in grade, or that there are not obvious differences in market positioning, target segments, or whatever. Quality is (so to speak) much simpler than that. Oftentimes quality is not so important in managerial terms. Managerial decisions on positioning and differentiation mainly depend on grade. In some sense, grade is a movement of horizontal differentiation derived from a previous movement of vertical differentiation.

5

Intervening on Quality

THE BASIC BUILDING BLOCKS BEHIND QUALITY MANAGEMENT

This chapter discusses the most direct way by which the quality concept appears in management: through organizations' initiatives to intervene in the quality of what they use and provide.

I am going to use the theory of quality in order to analyze, in a systematic manner, the basic structure behind quality management. I argue that this structure is more or less stable and that intervening on quality, whether it is done right or wrong, explicitly or implicitly includes some fixed aspects. Most of these aspects are quite standard in the accepted quality management wisdom:

I
- (a) Setting of quality criteria
- (b) Means' design*
- (c) Process' design*
- (d) Onsite planning*

II
- (e) Onsite control*
- (f) Standardization*
- (g) Process' improvement*
- (h) Means' improvement*
- (i) Rethinking reference preferences

(*) It should be preceded by: 'Quality-related aspects of…'

Generating Reproducible Means

The rationale for this list basically consists in showing (I) a set of things to do in order to generate reproducible means, and (II) a set of ways to preclude or fix deficiencies and lacks of fit that can occur in doing the things in the first group. In this chapter I study the aspects (a)–(i) in some detail and I pay attention to the different sorts of deficiencies and lacks of fit that can appear carrying out (a)–(d).

The terms belonging to the first group can be roughly defined as follows—as noted at the end of the list (*), I implicitly refer to quality-related aspects of each theme; I do not consider them in general:

(a) Setting of quality criteria: any activity aimed at defining or establishing reference preferences.

(b) Means design: any activity that is carried out during the conception of a reproducible means and takes quality criteria into account. Any activity that embeds quality criteria into the means design.

(c) Process design: any activity that is conducted during the conception of processes in order to generate reproducible means and takes the way in which quality criteria are embedded in the means into account.

(d) Onsite planning: any activity consisting in arranging technology (in a broad sense) and auxiliary actors in order to execute the process according to its design and the concrete situation in each time.

Note that (b) and (c) are put together with a brace. The reason is that they are not independent activities: actually, services are processes provided to someone as an exchangeable element in a transaction. Therefore, in such cases process design is intertwined with the means design. In other occasions (e.g., standard manufacturing) the means produced and the process to produce it can be clearly separated.

After onsite planning there is (implicitly) the process execution. In some sense, I assume that process execution is a black box that we cannot modify directly; i.e., only by means of onsite planning and control, process design, means design, and setting quality criteria—in increasing levels of generality.

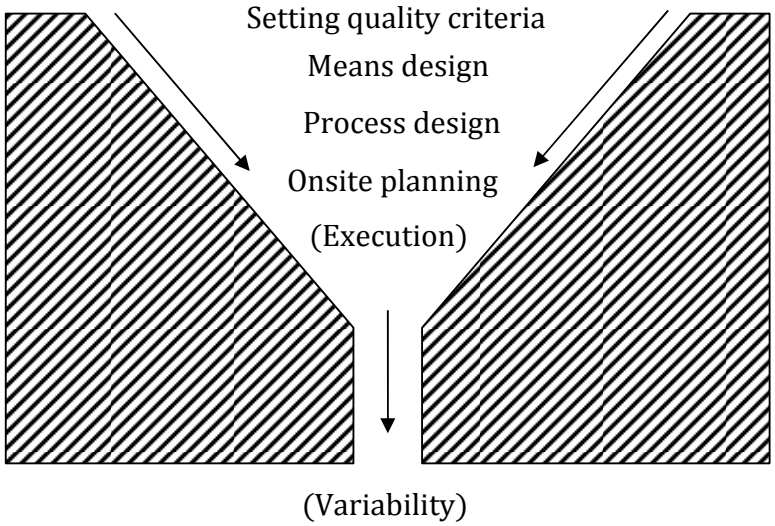
The Black Box of Process Execution and the Origin of Variability

The process execution, taken as a black box only modifiable from the outside, generates an inherent variability. The first problem of reducing variability is that we hardly have the knowledge or enough control to reduce the black box's inherent variability to a minimum—almost by definition, we cannot know which is that minimum in advance; it is an unavoidable amount of variation.

The second problem is how much avoidable variability we add to such an inherent variability during the generation of (tokens of) reproducible means. In a sense, possibilities in the generation of a reproducible means are gradually reduced through the activities mentioned in the previous subsection. Setting quality criteria makes the initial reduction in the number of possibilities, followed by a further reduction in the design and plan-

ning tasks. In the last step (process execution) several significantly different ways to generate the reproducible means coexist, adding potential variation to process execution.

Accordingly, we can depict this idea as a sort of funnel in which possibilities to generate alternative means diminish at each step. The more the width of the available final tube in order to execute the process, the more the variability:



Nonetheless, there is a point where variability reduction generates inconveniences. In most cases there is a trade-off between reducing variability and other aspects of the organization's performance—a too narrow funnel's final tube can be devastating to many important things to do.

Remark (5.1)

The idea of process execution as a black box which is only modifiable from the outside (and the emphasis on setting, design and planning tasks in order to intervene on quality) does not suggest any approach to HR management. In particular, it does not suggest any hierarchical conception of organizations. I am analyzing distinct kinds of activities, setting aside who should perform them. In fact, they could be performed by the same individuals. They do not imply that process execution is less important in general terms, either.

According to this approach, variability is the unavoidable residual in a successive reduction of possibilities; the point where design and planning activities cannot discriminate anymore. We tend to think that variability is a direct consequence of non-deterministic inputs; of course it is (this is mainly what I have called 'black box's variability'). Nonetheless, the main

point is that variability is an unavoidable by-product of many deficiencies in the abovementioned setting, design and planning activities—namely, in their capability to discriminate alternatives to generate the reproducible means.

Deficiencies and Solutions

Deficiencies can be caused by lacks of fit in any activity: lacks of fit between quality criteria and the actor's circumstances and purposes, between means design and quality criteria, between process design and means design, between onsite planning and process design and between executions and onsite planning. Such lacks of fit can be approached by the following activities:

(e) Onsite control: any activity to check whether each process execution has been executed according to onsite planning. Thus it provides feedback to onsite planning. It can generate data to be used eventually in process improvement, but this is not its main purpose—onsite control does not provide inputs to process improvement systematically.

(f) Standardization: moving a (unsystematic) way to do things from onsite planning to the process design—so, making it systematic.

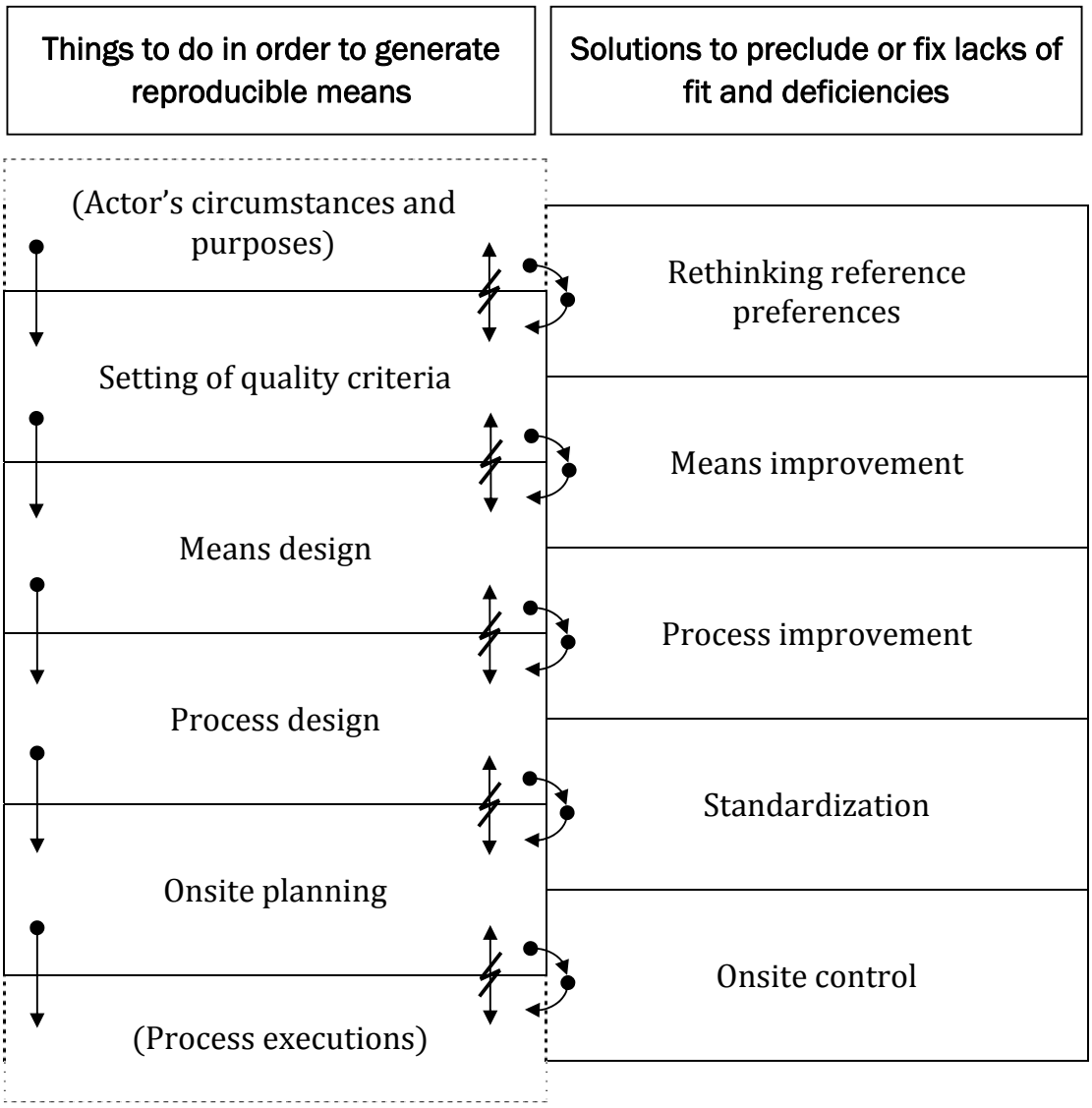
(g) Process improvement (or process redesign): any activity of design over an already existing process; again, we tend to focus on the particular case of fixing actual or potential deficiencies.

(h) Means improvement (or means redesign): any activity of design over an already existing means; in particular, when it is aimed at fixing actual or potential deficiencies.

(i) Rethinking reference preferences: when quality criteria do not fit with the actor's circumstances and purposes, any activity to re-assess reference preferences and re-state the analysis of the whole problem—in the technical sense. Quality criteria are deduced from reference preferences and the problem's analysis.

The table in the next page provides a summary on the role of these solutions. The left side shows the normal cycle to generate reproducible means, from the actor's circumstances and purposes to the process executions required to reproduce the means. The five generic lacks of fit (deficiencies) are depicted with the symbol

and they have been already listed:



(1) Lacks of fit between quality criteria and the actor's circumstances and purposes.
(2) Lacks of fit between means design and quality criteria.
(3) Lacks of fit between process design and means design.
(4) Lacks of fit between onsite planning and process.
(5) Lacks of fit between executions and onsite planning.

In the right side, the symbol

associates a generic solution or approach to each one of these deficiencies—thus to each consecutive pair of activities in the left side.

Descriptive Purpose

The statements (a)–(i) which have been discussed in this section have a descriptive purpose. The point is not that organizations should set quality criteria, design and improve means and processes, and so on; the point is that, in order to intervene in quality, actors necessarily set quality criteria, as necessarily design means and processes and necessarily do some onsite planning. They fix gaps doing (necessarily) some version of (e)–(i).

A very different thing is whether these activities are made unconsciously, implicitly or unsystematically. This may determine whether they have been made correctly or not, but actually they must have been done in some way.

QUALITY MANAGEMENT AS AN AUTONOMOUS DISCIPLINE

On the basis of the description of the core aspects of quality management, we could state the following working definition—actually, several versions of the same idea:

Definition (5.2) [Quality management]

Quality management is an applied field focused on how to intervene in the quality of reproducible means that actors (in any environment) use and provide.

Since quality is tantamount to the capability of improving the expected consequences of actions given the use of certain means, quality management can be regarded as the applied field concerned with quality-relevant attributes and how to modify their expected consequences.

In general, a simplified definition would be that quality management is a generic collection of activities and techniques which are aimed at making means work better for given ends. Perhaps a more suitable alternative would be ‘a generic collection of activities aimed at making means work properly for given ends’—in the sense that ‘improving’ means making things work more properly .

In my opinion, the last definition (generic activities aimed at making things work properly for given ends) is descriptive enough. The adjective ‘generic’ highlights an important point:

Remark (5.3) [Intervening on quality as a generic activity]

Quality management *per se* does not require a very specialized knowledge of the means, ends and contexts for which it tries to make things

work properly. It provides general criteria, rules and techniques that have to be adapted to each particular field of application.

Of course, in the implementation and use of quality management, specialized knowledge has to be merged with generic quality management knowledge. However, these specialized issues do not define quality management.

The remark just says that applying quality management to the reliability of infrared sensors requires some knowledge of the technology; applying quality management to governmental intelligence services requires some knowledge of the tasks and organizational culture of the institution. However, quite trivially, infrared technologies and the organization of intelligence services are not topics that define quality management.

In the case of business environments, the goal of making means work properly for given ends implies a close interaction with overall managerial decisions, determinants and implications. However, the particular issues of commercial environments (customer satisfaction, employee satisfaction, costs, and the like) do not define quality management. They are requirements to its implementation in that particular environment, but they do not define it as an applied field.

This leads us to the following assumption—which is coherent with the previous chapters' developments, but it is not implied by them and it does not imply them:

Supposition (5.4) [The autonomy hypothesis]

Quality management basically consists in the set of activities that has been roughly described in the previous section—this is its "proper core". More general business and organizational topics are critical to the implementation and use of quality management in business settings, but they are merely instrumental to it—not definitional. Examples of such topics include people's motivation, client's satisfaction, intervention on the organizational structure, quality cost accounting, and so on.

Thus quality management, in the adequate circumstances, can be used meaningfully without reference to such topics.

Note that quality management can be used and implemented in contexts where organizational issues are relatively unimportant. For instance, it can be applied to specialized services provided by individual experts to individual persons—context in which the relevance of some organizational issues diminishes, but the role of quality management remains unmodified. On the other hand, quality management can be used and implemented in non-commercial settings.

Remark (5.5)

In fact, quality management is applied in many non-business settings: from schools to military institutions and NGOs. Approaching these cases with premises such that quality is tantamount to client satisfaction and that quality criteria are defined by the voice of the customer, can have some good consequences but mainly a loss of the ability to understand the case in a proper manner. The reason is that actors in such settings can have radically different sorts of purposes and circumstances to those of clients in market contexts.

In addition, ideas from quality management can be applied in non-organizational settings such as sports training or only semi-organizational settings such as cultural production and events management—in the sense that they require the coordination of several actors but sometimes not a significant, structured organization.

It is true that the goal of making means work properly for given ends implies a close interaction with overall managerial decisions in some contexts, but this is the case of many applied fields used in business environments, not only of quality management—so this close interaction cannot be what defines it. Thus the autonomy hypothesis relies on a more basic assumption:

Supposition (5.6) [The common ground hypothesis]

Any applied field that is relevant to management shares a common collection of requirements to its implementation just because it belongs to a managerial context: treating people, interacting with organizational structures, facing the organization's internal and external environments, being constrained by cost and financing issues, focus on the client and/or the market, and so on.

These aspects are necessarily relevant to the applied field in question, but they do not necessarily constitute definitional aspects of it.

The common ground supposition applies to finance, accounting, tax and business law, information technologies, or whatever. Of course people's motivation can have an impact on financial indicators—but from that we do not infer that people's motivation is a topic in finance in the same sense of the time value of money, risk, or the cost of capital.

SOME REMARKS ON INTERVENING ON QUALITY

This section re-examines the points presented at the beginning of the chapter in a more compact way; it also discusses some differences between the presented approach and some widespread ideas and practices.

The Voice of the Customer

Quality management has traditionally assumed that clients define quality criteria. I have already noted that quality is sometimes understood, to practical purposes, as equivalent to customer satisfaction. The Kano model is often taken as showing that quality criteria depend on clients' preferences, thus quality can be broken down in must-be quality (does not cause satisfaction if it appears, causes dissatisfaction if it doesn't), attractive quality (causes satisfaction if it appears, does not cause dissatisfaction if it doesn't), one-dimensional quality (causes satisfaction if it appears, causes dissatisfaction if it doesn't) and indifferent quality (does not cause satisfaction if it appears and does not cause dissatisfaction if it doesn't). As I have said in Chapter 1, the Kano model is also consistent with other interpretations; actually it only assumes that quality is a contributory cause to satisfaction—which is obviously true.

The voice of the customer or VoC is the name that (particularly in Six Sigma) the process to capture what the client wants in order to define quality criteria usually receives. QFD (Quality Function Deployment) is the traditional technique in quality management to make quality criteria in an explicit way and link them with product features. Nonetheless, oftentimes quality criteria are obtained through market research methodologies: surveys, focus groups and the wide variety of quantitative and qualitative techniques developed in the field of market research.

In contrast, according to the theory of quality, quality attributions depend on reference preferences:

Definition (5.7) [Setting of quality criteria]

The setting of quality criteria is simply obtaining operationally suitable conclusions from reference preferences.

A reference preference is a rule (almost surely implicit, never completely specified) to order joint probability distributions of relevant, quality-related attributes. Setting quality criteria implies a translation from this rule to operationally suitable criteria.

The voice of the customer is just an input among others to guide the generation of reference preferences. Client's opinion is a way to obtain ideas rather than the ultimate test for preferences' correctness. For the arguments widely discussed in this thesis, correctness of reference preferences depends on actors' circumstances and purposes, not on their opinions or perceptions. Nonetheless, despite the fact that individual actors have cognitive biases, aggregately they have incentives to be rational, thus paying attention to what they say may be a useful guide in the process of thinking about reference preferences. Nothing in this thesis implies to

avoid hearing the voice of the customer in applied contexts, rather the contrary: it is an important way (adequately complemented) to understand actors' purposes and circumstances.

Troubles with Innovation

Depending on how it is understood, quality may become a problem to innovation. The continuation of an already quoted fragment by Deming (1994) explains that point:

"The customer's expectations. There is much talk about the customer's expectations. Meet the customer's expectations. The fact is that the customer expects only what you and your competitor have led him to expect. He is a rapid learner.

Does the customer invent new product or service? The customer generates nothing. No customer asked for electric lights. There was gas and gas mantles, which gave good light. The first electric lights had carbon filaments. They were fragile and inefficient. No customer asked for photography. No customer asked for the telegraph, nor for a telephone. No customer asked for an automobile. We have horses: what could be better? No customer asked for pneumatic tires. Tires are made of rubber. It is silly to think of riding on air. The first pneumatic tires in the United States were not good. The user had to carry with him rubber cement, plugs, and a pump, and know how to use them. We can testify to that. No customer asked for an integrated circuit. No customer asked for a pocket radio. No customer asked for facsimile". Deming (1994)

'Quality as an impediment to innovation' is the subtitle of a paper by Robert E. Cole and Tsuyoshi Matsumiya (2007) published in the California Management Review with the title "Too much of a good thing?". Cole and Matsumiya argue that while a focus on quality is quite compatible with incremental innovation its relationship with disruptive innovation is more problematic—in my opinion, its relationship with incremental innovation may also be quite problematic. I agree with Cole and Matsumiya's following diagnoses:

(a) A quality culture may lead to be unresponsive to technology and market developments that shift demand to reduced quality requirements.

(b) A quality culture with a focus on user-led innovation for current customers may blind firms to product features that would be attractive in new markets.

(c) A reliability culture may not be receptive to new technologies that initially display poor reliability

(d) A quality culture can breed risk aversion and slowness. A focus on quality in an early stage of the product's planning process accentuates risk

aversion when evaluating new products and materials, especially when there is rapid change in technology and markets during the product development process.

According to the view sketched in the previous chapters, I would add two additional points, somehow related to Cole and Matsumiya's second diagnosis—both rely on the idea that the focus on the gap between perceptions and expectations is caused by misunderstandings of the definition of quality as meeting clients' needs and expectations:

(e) A focus on the gap between clients' perceptions and expectations plays against both incremental and disruptive innovation: in many cases, clients expect what is already conceived in the market and, what is more important, perceive according to that.

(f) In particular, the widespread practice to measure quality with customer satisfaction surveys also plays against both incremental and disruptive innovation: this may restrict firm's focus to what it did wrong in the past and caused dissatisfaction—by the way, dissatisfaction conditioned by what was already in the market. Any attempt to fix this can hardly be named 'innovation', neither disruptive nor incremental.

If we think of quality focusing on client's circumstances and purposes, then this allows intervening on quality in innovative ways—something that can barely be done asking clients. In order to set innovative quality criteria it can be useful to pay attention to unarticulated (and sometimes unconscious) needs and expectations. Such things have to be detected (and its correctness have to be checked) looking at circumstances and purposes. Donald Norman (2004) presents a similar idea:

"How does one discover "unarticulated needs"? Certainly not by asking, not by focus groups, not by surveys or questionnaires. […] Because most people are unaware of their true needs, discovering them requires careful observations in their natural environment". Norman (2004)

Design Issues

As noticed, QFD (Quality Function Deployment) is one of the standard techniques to link quality criteria to product features. From Design for Six Sigma to the idea of quality by design (Juran 1992) or Taguchi's work in DoE to find product features which fit with quality criteria in a robust way (Taguchi 1986), quality management always has had some interest in the process of product design.

Definition (5.8) [Means design]

In relation to quality, means design implies intervening in the shape of (multi-dimensional) joint probability distributions of relevant and

quality-related attributes of a means under development.[20] The same idea is valid for reproducible means to provide (product design, service design) and reproducible means to use.

Since processes are also means, a parallel definition can be drawn:

Definition (5.9) [Process design]

In relation to quality, process design implies intervening in the shape of (multi-dimensional) joint probability distributions of relevant and quality-related attributes of a process under development. Since a process is what makes a production setting generate discrete or continuous executions in a predetermined way, its design involves designing settings and how they generate executions.

From the previous two definitions, the following remark is now clear:

Remark (5.10)

Intervening on quality (in particular, quality improvement decisions) entirely depends on defining, choosing and restricting ourselves to a problem (in the technical sense of Chapters 3 and 4). So to speak, it implies a bet that may be won if the problem was correct and it is probably lost otherwise. Roughly speaking, a problem is correct if it fits with what can be done in a given situation—if it fits with the constraints of what can be done.

Planning and Control Tasks

Process designs have to be implemented by some form of onsite planning—process design is the aspect of quality management that is more intertwined with general issues of operations management; actually, overall process planning is a concern of operations management setting quality management aside.

Definition (5.11) [Onsite planning]

As a process is what makes a setting (or production setting) generate discrete or continuous executions in a predetermined way, onsite planning is the activity that is dedicated to arrange and prepare such a setting in order to perform concrete executions.

[20] Taguchi's ideas on robust design are particularly coherent with this approach. Not surprisingly, Taguchi also opposes himself to a conception of quality as a subjective value.

Some parts of onsite planning are specified through planning schemes in process design, while some other parts are unspecified and carried out unsystematically. When the unsystematic parts generate undesirable consequences, they have to be explicitly inserted in the design—this is what I have defined as standardization.

Undesirable consequences of such unsystematic activities are observable after process execution looking at some suitable set of attributes—otherwise quality-relevant attributes have not been adequately specified. The onsite control of such attributes allows gathering information about execution tokens in order to draw out knowledge about execution types—which have to be compared with the designed joint distributions of means and processes.

Therefore, the parts of quality management that are closer to process executions are focused on how onsite planning can affect quality-related variables and on how onsite control can monitor these variables. As in the case of planning, process control is also a concern of overall operations management setting aside quality management.

Definition (5.12) [Onsite control]

Onsite control is the activity of comparing concrete process executions (tokens) with the process design implemented through onsite planning (their type). Accordingly, it involves gathering information about tokens in order to draw out conclusions about whether the process design is being fulfilled. Therefore, feedback from onsite control to onsite planning can be a solution to lacks of fit between concrete process executions and onsite planning.

SPC is the traditional statistical approach to process control—since the attributes' monitoring has to take into account that quality depends on orderings on joint probability distributions, statistical thinking is an unavoidable feature of quality management. For instance, one of the main problems in onsite process planning is under- or over-adjustment as reactions to process behavior. Onsite planners can react precipitately to some anomalies and trends in some attributes. A statistical approach seems to be the best systematic way to judge whether hypothetical anomalies or trends actually fit with some distribution.

Standardization and Adaptation

As mentioned above, unsystematic ways to do things in onsite planning can generate variability, thus sometimes a good option is to move such ways to do things from on-site planning to process design:

Definition (5.13) [Standardization]

Standardization is the incorporation to process design of previously unsystematic ways to do things in onsite planning—thus making them systematic in that sense. It usually implies to establish rules or reference standards. It can be a solution to lacks of fit between onsite planning and process design.

In highly systematic manufacturing processes standardization avoids potential failures and diminishes variability, but sometimes it can have side effects. Especially in some service contexts, many forms of standardization can generate too much rigidity given the wide variety of situations that can occur in service environments. Furthermore, inertia in highly standardized processes can be a brake to innovation and, above all, adaptability. Nonetheless, some degree of flexible standardization is usually desirable—despite the fact that 'flexible standardization' looks like a contradiction in terms, it is not (provided it is interpreted as conditional standardization; i.e., when standards are used only if certain conditions hold).

Far from being necessarily a bureaucratic rigidity, standardization may have an adaptive role in quality management—keeping process design as a work-in-progress with the feedback from onsite planning.

On Improvement Decisions

What is valid of process design is also valid of process improvement. Processes are usually redesigned for many reasons; quality improvements are a major motive, usually carried out in order to fit with changes in the competitive environment or other organizational constraints. Other reasons beyond quality management may include cost reductions and productivity (increased efficiency).

Definition (5.14) [Process improvement]

Process improvement is simply process redesign. Therefore, it mainly consists in re-shaping the joint distribution of quality-related attributes associated to a process. It can be a solution to lacks of fit between process design and means design.

The widespread substantive 'quality improvement' is usually a mixture of two related concepts: process improvements and product (or service) improvements—in general, of process improvements and means improvements.

Definition (5.15) [Means improvement]

Means improvement is means redesign. Accordingly, it consists in reshaping the joint distribution of quality-related attributes associated to

the means. Therefore, it can be a solution to lacks of fit between means design and quality criteria.

The most significant improvement decisions (particularly radical or disruptive improvements, but also continuous or incremental changes) come from a main source:

Definition (5.16) [Rethinking reference preferences]

Rethinking reference preferences is the activity consisting in re-examining the problem that founded a previous quality attribution and its associated reference preferences. As it has been already repeatedly explained, the problem includes the actor's circumstances and purposes, the primary end, the target partial end, and a characterization of the considered alternative means. Rethinking the problem can be a solution to lacks of fit between quality criteria and the actor's circumstances and purposes.

Continuous or incremental improvements also can come from rethinking reference preferences because a problem can be refined and its formulation made slightly more accurate again and again. This improves our ability to discriminate significant aspects that are hidden in the details.

When quality criteria are wrong, most things in quality management fail for the obvious reason that each activity builds on a more general one. Quality criteria are the very basis of quality management—because of that, it is so important whether they are conceived as the client's opinions or as what actually should be of the user's interest given some purposes or circumstances.

6

Competing Through Quality

The present chapter is aimed at discussing a hypothesis concerning quality as a driver of profitability—namely, that quality is associated with entry barriers that are typically considered as weak. In order to analyze this hypothesis, I discuss some basic reasons to intervene on quality. Several considerations on the profit maximization hypothesis and other determining factors of organizations' structure lead us to make use of the distinction between means to use and means to provide. The focus on means to use leads to the question of how their ownership, control and integration can have an impact on their quality. On the other hand, the focus on means to provide leads to the question of quality uncertainty. Issues on quality uncertainty are relevant to understand the potential strength (or weakness) of some entry barriers. The original hypothesis makes sense on the basis that the role of quality as a driver of sustainable profitability depends on how it relates to different entry barriers.[21]

WHY TO INTERVENE ON QUALITY IN ORDER TO COMPETE?

Profit Maximization

Profit maximization is a common assumption for the theory of production in microeconomics. Since we are going to ask ourselves about the role of quality as a driver of sustainable profitability, some remarks are pertinent concerning to which extent firms are actually structured according to the objective to maximize profits. If they are structured to maximize profits, this has some relevance not only in the choice of which means to provide to clients but also on the role and purpose of the means to use.

One way to approach the problem is to consider a factor that plays against the profit maximization hypothesis (namely, the separation be-

[21] For a different view (though not entirely contrasting) on the issue of quality and profitability, see Zeithaml (2000). The paper focuses on the notion of perceived quality.

tween management and ownership and the existence of an agency relation between managers and shareholders) and then to consider why the actual effect of that factor cannot completely avoid profit maximization—namely, the existence of incentive contracts and several forms of discipline that increase manager's costs if he or she doesn't maximize profits: internal mechanisms like boards of directors, pressure from product markets and threats from the labor market or the capital market (Cabral 2000).

The argument builds on the agency relation between managers and shareholders—an introduction to agency relations and information asymmetries can be found in Chapter 7. If shareholders could fully control the firm, there would be no doubt that the firm's objective would be profit maximization. However, ownership and management are usually separated and quite often firms are owned by a large number of small and uncoordinated shareholders. In principle (setting aside incentive contracts), profits are just another success criteria for managers, perhaps not one to prioritize: they are more interested in avoiding risks that potentially could call their bluff, to avoid acquisitions from bigger firms that could lead to them being fired, or perhaps to fulfill short term objectives even though this could reduce some profits in the mid- or long-term. Firm's performance depends on managers and they have more knowledge about it than shareholders. Actually, profit maximization may be a not so widespread objective.

However, manager's incentives can be aligned to profit maximization through incentive contracts. In addition, boards of directors can hire, fire and set rewards for managers; although boards do not have the same interests that shareholders, they suppose an in-between control in the ownership's behalf. Obviously, highly competitive product markets also build pressure to managers to maximize profits, because otherwise risks in terms of market share or losses could be too large. In addition, managers have to respond to the discipline of market labor if they don't maximize profits: negative reputation can cut away their future professional opportunities. There are also threats from capital market: if profits are not maximized, then the firm's value lowers under its potential, thus it becomes attractive for mergers and acquisitions that could lead to firing the management staff. Therefore, profit maximization can suffer deviations but in the long-run there are mechanisms that assure that such deviations have limited effects.

Remark (6.1)

We could ask why firms want to intervene on the quality of what they use and provide. This question is a key one in order to understand quality management initiatives. The answer impacts on the determining factors of the firm's nature and on its boundaries. The answer cannot simply be that quality leads to profits and firms want to maximize

profits—the analysis has to be fairly more complex for most (if not all) of business activities.

Firm's Nature and Boundaries: Transaction Costs and Hold-Up Problems

Coase (1937) approached the problem of the nature and boundaries of the firm in terms of the transaction costs in economic environments with imperfect information. If transaction costs of market exchange are high, coordinating the production in a formal organization may be a way to reduce them in relation to market. In that sense, Coase's fundamental insight was that firm boundaries can be explained by efficiency considerations (Holmström and Roberts 1998). Explanations of firm boundaries have to build on the sources and typology of transaction costs in different situations.

Coordinating the production is not the unique aspect that explains the firm's existence and boundaries; providing incentives offer interesting alternative (perhaps complementary) explanations of the same phenomenon. This is the case of the hold-up problem. Let us assume that A must make an investment to transact with B. This investment has not a significant value in any use other than supporting the transaction between A and B. Let us additionally assume that it is not possible to design a (complete) contract that covers all the possible issues (relevant for sharing the investment's returns) that might arise in carrying out the transaction. Let us now see that if A pays for the investment then it is vulnerable to hold-up. Since the contract is incomplete, difficulties, that require negotiation between A and B, are very likely to appear after the investment has been made. In the negotiation B is in a much better position (the investment is already done and can only be used when dealing with B), thus B can impose harder conditions to A. Therefore, if A foresees that situation, it could decide not to make the investment. A mutually profitable dealing is not achieved. This is the hold-up problem.

If a sort of dealing relationship is vulnerable to hold-up problems, the solution might be, in some cases, vertical integration. In this sense, the firm's structure and governance can be regarded as a way to deal with hold-up problems.

Remark (6.2)

Efficiency considerations, in various forms, shape organizations. Efficiency is closely related to how well things work for certain purposes. Therefore, determining factors of quality and quality management decisions probably are interdependent with issues concerning the structure of the firm. Accordingly, the quality concept probably plays a role

in management beyond customer satisfaction—and, for that matter, employee satisfaction. [22]

MEANS TO USE: OWNERSHIP AND CONTROL

Means to use in production or service operations have not necessarily to be owned by the firm. Actually, the term 'outsourcing' precisely refers to giving over the property of some means to use. Since means to use can have differences in quality depending on whether they are outsourced or not (think of an IT maintenance process outsourced to a supplier), and hence different impacts on competition, the question 'why firms buy business units and/or give over other activities?' becomes relevant.

In other cases the issue of control may be not as evident as in the case of processes that are outsourced. Let us consider the example of any horizontally integrated group with SSU (shared services unit). The control of such services is given over by the firms in the group and concentrated in a separated unit. Services provided by the SSU to firms in the group obviously have better or worse quality as any other service. The firm's decision concerning the SSU can be understood in terms of transaction costs and ways to deal with hold-up problems, thus: (1) there are reasons (good or bad) for horizontal integration, (2) these reasons relate to foreseen, expected efficiency of SSU services, (3) the actual quality of the SSU services plays a role in the viability and efficiency of the whole structure (SSU plus firms), so (4) intervening on quality requires an understanding of the determining factors and rationale of the whole business system. A key task is to analyze how well some means to use work for some purposes depending on who has the control over such means.

In accordance, it is interesting to consider which factors make it possible for the vertical integration to actually decrease the long-term organization's efficiency: (1) lack of size in one of the vertically integrated activities to use all the possible scale economies that the other one provides with the integration; (2) spillover effects consisting, as Jarillo (2003) points out, in

[22] Efficacy and efficiency are concepts closely related to quality—as intuitively we all could agree. A more effective means, assuming all other factors held constant, is a better quality means. Quality depends on multi-attribute preference orderings; efficiency and efficacy depend on goals—the latter make sense about a unique option, the former needs of at least two alternatives to order. Thus efficacy and efficiency are usually restricted to the performance in a given attribute or a limited subset of attributes; quality necessarily refers to the conjoint behavior of all the relevant attributes for a means (we do not speak of 'oil consumption of better quality', but of 'more efficient oil consumption').

the fact that “mediocre activities of an integrated company will possibly be less profitable, systematically, than if they were carried out outside the company, since there is a ‘contagion’ or ‘spillover’ of high costs from the truly profitable activities”; (3) heterogeneity in corporate cultures can cause more or less conflicting decisions between the staff of the integrated and the integrator company, which of course play against efficiency; (4) increasing operational risks, since integration involves the transformation of variable costs into fix costs (the same reason that precisely motivates outsourcing), thus drops in sales can cause more than proportional drops in profits; (5) decreasing flexibility as a consequence of the higher operational risk (i.e., the adoption of new technologies is much more difficult if assets are owned and involve fix costs); (6) decreasing learning capacity in the long term caused by the loss of contact with external agents (specially suppliers) that have to keep moving to beat competence (the integrated company normally has as unique client the integrator); this also leads to (7) loss of control, since a supplier is controlled because of the threat of purchase to other suppliers, a threat that is not credible in most cases when the supplier is owned by its unique client . See (Jarillo 2003) for this discussion.

Of course, outsourcing has, in its turn, its own problems. In particular, any possible lack of other truly potential supplier alternatives can lead to a loss of control as well—i.e., if the supplier knows that a change would be too costly for the firm; in many contexts, changing suppliers is always costly. In other words, avoiding ownership cannot guarantee enough control unless the threat of dismissal is credible enough. On the other hand, a supplier for which the firm constitutes a high percentage of revenues (overwhelmingly in truly competitive industries) can be under perfect control avoiding the inconveniences of ownership. Other inconveniences may include (8) the risk of copy or disclosure of sensitive information; (9) the risk of having outsourced activities in one moment that later would be better not have to be outsourced regarding its intrinsic future profitability (for changes due to network effects, experience effects, scale economies or other factors explained later on); and again (10) the loss of contact with other actors that have a more vigorous and flexible knowledge of the industry and hence can generate profitable innovations.

Factors that can increase efficiency in the case of integration are fairly more specific. Again from (Jarillo 2003), we have: (11) decrease in costs due to the acquisition of key technology with the integration, (12) protect or increase a competitive position (e.g., when integration avoids disclosing information to external suppliers or allows the acquisition of valuable knowledge), or (13) lower transaction costs if the supplier-firm relationship is particularly expensive for some cause (for instance for the volume of transactions, the amount of detailed information that they require).

Remark (6.3)

In most of these factors the quality of means to use plays some role, Therefore, understanding the role of quality in competition implies understanding how the control of means to use can affect efficiency.

MEANS TO PROVIDE: QUALITY UNCERTAINTY

Akerlof (1970), "The market for lemons: quality uncertainty and the market mechanism", discusses why quality uncertainty and information asymmetries can avoid the existence of certain markets. In particular, markets of experience goods with information asymmetries and incentives for sellers to pass off defective units, can be barely developed if some additional conditions hold—i.e., sellers have no credible ways to convince buyers of good quality, quality differences are continuous, average quality is expected to be low, and absence of public warranties.

'Experience goods' is a term coined by Nelson (1970) and refers to goods whose quality cannot be experienced before purchasing; search goods are those that are not experience goods. Akerlof's model entirely relies on that assumption. In this context, the additional supposition that sellers have no credible ways to convince buyers of good quality is reasonable enough.

'Lemon' is a slang word for a car that is found to be defective only after purchasing. Akerlof (1970) builds a model that is aimed at showing why markets of used cars in which the abovementioned conditions hold, cannot exist. In Akerlof's used car market, cars that are not lemons are named 'cherries'. Previous owners of lemons and cherries have to decide whether they sell the car in the used market for some price. Since there is quality uncertainty and used cars are experience goods (and additionally there is no technical way to convince a buyer of a car's non-defectiveness), the buyers' best option is to assume that a particular car is of an average quality. Thus, in the long run potential buyers of such a market only will be willing to pay the price that corresponds to the average quality.

On the other hand, owners of cherries, cars of much better quality than the average, in the long run will not be willing to sell their cars in that market. Since this reduces average quality in the market, this begins a vicious circle: buyers will expect lesser quality in their state of uncertainty, so they are willing to pay lower prices, so cherries' owners will abandon the market, and the phenomenon would be repeated again and again. As a consequence, no market equilibrium exists: average quality decreased so potential buyers tend to disappear in the long run. The market vanishes.

Quality uncertainty and experience goods are important notions to understand some aspects of the quality concept's role in management. In par-

ticular, we can analyze the role of quality in competition depending on the existence or absence of:

(1) Information asymmetries

(2) Incentives to cheat

(3) Public warranties

(4) Continuous quality differences (so to speak, they have no jumps)

(5) Credible ways for sellers to convince buyers

(6) Low (expected) average quality in the market

Remark (6.4)

These market characteristics will be relevant so as to understand the strength and influence of some entry barriers later on—and thus how quality relates to these entry barriers.

QUALITY AND ENTRY BARRIERS

Entry Barriers

The relationship between market concentration, entry barriers and profitability, together with the relation between the control of business units and the determining factors of profitability maximization, provides us with the necessary conceptual basis in order to understand the role of quality as a driver of profitability, taking into account the quality of means to use as well as the quality of means to provide.

The key point to understand the role of quality as a driver of profitability is how quality relates to several entry barriers. Sustainable profitability does not only depend on the value provided to customers, but on the strength of the entry barriers for an activity performed by a company in order to create value. If entry barriers do not exist, new entrants have incentives to copy what a company is doing, thus profits are momentary and do not provide a sustainable advantage. Sustained profitability implies that a company can conserve, protect and capture the value that it generates.

I shall consider the following entry barriers—actually, it is a quite standard list (Johnson and Scholes 2006, Porter 1980, Jarillo 2003):

(a) Experience effects (or learning curve effects): costs decrease with time due to the fact that they have more or better knowledge about the process and/or dexterity in its execution. New entrants would have higher costs because of its lack of experience.

(b) Scope economies: average costs lower by producing several types of products; the reason is the existence of synergies between the production processes of each product. That is, $c(q_i, q_j) < c(q_i, 0) + c(0, q_j)$ where $c(\cdot,\cdot)$ returns the associated cost to produce certain quantities of two goods and q_i, q_j are produced quantities of goods i and j. New entrants would have higher costs to produce only one of the products.

(c) Reputation: it is the classical entry barrier associated to quality. Typically firms looked for a reputation offering outstanding quality. This is quite clear in the case of services. Moral hazard (see Chapter 7) can be an entry barrier of that kind (Farrell 1986). As Farrell notices, in markets of experience goods, one problem that any new competitor faces is to persuade potential clients that his product is of a high quality. In some occasions, buyers may be unwilling to buy from a new competitor, because buyers may foresee the possibility that the new entrant attempt to cheat buyers providing goods of low quality—earning short-term profits. Reputation is a guarantee for buyers and thus provides a protection to reputed suppliers. In a similar setting to Akerlof's, Farrell notes that reputation can smooth information asymmetries.

(d) Product differentiation: in the case of horizontal differentiation, a product with significantly different characteristics can be hard to beat if consumers have a strong identification with it; new entrants would have higher costs (for instance in advertising) to break down this privileged position. The case of vertical differentiation is precisely that of quality: better products can be more demanded by consumers. However, strong identification with better products with the same characteristics (thus not horizontally differentiated) is rarer unless stronger brands and loyalties are built through advertising, design and identity—both kinds of differentiation can be combined and are usually combined. Nonetheless, vertical differentiation can reinforce (and be reinforced) by reputation, so the combination of vertical differentiation and reputation may constitute a significant barrier to new entrants.

(e) Switching costs and network effects: network externalities appear when the consumer's associated value to owning a product is greater when the number of other consumers increases. Thus consumers want goods that more consumers have, and they have significant costs (loss of value) for changing to a good with fewer users. Technology is the best source of examples; e.g., technological standards and social networks. Mobile phone companies generate network externalities on the basis of the lower price that calls to phones of the same company usually have. Moreover, switching costs (the cost to switch from one company to another) radically protected company's market power in the industry's beginnings—nowadays different standards and regulations on MNP (mobile number portability)

are adopted in most countries. Note that switching cost sometimes are brakes to quality improvements, since they are not required to maintain a significant share—in fact, better quality products can be unable to beat stronger competitor protected by switching costs and network effects (who wants to join a better designed, more complete social network website if everybody belongs to another network?).

(f) Patents and legal barriers: patents are a classic barrier to protect innovative products. In fact, any intervention of the legal system to protect property rights may constitute an entry barrier to new entrants, since copy is the usual way to enter in an industry.

(g) Capital requirements: if significant investments are required to begin or maintain an activity, new entrants that do not have such a financial power are automatically discarded. In particular, there are many examples where establishment costs are rather dissuasive; e.g., oil refinery industries.

(h) Privileged access to distribution channels: if the distribution channel of a product is relevant to its success and not all competitors can have access to the best channel, the competitors that do have it are protected by such a privileged access. New entrants would have higher costs (or lower revenues) to use worse distribution channels.

(i) Scale economies: as noted above, new entrants would have higher average cost if they don't have enough scale. A firm protected by scale economies has enough market share to have (or tend to) the minimum total cost per unit—since it works with larger volumes. So it has a cost advantage over competitors with smaller share, thus they have more difficulties to conquer share to the firm, and so on—in a virtuous or a vicious cycle, depending on the point of view.

If we are able to identify which barriers reinforce quality improvements (or are reinforced by quality improvements) and we know their relative strength, then we may be able to make some hypothesis about the generic ability of quality to reach sustainable profitability.

Even though it depends on the industry and the particular competitive context, most authors would concur that scale economies, switching costs (including network effects), capital requirements or privileged access to distribution channels usually constitute strong barriers. Patents and other legal barriers can be strong as well depending on the context. In most occasions reputation and horizontal differentiation constitute significant but vulnerable barriers. Finally, experience effects and scope economies are considered to be weak barriers in many situations.

For instance, Porter (1980) alerts on the lack of power of experience curves to build significant barriers, in the sense that it is hard to find a case

in which experience constitutes an actual protection—perhaps specialized expert services concerning critical issues for the clients: given the criticality, nobody would take the risk of hiring a new entrant with no experience or less experience. Notice that barriers are not independent; in this particular case reputation reinforces (and is reinforced by) experience and probably by a sort of vertical differentiation.

For most entry barriers it is possible to find cases in which the strength is higher or lower because of particular factors that apply in a situation. Accordingly, the generic orientations that are usually considered as correct have to be checked in each particular case—i.e., they do not imply that scope economies will never provide a comparable protection to network effects or scale economies (only that they do not provide it in typical occasions).

Entry Barriers Associated to Quality

Perhaps the most important point in this chapter is to determine how quality interacts with entry barriers. That is, in how many ways quality determines or is determined by each one of the abovementioned entry barriers. This leads us to the concept of entry barrier associated to quality:

Definition (6.5) [Entry barrier associated to quality]

An entry barrier is more associated to quality to the extent that one or more than one of the following conditions hold in a significant way (the more the effect, the more the barrier is associated to quality):

(i) The efficacy of the entry barrier increases (decreases) with improved quality (lost quality).

(ii) More effect of the entry barrier generates more future capability to achieve further quality improvements.

(iii) More effect of the entry barrier impedes new entrants to achieve the firm's current quality level.

The table in the next page shows a classification. Some values admit several interpretations and rely on particular criteria. A short justification and explanation of the criteria used in each row is as follows:

(a) Experience effects are stronger barriers if processes are better or more innovative. Experience can be accumulated, thus more learning effects implies (in principle) more capability to achieve further improvements. More experience effect may make it harder for new entrants to copy the firm's current quality level.

	Efficacy as entry barrier increases (decreases) with improved quality (lost quality)	More effect generates more capability to achieve further quality improvements	More effect impedes new entrants to achieve the firm's quality level
Experience effects	YES	YES	YES
Scope economies	YES	NO	NO
Reputation	YES	NO	NO
Product differentiation	YES	NO	NO
Switching costs and network effects	NO	NO	(YES)
Legal barriers	NO	NO	(YES)
Capital requirements	NO	(YES)	YES
Access to distribution channels	NO	(NO)	YES
Scale economies	NO	NO	NO

(b) Scope economies are stronger barriers when processes are better or more innovative. *Per se*, scope economies do not increase the capability to generate further improvements. They constitute a barrier on the basis of the production cost, but in general nothing impedes new entrants to copy the firm's quality level.

(c) Reputation is a stronger barrier when products and services have better quality. *Per se*, reputation does not increase the capability to generate further improvements. More reputation does not impede new entrants to copy the firm's quality level.

(d) Product differentiation is a stronger barrier when products and services have better quality. *Per se*, product differentiation does not increase the capability to generate further improvements. More differentiation does

not impede new entrants to copy the firm's quality level—even though they can make it harder to gain market share. In general, here we assume horizontal differentiation or mixed differentiation (horizontal + vertical).

(e) Switching costs and network effects are not stronger barriers if products have better quality—actually, they can have rather poor quality and the network effect can still work well enough. In general, they do not facilitate further improvements. However, if we include the quantity of users as a quality attribute (as it is reasonable in most cases; e.g., social networks), they impede new entrants to copy the firm's quality level.

(f) Patents and legal barriers, *per se*, are not stronger barriers if products have better quality. In normal cases, by themselves they do not generate further improvements—they only protect the possibility of generating them without copy threats. If we consider the possibility to copy the same product, obviously patents impede new entrants to copy the firm's current quality level. Nonetheless, nothing in the legal protection impedes new entrants to achieve the same level with a significantly different product.

(g) Capital requirements are not stronger barriers if products have better quality. In some way, a firm that is protected by capital requirements in one of its activities presumably would have some financial capacity; more financial capacity tends to facilitate the achievement of further improvements (nonetheless, strictly speaking capital requirements in the activity, *per se*, do not involve more achievable improvements in any other reasonable sense). In general, if capital requirements are an entry barrier to an activity, they also impede new entrants to copy the current levels of quality in this particular activity.

(h) Privileged access to distribution channels does not become a stronger barrier if products improve their quality. Privileged access normally does not facilitate the achievement of further improvements in a particular and significant way—even though we can think of possible exceptions if the distribution process becomes a condition to carry out some activity that otherwise could not be performed. Nonetheless, privileged access impedes new entrants to copy the current levels of quality in the distribution process—provided that the channel is truly better.

(i) Scale economies have little to do with quality. In general, the effect depends on the quantity, irrespective of the quality of what is produced. Therefore, they do not become stronger barriers if products improve their quality. More scale economies *per se* do not facilitate further improvements in any reasonable sense. They do not impede new entrants to achieve a given quality level—even though they can impede them to do it at a competitive cost.

From these explanations, notice that, in most cases, each entry barrier relates to the quality of one kind of means (when it does it):

(a) Experience effects: means to use
(b) Scope economies: means to use
(c) Reputation: means to provide
(d) Product differentiation: means to provide
(e) Switching costs and network effects: means to provide
(f) Patents and legal barriers: both, means to use and means to provide
(g) Capital requirements: means to use.
(h) Privileged access to distribution channels: means to use.
(i) Scale economies: it doesn't relate significantly to quality.

QUALITY AS A DRIVER OF PROFITABILITY

A major theme in this thesis is that quality is not equivalent to value. There are valuable things that are of a poor quality, and good quality things that may be not valuable. Even without the existence of cognitive biases, better quality does not necessarily provide more value—since value may depend on a concrete, particular situation while quality depends on types of circumstances.[23]

In addition, more value does not necessarily provide more medium- and long-term profits. As noted above, stable profitability does not depend on the value provided to clients, but on the strength of the entry barriers for an activity of the business model. Without entry barriers, new entrants have incentives to copy what the firm is doing: the firm is still offering value, but profitability lowers. Without entry barriers, increasing value only yields momentary profits, not sustainable advantage. Sustained profitability appears when a company can conserve, protect and capture the value that it creates—with quality or without it. Profitability, in other words, depends on the competitive context, not only on value (Jarillo 2003).

Remark (6.6)

Quality itself cannot be an entry barrier. Supplying things that work better for a given purpose never will constitute an entry barrier in its own right. That fact has a direct consequence: quality by itself (without the protection of any other entry barrier) cannot be a driver of sustainable profitability.

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[23] From a rather different viewpoint to that that is adopted in this thesis, Zeithaml (1988) presents a conceptual model of the relation between price, quality and value from the viewpoint of customers' perceptions.

Remark (6.7)

However, if (A) quality is capable to generate profits, and (B) there are entry barriers associated to quality, then quality can provide a competitive advantage.

If at least one of the two conditions does not hold, quality will not be a source of sustainable profitability.

Managers and entrepreneurs who are interested in quality should understand both issues: how quality can generate profits, and which entry barriers associated to the existence of quality.

Remark (6.8) [How quality can generate profits]

To generate profits, quality has to be sold at a higher price than costs to obtain it.

Surprisingly, such an obvious principle generates confusion. This is one of the main themes in this thesis: that quality has to be sold does not necessarily imply to focus on what people ask for—minimizing gaps between perceptions and expectations, of course, usually is tantamount to focusing on what people ask for.

In fact, a focus on what people ask for simplifies the question A (how to generate momentary profits), but it may be easily replicable—so it makes the question B more complex, how to build entry barriers. That's not to say that it is necessarily a bad strategy in relation to quality. If the activity has entry barriers due to other factors, it may suffice.

Remark (6.9) [Quality and entry barriers, summary]

Entry barriers can be combined. Actually, entry barriers associated to quality usually fall in a mixture of reputation and differentiation together with slightly experience effects and, perhaps, some scope economies.

That is, the typical case of quality as a successful driver of profitability is that better designed processes from the point of view of quality generate better reputations and stronger brands and loyalties (differentiation). The improved designs of these processes enhance the effect of experience in their performance: new entrants have slightly greater costs to copy them to the extent they are more innovative processes. In the particular case that these improved processes are used in different products, costs are shared out between them: new entrants would have greater costs to copy them in only one product.

Therefore, a generic hypothesis is that it is not easy to build sustainable advantages on the basis of quality and its associated barriers alone.

Most reputations are unstable: hard to build, easy to lose. Differentiation does not usually depend only on quality. Learning curve effects provide weak barriers. Quality only enhances, but hardly creates, experience effects and scale economies.

Patents would be the most reliable entry barrier associated to quality, but its actual role to justify the profitability that is generated by quality improvements is negligible: most quality improvements, obviously, cannot be patented.

Stronger entry barriers (scale economies, switching costs and network effects, privileged access to distribution channels, or capital requirements) do not particularly relate to improved quality. Some exceptions may appear in the case of access to distribution channels and capital requirements.

As a conclusion, quality is not a driver of sustainable profitability by its own right, but it can have a complementary role to an entry barrier associated to quality in the sense of (i) in Definition (6.5) above (the efficacy of the entry barrier increases with improved quality and decreases with lost quality): experience effects, scope economies, reputation, and horizontal product differentiation.

I believe that the question about the competitive function of quality setting profitability aside is somehow wrong; in competitive environments, sustainable profitability may not reflect all of the firm's interesting abilities, but it does reflect its actual long-run competitive strengths. In particular, I downplay the long-run competitive relevance of any quality improvement if it has not an associated entry barrier in some way. For the reasons that I have previously discussed in this chapter, firms and their managers are compelled to long-term profit maximization—even though managers have incentives to prioritize short-run profits. Thus most decisions that are significant to competition sooner or later must have an impact on profitability.

However, that's not to say that quality is important only if it generates profits. Actually, it is not only that here I am studying specifically its role in competition, but that profitability has many aspects:

Remark (6.10)

Any complementary role of quality in competition must have a translation in some aspect of profitability (perhaps on the long run)—i.e., profits' variability, sustainability, seasonal periodicity, and the like.

Moreover, the quality of means to use can reinforce other operative strengths when:

(1) It increases the efficiency, reliability or durability of a critical technology.

(2) It reduces the inconveniences of (thus it makes it achievable) a cost reduction in other processes.

(3) It reduces warehousing; e.g., means to use (processes and the like) that make a just-in-time system possible.

Such complementary roles are important, but they have not to be confused with drivers of sustainable profitability by their own right. They only have a long-run competitive role if there is a key technology, if a cost reduction is a correct strategic move, or if warehouse reduction makes actual competitive sense—respectively. If the protection of the main objective disappears, these particular quality benefits disappear to some extent.

Therefore, (a) firms with existing competitive advantages will be able to use quality in some way related to profitability, and (b) for firms with a weak competitive position, quite likely quality will not be a reliable long-run solution in order to gain a competitive advantage. Particularly (b) it is not a rigid law; exceptions may arise in several concrete situations.

Remark (6.11)

These statements do not subtract relevance to quality; however, in the specific case of competition, quality has to be embedded in a more complex system of profitable activities and entry barriers.

The belief that quality is tantamount to client satisfaction in such a way that it yields sales increases and hence higher profits is simply inadequate to many usual competitive environments.

ADDENDUM. DIFFERENTIATION AND PRICE DISCRIMINATION

Price discrimination provides a straightforward example that considerations concerning quality have to be made under a more complex analysis of profitable activities and competition. From the viewpoint of pricing, quality may be not something to improve and maximize, but something to play with in order to implement better pricing policies—the reason, of course, is that many people are not willing to pay for quality that they don't want.

Price discrimination is the practice of setting different prices for the same good or almost the same good, depending on buyer's characteristics and sales clauses (Cabral 2000). This is a common phenomenon—especially nowadays, when on-line sales can sell goods or services in different conditions (e.g., very short time between sale and service) and

clauses (e.g., cancellation policies). Flights or theatre shows are usual examples.

Price discrimination does not appear in the standard description of perfect competition, where goods not only are undifferentiated but have only one price in function of quantity. In perfectly competitive markets there is perfect information and as many suppliers as required, thus actors always would buy at the cheapest available price and price discrimination would disappear in a market equilibrium.[24]

Sellers can discriminate prices (a) on the basis of observable buyer characteristics or (b) inducing buyers to self-select among offers—actually, sellers also discriminate prices when (c) they have knowledge enough to fix a price for each product and buyer (e.g., Boeing or Airbus pricing aircrafts to airlines; Cabral 2000). This classification actually corresponds to different degrees of uncertainty about individual buyers and their segment: almost negligible in (c), sufficient to define the segment on the basis of observable characteristics in (a), certainty about how the segments are but total uncertainty about whether a buyer belongs to one segment or not, in (b).

The second type of price differentiation (b) is relevant to understand some issues concerning quality. In the attempt to indirectly classify consumers by segments, firms change the way in which products are marketed. There are two ways to do that with some implications to quality: versioning and bundling.

Versioning is the classical mechanism of price discrimination: offering different mixes of price and quality, buyers classify themselves according to their willingness to pay for better options. An example is classes in airlines or other travel services (first, business, economy). Another case is that of reducing quality to discriminate prices:

Definition (6.12) [Intentionally damaged good]

Selling (systematically and intentionally) damaged goods is relatively frequent in some industries. This is not just selling lower quality products, it is incurring in additional costs to actively reduce the quality of versions of an already existing product.

(This phenomenon must not be confused with selling defective units at a lower price.)

[24] Just as a side issue: as Cabral (2000) points out, in actual more or less concentrated oligopolies with imperfect information, price discrimination exists to the extent that there are not clear opportunities of resale. In activities such that resale is not possible, illegal, difficult and/or expensive, there is more price discrimination.

Cabral (2000) discusses some cases in technology, from disabled co-processors in microprocessors, to wait states inserted to reduce speed print in printers, or labels with false recording capability in recordable discs—as if it were lower than what it actually is.[25] In all these cases, the resulting means is comparable with the initial one but it has worse capabilities to carry out the intended action and worse expected consequences.

Remark (6.13)

The damaged means is comparable with the initial one and has worse quality—to the extent that, setting aside cost considerations (which are not relevant to the quality concept), the user should choose the non-damaged version given his circumstances and purposes.

The point is that the user has to carry out some action with the product and given his circumstances and purposes the initial means would be presumably better. A very different thing is whether he is willing to pay for a better means, or not—in fact, if versioning actually works as a discrimination strategy, there are clients that are not.

Bundling refers to how products or services are packed to sale them. Different available bundles with different prices can induce buyers to classify themselves in the adequate segment according to the willingness to pay for one bundle or for another. This can lead to revenue maximizing combinations of price and potential demand.

Pure bundling occurs when buyers have to purchase a bundle or nothing—as it may occur in some academic programs (bundling courses). Mixed bundling occurs when buyers can purchase a bundle or a separate part—a usual case is that of products with or without support or after-sales services; another example is that of the software suites of several programs.

Remark (6.14)

The bundle's quality can be different from its components' quality—think of a product with or without a support service. Actually, they are two different means with different capabilities as helps to carry out an action.

That is, even though in terms of products and services versioning and bundling are different strategies, in terms of means bundling is a special

[25] As a complement to the discussion in Chapter 2 about the components of means, the example of discs' labels shows a case in which the two means with almost the same components (in that case, almost the same physical device) are different because contents differ.

case of versioning—there is a complete means which is actually available but the company sells partial, worse quality means in order to discriminate prices. As a conclusion:

Remark (6.15)

At least in competitive environments, the quality of means to provide may be something that is not necessarily done in order to improve and maximize. Since it can be considered as something to play with in order to conduct better pricing strategies and policies, there is a need to separate the quality concept from other related concepts and some slogans—i.e., to separate the quality concept from the alleged fact that "the client is number one" or "the client is king".

7

Information Flows' Quality

This chapter is aimed at presenting an example (about information flows' quality) to show a particular case in which a more rigorous definition of quality is needed—i.e., an example of cases where an understanding of quality that is based on the ideas of product, client, expectation and perception is not well-suited to their analysis. The chapter explains what information flows are and discusses some of the features which are relevant in order to understand their quality.

AGAINST THE DATA – INFORMATION – KNOWLEDGE HIERARCHY

The DIKW (Data – Information – Knowledge – Wisdom) hierarchy states that information derives from and improves data, knowledge derives from and improves information, and wisdom derives from and improves knowledge. It can be explained in the following way:[26]

(a) Data is the representation of facts about things. Data is a symbol or another representation of some fact about something.

(b) Information is meaningful data. Data is the raw material from which information is derived. Information is data in a context. Information is usable data.

(c) Knowledge is not just known information; it is information in a context. Knowledge means understanding the significance of information.

(d) Wisdom is applied knowledge. It emerges from it by means of intelligent learning processes.

[26] Classical references about the DIKW hierarchy are Zeleny (1987) and Ackoff (1989); Rowley (2007) provides a good summary. Points (a) to (d) are extracted almost literally from English (1999), pp. 17-20.

This conception may be useful for some purposes, but I will argue that it is deficient to most applications concerning quality, process improvement, and improvement decisions in general.

We people, and particularly statisticians, extract information from data. However, from that we cannot infer that what defines information is to be obtained from data—that is, that information is distilled and meaningful data. Primarily, facts carry information; this is the reason why information is useful. The fire alarm carries information about the presence of smoke, and the presence of smoke carries information about the presence of fire. It allows us to leave the building and save our lives. What define information are not symbols or representations of facts about something, but facts connected to other facts.[27]

Data have to be generated by information capture and coding activities (i.e., measurement): in general, only if these activities are well-performed, data will carry enough information about facts. If there are capture and coding errors, data may be not as informative as they should be. What define data is to be generated from information capture and coding activities.

Information is not meaningful data: on the contrary, meaningful data are data that carry information about certain facts. This is the reason to why people (and statisticians among them) can extract information about facts from data. If we are not actually interested in these facts, that's not to say that data were not informative.

If information were meaningful data then everything informative that were would have to be a datum (a representation of a fact about something). Of course the presence of smoke carries information about the presence of fire. However, the smoke is not a representation of any fact, it is not a datum.

Some people would claim that they do not use the term 'data' only referring to representations of facts about things. The presence of smoke is itself a datum: data are facts taken to be evidences for an inference. This is similar to 'datum' in its etymological sense of something given (to reasoning, to inference). Nowadays, everybody uses the word 'data' as a sort of

[27] There is no need of a very rigid conception of what facts are in order to make this statement true—actually, no particular conception is assumed. Speaking extremely loosely, I would define a fact as what is going on in a certain situation, thus the device we use to individualize things, states and events when we carry out actions in a given context—Barwise (1989) is a useful reference on the puzzling distinction between facts, situations, relations inside situations, and true propositions. Actually, I would be even willing to admit, with Goodman (1978), that fact and fiction are certainly different, but not on the ground that fiction is fabricated and fact found. Therefore, the claim that information emerges from facts connected to other facts is not so restrictive—see Appendix 3.

representation, despite that some people also use it as evidence which is available for reasoning.

In this sense, 'data carries information' simply means that facts carry information, since data are just facts taken to be evidences. I completely agree. The problem is that for most people the rest of the DIKW hierarchy does not change: information is meaningful data (evidences put in context) and 'knowledge' means understanding the significance of information. However, as it has been mentioned before, evidences which are available for reasoning come from information from the environment: this is precisely what making evidences available for reasoning means—to notice connections between facts. This is the reason why the fact that data carry information and reasoning on their basis can be useful.

Remark (7.1)

In any sense of the term, data derives from information carried by facts—that is, from connections of facts to other facts. This is exactly the contrary that information derives from and improves data.

Trivially knowledge is just known information. Of course, there is useless knowledge. I know that Paris Hilton has owned a dog. This is knowledge, but not because it is information put in a context in which it acquires special significance. This is knowledge because I know it. If I am wrong and Paris Hilton has never owned a dog, this is not knowledge because actually I cannot know something that is not the case—not because it is not information put in a context. Arguably, that Mr. Smith has the knowledge that P simply means that Mr. Smith knows that P. According to the point (c), Mr. Smith can know that P but not to have the knowledge that P—which is almost a *reductio ad absurdum*.

The study of information flows is interesting to process management. They are important processes by their own right; furthermore, many processes include information flows as sub-processes. Quality experts will not be able to deal with information flows with conceptual tools such as the DIKW hierarchy which do not show *why* and *how* the presence or absence of signals, events, things, actions or whatever carry information.[28]

Actually, the information concept is useful in process management precisely if it refers to connections between facts which are relevant to decision making. Other usual senses of the term, in which information means meaningful contents and particularly meaningful digitalized contents, are

[28] My understanding of the concept of information comes from, among others, the following works: Dretske (1981), Barwise and Perry (1983), Barwise (1989), Barwise and Seligman (1997), Devlin (1991).

useful to other purposes, but hardly regarding how to manage processes and how to make improvement decisions.

INFORMATION FLOWS AS REPRODUCIBLE MEANS TO USE

Information Flows

An information flow is a process in which information is moved from the environment in which it is generated to decisions. In each flow's execution, some information is captured from the environment and moved through different steps to a decision or an action that is going to be performed according to the information. As a process, it is a mean to an end—namely, a reproducible means to use. The end is to obtain knowledge about a situation, normally in order to make some kind of decision.

Non-reproducible information flows are not considered in this thesis. In accordance, how the information should be managed in some sort of occasional crisis (a scandal, an accident or whatever) is out of the scope of my research. Likewise, even in the case that an information flow could be taken as a reproducible means *to provide* (e.g., an informational service), this is not the case I consider here.

Two cases that presented later on in the thesis provide two examples of information flows. Any regular process of complaints management is an information flow. In the case that will be discussed further along, the flow begins when a citizen obtains information about a situation or event in the city. It continues when such information is captured by the city council through different specific communication channels. The flow performs several steps until an answer is given to the citizen and/or a solution to the problem is planned or executed.

A process of hiring needs' analysis in a university is another example of information flow. The relevant information to human resources' decisions includes hours of teaching that have to be given during a period of time (needs) and the number of available professors to give them (capacity), taking their respective profiles and experience into account—as well as research dedication and other occupations, retirements, sabbaticals, and so on. This information has to arrive to a decision maker who has to make the decision. As we shall discuss, this apparently straightforward process is quite complicated due to information asymmetries and subsequent phenomena of adverse selection and moral hazard. At any rate, information about the environment is regularly moved to a decision to modify it—professors that have been hired or fired are an obvious modification of the environment.

In these two examples there is a substantive process that mainly consists in moving information to make decisions. In other cases, information

flows can be sub-processes of more general processes. Actually, this is the typical case in process control—the information that is generated by a process is captured in order to control it. In process improvement, there is an information flow that moves informative contents about facts which have occurred in the process to improvement decisions. Of course, the same information flow can be used for different purposes—i.e., performing a regular onsite control or obtaining information in order to design a radical improvement.

Definition (7.2) [Components of an information flow]

As processes (and reproducible means), information flows involve components such as auxiliary actors and technology—in many occasions, that physical setting is the organizational system that performs the flow, and it may include wireless technology, presentation devices, meeting rooms, physical archives, servers, and many other things.

Contents (more precisely, informative contents) are the main component of information flows—in the sense that flows accomplish their aim as means by providing an informative content to somebody.

Moves can be categorized in some informational tasks:

(1) Information capture } Measurement
(2) Coding }
(3) Representation
(4) Storage
(5) Retrieval
(6) Analysis
(7) Interpretation
(8) Decision

There can be even more steps, but for the sake of simplicity I will assume that any other can be taken to be a sub-step of one or more of the ones that have been listed above. As in the case of measurement (information capture and coding), it is also possible that other steps are combinations of some of the listed ones.

Disconnections

Any information failure causes a disconnection in the flow, and hence a modification of the content that is carried by the different parts of the system. In the worse case, the content which arrives to the last actor may even be not informative about the situation. It is also possible that some informa-

tive contents were lost while others remain, in such a way that the output of the flow is only partially informative.

Remark (7.3) [General analytic methodologies]

The abovementioned informational activities can be regarded as similar activities to those which appear in any other process. Therefore, usual techniques like process mapping and failure modes' analysis are useful to analyze information flows' disconnections.

A complementary way to carry out an analysis of an information flow and its potential disconnections is to describe the system which performs the flow (people and technology which are involved in it) and define the different states through which it passes. A system's state can be defined by any change in an actor knowing or having a piece of information and/or a technological item storing or having informative contents—a balanced level of detail has to be achieved. Recall that we are talking about a stable, repeatable, structured process. We are interested in how well transitions between states are performed—information flows' quality depends on correctness criteria about transitions in such systems; so to speak, transitions can be analyzed as lower-level partial means to perform the flow.

On the basis of the description of the system and of its states and transitions, standard techniques such as failure modes' analysis can be used. A more or less closed list of informational activities allows us to study frequent errors in a systematic manner.

(This was the approach that was used in the two actual cases which are described further along.)

INCENTIVES AND ASYMMETRIES

Agency Relations

Actors that are involved in an information flow have interests, sometimes in conflict. They may have incentives to use the information they have to gain in their advantage having some interest conflict.

This is very usual when somebody carries out an action on the behalf of somebody else. This is exactly the context that we find when we speak of auxiliary actors in means in general and, specifically, in information flows. This kind of relation between people is named agency relation and leads to *the principal – agent problem*—see Rasmusen (2001) or Tirole (1988).

We speak of an agency relationship when someone (an individual or an organization) depends on the action of another person or group of persons. The person who performs the action is called the *agent*; and the per-

son who depends on the agent's action is the *principal*. The shareholders of a company are in an agency relationship with the company's executives: shareholders are the principal and executives are the agent. At the same time, workers of this company are agents of an agency relationship in which executives are the principal. Similar relationships occur between patients and physicians, clients and lawyers, university departments and university rectors, professors and students. The ubiquity of relationships in which somebody determines the main aims and objectives (usually with bargaining power) but somebody else has the ability, knowledge and information to do the work, makes it understandable why agency relations have such an importance in economics or law.

The most interesting case of agency relation is when the principal cannot control actions of the actor without incurring in significant costs. For example, shareholders cannot easily control the actions of the executives, not because they lack of the technical knowledge to do so, but because they cannot observe all of their actions. A lawyer's client (or a doctor's patient) can usually observe what he does, but he rarely has the technical knowledge to figure out whether these actions are the best options to achieve his purposes. In all these cases there are information asymmetries, since the agent knows things that the principal ignores, but they take different forms: unobservable actions or hidden knowledge.

Information Asymmetries

Information asymmetries cause inefficiencies known as agency costs: the costs in which the principal incurs because he cannot control the actions of the agent. If the information would be disclosed without limitation, there would be no agency costs—even when principal and agent would still have conflicting interests. The principal would have control over the agreement or contract that satisfies his interests. Furthermore, he would also control that the agent's actions would be performed according to the agreement.

These are the two most basic reasons of information asymmetries in the literature. When the principal cannot know whether the arrangement meets their interests before signing an agreement, we speak of *adverse selection*. When the principal, after signing the agreement, cannot know whether the agent's actions are performed according to the agreed terms, we speak of *moral hazard*. Both names come from information asymmetries between insurance companies (principals) and insured persons (agents). The company cannot know whether the insured is actually the kind of person (healthy, responsible) that he claims to be before selling an insurance policy. If the company cannot distinguish responsible people from these who are not, then the terms of the insurance policy will tend to disserve those that are more responsible: they will pay part of the risk of

people who are less responsible—this is the reason for the name 'adverse selection'.

After signing the insurance policy, the company cannot easily control whether the insured behaves recklessly in the terms of the contract—for example, whether he adopts unhealthy habits or neglects his house security. This is a case of moral hazard. Adverse selection depends on hidden information; moral hazard depends on unobservable actions. Both phenomena make the agent have more information than the principal.

Contracts or agreements should establish systems of incentives and mechanisms to minimize the agency costs and the loss of efficiency. In the case of moral hazard, incentives should be focused to ensure that the actor observes the agreement. In the case of adverse selection, mechanisms must be designed in such a way that the actor would have incentives to provide the required information.

These patterns are critical in information flows' analysis. Information asymmetries almost necessarily create the need to establish agreements which modify agent's incentives to disclose information and/or observe covenants. If there is no actual and significant intervention on incentives, there is no way to improve information flows affected by agency relations and information asymmetries.

Remark (7.4)

The attributes to assess the quality of information flows can be varied: accuracy, consistency, timeliness, completeness, reliability, precision, relevance, clarity, conciseness, understandability, and so on. Most of them conjointly collapse if an actor has incentives to do not disclose information or to hide what he is actually doing. Therefore, information asymmetries are a key factor of information flows' quality.

COHERENCE

Since we think of information flows as repeated and more or less structured processes, usually there is some kind of predetermined decision to be made with the information provided by the flow—this is the case of complaints management or hiring needs analysis.

In some occasions, moved informative contents are not actually coherent with the decision to make. More importantly, the design of the information flow may be not really coherent with the kind of decision to make. Some examples will make this point clear.

Sometimes information flows are established because there is an intention to obtain data, but there is no clear idea of what has to be done with such data. It is assumed that some kind of decision will be made, but this

decision is ambiguous or insufficiently specified. Amounts of data are accumulated for indeterminate time periods; all-purpose reports and data summaries are produced, but they are not actually oriented to a specific decision—at best, they give an impression that some part of a process can be controlled, if needed. Occasionally, perhaps an occasional need appears and somebody tries to carry out a specific data analysis in order to make a decision. The frequent outcome is that the data has been captured and codified in such a way that it is not actually suitable to make a proper analysis. The consequence is that the information flow design is modified according to the occasional need, and the sequence re-starts again.

In this case, the lack of coherence comes from the weak specification of the decisions to make according to the moved information. Sub-cases appear when there is more than one thing to do with the information, but the flow's design is not adequately balanced to correctly respond to all of the intended purposes—a case study in the ensuing sections can be seen as an instance of that situation. Conflicts of interest, information asymmetries and anomalies in the organizational structure can cause that such situations of multiplicity of purposes remain for long time periods.

In other cases, the lack of coherence comes from differences in the organizational structure assumed by the information flow's design and the actual organizational structure's relevance in decision making. This situation appears when the official hierarchy in an organization does not correspond with the actual balance of power or responsibilities. Information flows can be designed to provide information to people that has a weak actual role in some decisions, while more relevant people are not adequately informed. Again, despite the fact that such distortions are easy to diagnose, conflicts of interest, information asymmetries and anomalies in the organizational structure can cause them to remain for long periods.

Coherence problems concerning information flows can be systematized by looking at which elements have to be matched between aspects in the information flows' design and aspects of the organization in which they appear. Information flows assume, at least, the following elements:

(a) A decision to be made.

(b) An organizational structure and some formal or informal communication channels in the organization that have to respond to that structure.

(c) A time horizon which is relevant to the decision (including information update timings).

(d) A technology to be used

Any of these aspects, that have been assumed by the information flows, can be mismatched with the actual decision (or lack of decision), the actual

organizational structure, the actual time horizon required by the decision, or the actual technology that the organization wants to reinforce, respectively.

Remark (7.5)

Organizations and information flows are complex: both involve groups of people with different interests, mindsets, perspectives, and categories to perceive what is going on in the organization. Differences of interests and languages (in the broadest sense) cause incoherencies between information flows and the organization in which they appear. In a quite obvious sense, such incoherencies are a threat to the quality of information flows. As in the case of information asymmetries, most of the quality attributes we could think of, collapse if flows show a lack of coherence.[29]

CASE STUDY 1: COMPLAINTS MANAGEMENT IN A CITY COUNCIL

Case Description

Esplugues del Llobregat is a city of 46,500 inhabitants adjacent to Barcelona, the capital of Catalonia and Spain's second largest city with 1,615,000 inhabitants in 2010. It is part of the county of Baix Llobregat (800,000 inhabitants). In 2010, its average GDP per capita (25.7 thousands of Euros) was just slightly under that of Catalonia (27.3 thousands of Euros), even though its gross disposable household income (17.1 thousands

[29] To my mind, there are many conceptual mistakes in most of the information and data quality research, and particularly concerning "information quality dimensions". In short, some basic distinctions are not observed—e.g., informative vs. non-informative contents, contents vs. carriers vs. activities, carrying information vs. having information vs. knowing, information vs. data vs. knowledge.

For instance, Lee, Pipino, Funk and Wang (2006) write: "managers typically use the traditional distinction between data and information: data comprises raw facts or materials, and information is data that have been processed. One person's data, however, may be another's information. In one information system, for example, the input is raw data and the output is information, but if the output is then fed into another information system, then this output information would also be input data. Whether input data is the product (output) of a previous process is not necessarily known at all times. Because such ambiguities sooner or later arise [...] we use the terms *data* and *information* interchangeably throughout this book." Many errors come from taking the paradigm of product quality in the traditional sense—this is the explicit approach of Wang (1998). See English (2009, 1999), Redman (2001), Wang, Huang and Lee (1999), Pipino, Lee and Wang (2002).

of Euros) was slightly greater than that of Catalonia (16.9 thousands of Euros). As a reference, the GDP per capita of Spain in 2010 was about 23 thousands of Euros, which implies a +3% respect to the EU-27 average in PPP (purchasing power parity). The percentage of population born abroad is the same that the overall one in Catalonia (17%).[30]

Esplugues' municipal government has enjoyed political stability and fairly managerial continuity since the early 80s. Initiatives to establish a management system have had a sustained political support and they have succeeded to a large extent. It adopts the EFQM European Model in 1996. In 2000 it wins the Premio Iberoamericano de la Calidad (Latin American Quality Award).

In 2010, the city council's budget was of 49.2 million Euros, a variation of about −6% in comparison to 2009 due to the economic crisis. About a 30% of the budget is allocated to investments and a 70% to ordinary operations. From that 70% (35.6 million Euros), about 371.000 (1.04%) are dedicated to a network of advice centers and information services to citizens. The network consists in four *punts d'atenció a la ciutadania* (citizen advice offices or citizen service points), a free phone number, and focused capabilities in the webpage *www.esplugues.cat*. In addition, the local police and specific personnel called 'civic agents' make informative and advice tasks in the streets.

The council publishes a set of service commitments, 132 at the moment of our intervention in 2010, divided in several activity areas: security, environment, citizenship, and services to people. The process of complaints, suggestions and observations management ('complaints management' for short) is a key one from the viewpoint of both council's managing director and the mayor—thus some service commitments are referred to it. For instance, up to 48 hours after receiving a complaint, a courtesy contact has to be made indicating that the issue has been communicated to its responsible. Another commitment is that the 100% have to be answered no later than 10 days, even when a hypothetic solution requires much more time.

A simplified version of the process is roughly as follows. A citizen has many means to communicate a complaint, suggestion or observation: face-to-face at different contact points, telephone or e-mail. Complaints are centralized at the citizen service points, where they are registered in a database using specific software. The mayor receives all the complaints at the moment of the registration via smartphone. She can stop the process' course if she wants to manage a complaint herself. The service point managing the complaint assigns a technical responsible (architect, local police, maintenance chief, or anyone else), whom has to assume it. The complaint's assumption is an important part of the process because service

[30] The sources of the data are: *www.esplugues.cat*, *www.idescat.cat*, *www.ine.es*.

points can make mistakes when assigning a responsible. Usually, any waste of time at this task has an impact on the service commitments. The town councilors receive, via smartphone, all complaints of his area at the moment of the technician's assignation.

The complaint responsible has to investigate it, solve it if possible, and answer it. He receives software alerts about every open complaint when the commitment's deadline is near. When it is answered, he can close the complaint and the service point's personnel can perform the process' final activities. They check answer's quality (which can be returned for revision), contact with the citizen (usually by telephone), and if the contact succeeds they close the complaint at the database.

This is the main information flow in the process; it moves the information from the fact that motivates the complaint, which is collected by a citizen, to a response decision mostly made by a technical responsible, and finally to a closed register in the database of complaints, suggestions and observations. Notice that the key issues are the responses, not the solutions. Complaints cannot be solved in all cases. However, an adequate response is a commitment.

There is a second flow which is rather less structured than the first one. Periodical satisfaction survey from a sample of already managed complaints provides the main input to process monitoring. It consists of eight questions and is applied to 50-60 complaints of different departments. It is performed telephonically. About 3 of 8 questions have coincident answers systematically, which induces to think that the survey is redundant and not efficient. The process owner has access to the database in order to make queries and reports, but regularly only complaints beyond the deadline are listed. Weaknesses of satisfaction survey and lack of direct information from complaints caused that even if information from complaints is obsessively promoted, captured, transmitted and used, information for process management is quite disregarded.

Both flows are executed by the same organizational system:

(i) Actors: citizen, service points personnel, technical personnel (architects, local police, etc.), mayor, town councilors, complaints management's process owner.

(ii) Technology: complaints management software, smartphones, e-mail, telephone.

(iii) Procedures: the complaints management procedures are fully documented and include most of the activities of the main flow. Activities for the secondary flow (information for process improvement) are not documented and are not systematically approached.

The analytical approach followed in our intervention at Esplugues del Llobregat was to represent the process in terms of changes in this system. The main states in the system were identified in function of which knowledge is acquired by agents or which information is stored or retrieved by each technological element. Transitions from one state to another were studied and potential or actual anomalies were detected for each transition. Anomalies were analyzed, weighted and prioritized according to several criteria—in a way akin to a failure modes analysis (FMEA).

Several elements of the complaints management process presented actual or potential failures. For instance, the task of deciding a response and writing it up in the database could be improved: answers did not fulfill quality criteria, mostly for (i) being too long and for (ii) using too many technical terms. Interviews revealed that some technicians were not actually aware that their responses had to be explained orally by a non-technician employee to a citizen. In fact, they did not have a broad perspective of the complaints management process. As a consequence, some citizens perceived that (1) the complaint was not actually answered, and (2) his interlocutor (an employee of a citizen service point) had not the necessary knowledge in order to solve it.

The task of receiving complaints also generated some problems that weren't easy to deal with. The citizen usually transmits different issues in a unique communication. Each issue corresponds to a different complaint, suggestion or observation, probably referring to different services or matters. Of course, the citizen expects a single response to his communication. If the complaint is divided into eight different registers, the citizen will receive eight courtesy contacts up to 48 hours, and eight final communications, one for each issue. If the complaint is treated as one, to which technician does it have to be assigned? Actually, the policy was that the service points divided each complaint by department—a happy medium. This is not an optimal solution, because it has some disadvantages of each alternative. For instance, one problem of bringing issues together is that technicians tend to omit difficult responses when there are several issues to answer (passing the buck to the citizen service point); the citizen perceives that the council is pretending to give an answer when actually the important points of the complaint are omitted or hidden—i.e., the citizen perceives a feigned answer.

Multiple Purposes and Limited Resources

Basing ourselves on the obtained material about anomalies and deficiencies in the system's changes (i.e., in the information flow's performance), we made a general analysis concerning broader implications of information flows' quality.

In the case of Esplugues de Llobregat, there are two clear benefits of the process of complaints' management: (a) complaints, suggestions and observations provide inexpensive information about a broad range of issues concerning the town, and (b) complaints increase the citizen's implication with the council and the city. To acquire the same amount of information using hired personnel would be extremely expensive, and the citizen's implication may have direct political rewards. Thus information flows about complaints play a critical role for the local government. The higher the volume of received complaints, the more adapted the local administration will become to its citizens and to its context. The more the process is known and used by citizens, the more citizens can feel that the council pays attention to their opinions and concerns. Nonetheless, resources are scarce; hence the process has to be reasonably efficient; otherwise an increasing complaints' volume will become too costly.

In summary, there are two kinds of advantages that are derived from the process:

(1) Technical advantages derived from cheap information.

(2) Political advantages derived from an increased implication of the citizen (loyalty, visualization of an active role of the council).

In accordance, there are two kinds of criteria to assess whether the process of complaints management works well or not:

(3) Technical criteria: whether information about urban situations is obtained efficiently.

(4) Political criteria: whether citizens' implication and loyalty increases and the active role of the council becomes more visible

Of course, both criteria are at least partly compatible and both criteria are desirable. Nonetheless, since resources are scarce, the two criteria cannot be maximized at the same time. In fact, interviews with managers and personnel involved in the process showed that the volume of handled complaints was near the capacity allowed by the available resources.

Actually, there are two different models to balance, as it is shown in the next page's table. A look at the purposes and circumstances of different actors showed different interests regarding the process of complaints management, in such a way that some people acted according to one model and other people acted according to the other. The process design as it was actually implemented allows a more or less unstable coexistence of both models. Of course, this is not good in terms of efficiency and the perception of personnel about their own work.

	Political model	Technical model
Focus on…	Answer	Solution
Role of the answer	Key role	Feedback, keep the process working
Operative definitions of what complaints are vs. suggestions vs. observations	Irrelevant: all of them need a response	Extremely critical: each one provides different information of different relevance
What to do with "multiple" complaints in a sole communication	Unify: a unique response has to be provided	Separate: different solutions have to be found for each problem
Role of the courtesy contact at 48 hours	Very important. It reinforces the council's image and commitments	Relative. Sometimes it is unnecessary or counterproductive. Useful basically to maintain the process alive and healthy.
Technician's role	1st place: answer adequately 2nd place: act according to the complaint when possible	1st place: find a solution according to the complaint, when possible 2nd place: answer adequately in order to provide feedback
Role of people at service points	Very important, they have actual power over the response	Relevant but subservient to the technician's
Process success criteria	Citizen's satisfaction. Fulfilled commitments. Cost of that satisfaction	Information obtained. Cost of that information

Some of the detected consequences of the unstable coexistence of the two models were:

(1) Most people mostly believed that the focus should be on responses, not on solutions; nonetheless, technicians (perhaps unconsciously) prioritize solutions. They procrastinate with complaints, suggestions and observations that do not involve solutions (occasionally they accumulate in the database awaiting a response), and they focus on what they can solve or plan to solve.

(2) The function of the response is not understood as critical to most technicians.

(3) Accordingly, the perception of the technicians' role is different between them and other people involved in the process.

(4) The managers of the process do not give much relevance to operational definitions of complaints in opposition to suggestions or observations. The distinction between them is seen as absolutely critical to most of the personnel in the service points and many technicians.

(5) A similar phenomenon occurs with the courtesy contact: it is critical for the process managers but much of the personnel in the service points think that sometimes the citizen does not value it or that it is even counterproductive (the citizen does not understand why he receives a call if the complaint is not solved yet). Courtesy contacts are one of the causes of the fact that the volume of handled complaints is near the maximum allowed capacity by the system.

(6) Even though the political model is preferred by managers, sometimes the process does not have mechanisms to avoid inadequate responses (too technical, too long, and perhaps too direct) from technicians. Actually, the personnel in the service points do not have an actual responsibility over the final response. The procedure to check the response quality is not always satisfactory.

(7) In the case of multiple complaints, there is some disparity on how personnel in the service points treat them. Mostly, they tend to unify them (in some cases against what they believe that should be), despite technicians would prefer to receive separate, specific complaints.

(8) Measures on process performance only strictly on the political model: satisfaction surveys and commitment compliance (% of received commitments, suggestions and observations). Despite that everybody agrees that a balance with the technical model is also important, almost nothing is systematically measured about it.

The main conclusion was that the city council was not aware of the extent and implications of the coexistence of two different models about the process of complaints management. Without a proactive decision about how to balance the two models, the involved personnel unsystematically and unpredictably behave according to their own interests conditioned by the interests of their interlocutor in the information flow in each occasion.

A process can barely work in a stable way with significantly different perspectives about its role and function in the organization. The conflict between the two models had worse consequences because some particular phenomena (for instance, that of multiple complaints) were extremely frequent and they had extremely different treatments according to each model. In addition, the operational definitions of complaints, suggestions and observations, were actually relevant in terms of what to do with each one of them, despite the fact that all of them needed response. To make them

undistinguishable (apparently in coherence with the political model) caused inefficiencies setting aside which model is actually prioritized.

The main managerial implication is that both models have to be made explicit and apparent. Only then it is possible to show which their respective limits are and which one has to be prioritized. In order to do that, it is necessary to establish operational definitions (that is, distinctions) concerning the concepts of complaints, suggestions and observations.

There is a need to be aware of the different interests and incentives of the personnel that is involved in a process. To ignore such differences can lead to allow unstable equilibriums in which each person can manage its part of the process according to its own possibilities and criteria, out of the global optimum. Since people cannot be always controlled, the emergence of information asymmetries (particularly, of moral hazard problems) can reinforce such unstable equilibriums. In Esplugues, notice that the technicians (mostly tenured state employees, an important detail to understand power relations in public institutions) have more knowledge about their fields of competence—and a great deal of empowerment and responsibility in their areas.

This case shows that information flows' analysis is not a matter of representing processes and detecting potential failures, but a matter of understanding the underlying structure of incentives and interests among the involved actors. This is a critical issue in order to analyze the coherence between the information flow and the organizations' more general purpose and structure.

CASE STUDY 2: HIRING NEEDS ANALYSIS IN A UNIVERSITY

Case Description

The Universitat Politècnica de Catalunya – BarcelonaTech (UPC) is a public university located in Barcelona and its surroundings. As a part of the Catalan university system, it has been traditionally devoted to engineering and architecture studies, later expanded to other technical fields and applied sciences—computer science, mathematics and statistics, optics and optometry, and the like. During the academic year 2009-10, when the most part of the project presented in that section was performed, the UPC had 3,320 employees in research tasks and professorship (40% tenured state employees and 60% hired non-tenured), 1,630 employees in administrative tasks (50% tenured state employees and 50% hired non-tenured) and about 40,000 students. From 2005 to 2010, the increase in total number of research and teaching personnel was of 7% (from 3,100 to

3,320) and the increase in the administrative workforce was of 20% (from 1,360 to 1,630).[31]

The university has a matrix organizational structure. There are 47 departments (usually divided into sections) that lecture in 23 centers that are distributed in 11 campuses or territorial locations. Departments horizontally cross centers: a professor in a department can have his office at a center and he can lecture in that center and other ones as well. The administrative workforce is assigned to centers, departments and other units like research institutes—there are 6 research institutes and 17 centers focused on research. General administrative services (such as human resources and the like) provide services to both centers and departments.

Other general instances include the university rector and the managerial staff. The rector (necessarily a tenured professor, thus a *primum inter pares*) is elected every four years by all the members of the community—professors, administrative workforce and students. The rector hires a managing director, who merely implements strategic decisions made by the rector and his team—professors are also elected in the same candidacy.

The analysis of the recruitment needs of teaching and research staff (professors) is a process of fundamental strategic importance, especially in a time of reorientation of the role of the institution in Europe. From 2000 to 2010 the cumulated deficit increased from about 5 million Euros to about 75 million. The economic crisis that began in 2007-08 made the financial situation of the institution very unstable: breaches of budgeted money transfers from the Government of Catalonia in 2008, 2009 and 2010 turn the results from -0.5%, 2.2% and 14.2% respectively (hence surplus in 2009 and 2010) to deficits of -5.0%, -2.2% and -2.6%.

Expenditure restraint situations, steady decline in enrollment in some schools, or changes in curricula and study plans (as a result of the Bologna process) makes the analysis of the balance between available workforce and the needed workforce even more critical—not just one year ahead but for longer periods. This necessary assessment involves gathering information from many different sources and managing it to ensure its reliability, accuracy and, ultimately, quality.

The key point in the hiring process is the existence of negotiations between the vice-rector of personnel and the basic units—schools and departments, mainly. Before the negotiation, the vice-rector of personnel receives information from various sources (the human resources depart-

[31] The sources of the data are: *www.idescat.cat*, *www.ine.es* , and *www.upc.edu* (particularly *http://www.upc.edu/gpaq/noticies/dades-estadistiques-i-de-gestio*).

ment and the bureau for planning, evaluation and quality) in order to assess the available resources and which needs have to be covered for the next year in each department. Unofficially, the departments do their own figures—which is the available capacity that they will have for the next year and how much lecturing they should carry out.

The structuring of that information is possible because there is a procedure to compare the professors' expected dedication to lecturing and coordination activities and the potential burden of the resources available. The comparison procedure is articulated on the basis of points—aggregated lecturing points plus coordination points should be equal or similar to the amount of points of potential capacity. Together with the dedication to lecturing and coordination, another very important area of time consumption is research, but the procedure does not take it into account—in fact, the available time for research is implicit in the balance between lecturing or coordination points and the points of the potential burden.

The vice-rector of personnel's own tacit knowledge (and the knowledge of other people which is involved in the process) is added to this structured information. The vice-rector has some idea (or can gather some information) about which departments actually have a deficit or surplus excess of personnel—or which departments tend to cheat against the university rector or hide information in order to gain an excess of capacity. The negotiation takes place in a meeting with the vice-rector of personnel and the director of each department. In the meeting, they discuss the information and estimates and they agree on establishing a number of staff to hire or to dismiss the following year.

An important point is that the structured information only refers to the year that the hiring should take place. The anticipation of needs in the medium and long term is only guided by unstructured information and the tacit knowledge of the parties in the negotiation.

During the interviews that were performed in order to carry out the present analysis, the identified problems could be classified into three groups. First, there are discrepancies between the information used by different actors at different times. A priori, these differences may respond to different causes, such as using historical data from the previous years (which are not updated at the same time), or the use of adjustable parameters that can vary according to the scenario. In general, the cause is that the use of input data and estimates based on it is not unique and not standardized—each party has its own source, despite that some information is publicly available.

Secondly, the centers and departments make different actions in order to gain a better position in the negotiation. These actions may include, for example, concealing unfavorable information, seeking the admission as teaching hours of activities that are not admitted as such, or trying to press

for making *ad-hoc* amendments to the estimates. Some schools have suffered sustained declines in the enrollment in recent years, thus the interest of the basic units are, in this case, at least to maintain the personnel that is currently hired.

Finally, many of those who are involved in the process believe that the cost of structuring all the information (with the procedure based on points) is too high compared with its actual usefulness in the final negotiation. This cost comes from time of administrative workforce and it is increased by the duplicate treatment of the same information by different parties. Our interviews detected that most people believes that the role of the structured information merely consists in outlining or sketching the department's situation, but that the determining factor was the unstructured information, the tacit knowledge and the negotiating skills of each part. In this regard, the cost of obtaining and processing the structured information is barely worth it.

Informational Asymmetries and Organizational Structure

In the process of analyzing hiring needs in the UPC, there is an agency relationship in which the rector (or the vice-rector of personnel in his behalf) is the principal and departments are the agents.[32] The departments have information that higher managing and administrative units such as the rector or the Human Resources department do not accurately know. Issues such as the research activity of individual researchers (including the projection and interest of that research), their expertise, strengths and weaknesses, their actual role in teaching, their actual productivity, synergies between their activities and those of the rest of professors, or the personal suitability as a member of a team (whether in teaching, research or coordination activities), can only be assessed by the department.

Therefore, a situation of adverse selection may emerge: honest departments can be underprivileged because the rector's team does not exactly know which departments can be cheating, thus it has to suggest agreements precluding that possibility to some extent. Obviously, once the agreements between the vice-rector and departments have been reached, usually there are no affordable channels to ensure that departments observe the agreement's stipulations; hence moral hazard situations may emerge as well.

[32] There is some amount of literature on issues on university administration from viewpoints which are particularly close to those that have been taken here. See, for instance, the ninth chapter in Stinchcombe (1990); it discusses most of the topics treated here.

This is the point in the debate on the assessment of professors in the university: much of the knowledge which is needed in order to manage the institution is in the departments, but it is rarely communicated to managers—departments have no incentives to do that. Evaluation systems are a mechanism to reduce information asymmetries and to allow the principal to minimize the private information that gives advantage to agents. In the university, as well as in business, the group who is the subject of monitoring and evaluation tends to oppose precisely because it loses power to defend his interests.

Moreover, asymmetries are exacerbated by several peculiarities of the university's environment. For instance, there is a limited capacity of control over tenured personnel—this is typical of most public institutions, where tenured personnel have more power or influence—and the lack of incentives of tenured personnel to disclose information against their own interests. In addition, agency costs associated with information asymmetries tend to be reduced when the agency relationship is established in the long term. The agent's good reputation in disclosing information and observing stipulations, as the principal's good reputation in giving incentives to the agents in order to do it, tend to be in the better interest of the parties in long-term relationships. When it is not possible to establish long term relationships, minimizing agency costs becomes more difficult. However, in universities there are different elements that prevent long-term relations.

Firstly, the people involved in negotiations (both in the behalf of the rector and departments) are professors which are periodically elected by the same university's community. This involves two difficulties, one by the periodicity of the elections and the other by the fact that the elected people arise from the same community. If positions are of a limited duration, it makes it difficult to establish a good reputation, because in fact the succession of management teams often involves new ways of working—often to distinguish themselves from their predecessors.

Furthermore, when the positions are occupied by people from the same group there are no incentives to reduce agency costs. In order to do that, the principal may have to restrict or control. The people with whom today you are negotiating can be your partners tomorrow, so incentives to take unpopular measures for efficiency are reduced. Similarly, the possibility to design agreements which are preferred for honest agents implies, from the principal's viewpoint (in this case, agents more aligned with the institution's strategy), an effective capacity to respond to the opposition of the agents who are contrary to such kind of agreements—and again this is quite in conflict with the highly cooperative habits of governance in many public universities.

However, this phenomenon is also aggravated by the limited role given to the administrative workforce, which could be a stabilizing factor that

could help to consolidate management habits and procedures for the medium and long term. Actually, some professors' perception about the administrative workforce range from indifference to hostility: they seem to believe that universities have to be managed by scholars and that the administrative personnel only have to give assistance in implementing their decisions.

The university, which is conditioned by its culture and structure, not only has no mechanisms to limit the inefficiencies created by agency costs, but it seems that it does not have many ways to establish such mechanisms. Two partial but simple and reasonable ways to mitigate the problems discussed above are (1) developing informal staffing plans in the departments (merely consisting in structuring and making some expectations, projects and assumed duties explicit), and (2) accentuate the role of the administrative staff as a way to enhance continuity in good management practices and consolidate relations of good reputation. Nonetheless, none of these solutions seem to attract a broad consensus within the professors' community.

Constraints to Information Flows' Quality

Three comments are relevant to understand which are the constraints of information flows' quality in the process of hiring needs' analysis. To analyze these constraints, I will use a thought experiment aimed at showing the difference between different root causes of some problems. The thought experiment consists in assuming that at the time to analyze the hiring needs, all the necessary structured information is available in the best possible conditions. Accordingly, we have eliminated the effect of uncertain estimates, caused by actual situations that happen after the negotiation (e.g., student enrollment, long-term sickness leaves, and the like), and we have assumed that we know it with certainty. That is, I am going to analyze the situation as if there were no uncertainty due to poorly obtained information or changes in the environment after negotiation.

What would change and what would not under the assumptions of the thought experiment? Obviously, just by the hypothesis of the experiment, currently used estimations would not be necessary anymore. However, although the amount of lecturing to be carried out, corrected for the dedication to coordination tasks, and the aggregate availability of professors in each department would be known without error, the hypothesis does not determine how this information has to be translated into concrete hiring decisions—in the last analysis this is not only based on aggregated criteria but on the departments' judgments about the role of each individual; not all professors in a department can lecture any course at the same level of excellence, not all professors have the same dedication to research, and so on.

For this reason, some things do not change even in the ideal, artificial situation. We would still need a procedure to compare the available work hours (teaching or coordination) and the burden. In the certainty case, weight of research activities would be still implicit in the balance between the teaching and coordination points and the burden points. It does not change the need to enrich the structured information with *ad hoc* mechanisms in order to anticipate mid-term and long-term changes, either.

Among the things that would not vary in the ideal situation, the most important is that the rector and departments still have interests partly overlapping and partly contrary. The rector wants to optimize the university's resources. The departments want to have as more resources as possible and as less interference as possible. However, all the parts prefer to reach an agreement.

It is interesting to note that, under the assumptions of the thought experiment, it is not possible to solve the question of who, formally, should make the distribution of burden points to the departments—directly the rector or indirectly the centers. (Recall that the UPC departments teach in different schools; currently the rector makes an assignment of burden points to the centers, and the centers distribute the points among the departments; the total burden to be covered by a department is the sum of the burden in all the centers in which it teaches.)

On the one hand, if all information would be ideally available, there would not be the need to make an initial assignment to centers, since the rector would know which courses are taught, to how many students, and so on. The rector could directly negotiate with the departments. On the other hand, nothing in the fact that the structured information is ideally available implies that the centers should not distribute the burden; in fact, who offers each degree is the center. *A priori*, there is no reason to limit the center's ability to intervene in how they want to actually implement their degrees. However, the question of who should decide it still remains.

Therefore, a source of poor quality information flows' would be avoided in the ideal situation. In this source, inadequate procedures to manage estimates and uncertain events increase the "noise" in information flows. Improvements in the procedures and techniques would not avoid the inherent uncertainty of facts that will happen the next year, but they would reduce its consequences. At any rate, this source relates to "information uncertainty".

Another source of information flows' poor quality remains in the ideal situation. It is a structural and more decisive source of anomalies, and it relates to information asymmetries. It is the agency relation between the rector and the units—and, most importantly, departments. Actually, there is a triangle of agency relations between the rector, the centers and the departments. Nothing in the ideal situation avoids these agency relations.

Any managerial effort to solve the problems generated by the first source has nothing to do with the managerial efforts to fix problems generated by the second source.

Some initiatives have been proposed to reformulate the governance structure of European universities, replacing the election of the rector by its designation by a Board of Governors. The rector's role would change from being a *primus inter pares* to be something more like a CEO (Chief Executive Officer). As the ideas to change the appointment systems for deans and center directors, these initiatives have not been too well received by influential segments of the community. However, they are measures that would address some of the difficulties caused by the structural problems discussed above: agency relationships, information asymmetries and agency cost. The entire culture and structure of most universities (and particularly the case of the UPC) seems to be accurately designed to aggravate the consequences of agency relations: elective positions, the minor role of the administrative staff, the relevance given to scholar experience to coordinate people within the institution, the matrix organizational structure, and so on.

Information flows' quality in the process of hiring needs' analysis can be slightly improved with some measures on how data and estimations are used and managed. Nonetheless, the impact of such solutions is pretty limited. Provided that the core activity in the process is a negotiation in the context of an agency relation with hidden information and unobserved actions (thus with information asymmetries), substantial solutions only can consist in minimizing the effects of that phenomenon. Staffing plans within the departments and empowering the administrative staff to ensure more stable management practices are only limited approaches. Changes in governance policies, of course, would be the most promising approach from a technical viewpoint—but they obviously have broader implications, so the issue goes beyond technical considerations.

8

Conclusions

THE ECONOMIC SIGNIFICANCE OF INTERVENING ON QUALITY

Grossman and Helpman (1991) pointed out that every product exists in a quality ladder. We can build models of technical progress based on quality improvement rather than product variety—so to speak, based on vertical differentiation rather than on horizontal differentiation. Economic growth takes shape in the improvement of a limited number of products' quality, rather than incrementing their variety. When a company beats the quality of a given product, it makes the product that has been beaten obsolete, in a process of creative destruction as named by Joseph Schumpeter (1942). In this sense, this approach may be called Schumpeterian—see Barro and Sala-i-Martin (2003).

An interpretation of the Schumpeterian approach of quality ladders is that some of the innovations which are relevant to economic growth do not generate new kinds of actions; they rather improve the way in which we carry out actions that we already do. In fact, from the very moment that a means is available to carry out a new action, a quality ladder emerges. It is possible to improve the means and beat the initial one, again and again.

Since contexts and circumstances change, this process has not to be necessarily cumulative, lineal. In fact, technology developments in a product can involve changes to how well other products work for a given purpose—as quality improvements in the paper industry conditioned the writing instruments' industry, or operating systems condition software developers.

At any rate, anytime we use the quality concept there is already an action that we can do better. In this thesis I have argued that all of the situations in which we use the quality concept have the same structure: actors carry out actions with the help of means. Being aware of this recurring scheme can help us understand the particular economic significance of intervening on quality: to intensify the competition (within and outside the markets) through the creative destruction of ways of carrying out actions.

AVOIDING A MISINTERPRETATION

The following quotation can help to avoid a major misinterpretation concerning this thesis:

"The peculiar character of the problem of a rational economic order is determined precisely by the fact that the knowledge of the circumstances of which we must make use never exists in concentrated or integrated form, but solely as the dispersed bits of incomplete and frequently contradictory knowledge which all the separate individuals possess. The economic problem of society is thus not merely a problem of how to allocate "given" resources—if 'given' is taken to mean given to a single mind which deliberately solves the problem set by these 'data'. It is rather a problem of how to secure the best use of resources known to any of the members of society, for ends whose relative importance only these individuals know. Or, to put it briefly, it is a problem of the utilization of knowledge not given to anyone in its totality." (Hayek 1945)

Hayek is defending (as in most of his work) a free market model against a state planning model. In this thesis I defend that the quality concept is not grounded on what particular individuals choose but rather on what a given type of individual should choose given certain circumstances and purposes.

Somebody could think that my statements may have an ideological implication, in an exactly contrary way to Hayek's perspective: people do not actually know what works better, so somebody (the state, maybe) has to tell them what to choose, what has good quality. Such a conclusion would be absolutely wrong.

My statements do not have such clear ideological connotations—at least they do not have *these* particular ideological connotations. They are perfectly compatible to Hayek's views in most aspects; actually, my own personal opinion is pretty close to Hayek's—but this is not relevant at all here.

I am just analyzing a concept. People could freely discard good quality products and could freely choose bad quality products; likewise, the state could protect bad quality products and it could put barriers and impediments to good quality products. It is just that the quality concept is independent of such decisions, for the reasons that I have presented in the dissertation.

I defend that quality depends on how well things work for a given purpose under certain circumstances. In actual situations we never know which purposes an individual exactly has and under which circumstances he acts—this is one of Hayek's points. However, this has nothing to do with

what defines the quality concept; at best, it only has to do with what we can do with the concept.

At least in a free market setting, it is reasonable to think that incentives should make most good quality means to do things to be more preferred in the long term and in the markets' aggregate behavior—this is somehow a variant of the rational expectations hypothesis. Again, nothing in this thesis implies or denies such hypothesis—in fact, I believe that it is true, but strictly speaking this is not relevant at all here either.

RESEARCH RESULTS

The conception of quality on which this thesis relies, depends on two fundamental principles:

(a) Quality is not subjective; it is not about what people want and expect, but about what people should want and expect. Quality does not change depending on people's perceptions.

(b) Quality is not an intrinsic property of things like products or services (thus it is not objective either); quality depends on means-ends fitness in certain contexts. Ends change and contexts change, so the quality of the same product or service can change in the mid- or long-term (less likely in the very short term).

It is well-known that 19th Century economists used the notion of utility as measuring the degree of pleasure or satisfaction that something provides to a consumer. It was taken to be a non-reducible concept and, roughly speaking, as a psychological magnitude. Vilfredo Pareto (1868-1923) realized that such an unobservable magnitude was not needed in economic theory, since the significant fact is the preference ordering between alternatives. This lead to a pure ordinal notion of utility—reduced to the function of representing preference relations.

Quality is usually regarded as a magnitude—products and services have *more* or *less* quality, quality improvements *increase* the product's *degree* of quality. Moreover, it is seen as a psychological concept: quality depends on client's perceptions—if the client doesn't like something, it cannot have good quality.

This thesis takes a very different view and shows that the psychological conception based on perceptions and expectations is quite in conflict with our most basic intuitions about the quality concept. Quality is nothing else than a particular sort of means-ends fitness.

In my opinion, the most important conclusion is that quality is not, and cannot be, a comfortable concept; I mean:

(1) Quality depends on multiple attributes; there is no way to systematically reduce these attributes to a unique magnitude. This is an unavoidable fact about quality.

(2) Quality is about what should be preferred in some circumstances: it is hard to justify without doubt what should be preferred. Judgments about quality are hardly definitive and unassailable.

(3) Quality is relative to many things that mainly depend on which viewpoint it is taken from: a description of an actor and its circumstances and purposes, a selection of a primary end and a partial end, the definition of a set of alternative means to achieve the partial end, the identification of many suitable attributes, a description of reference preferences on these attributes, and so on. Different people can take different viewpoints according to distinct interests. Quality attributions mostly depend on suppositions that are reinforced with partial evidential support.

(4) All of these things are subject to change: ways to perform an action evolve; actor's circumstances and purposes also change. Quality attributions have to adapt themselves to a changing context.

(5) Quality management mostly consists in shaping multivariate joint distributions of quality-related attributes, but it does not make much sense to have a complete specification of such a distribution—attributes are not properties of some sort of "natural" phenomenon; in a sense, we create the problem and the attributes, but they have to be correct according to some pragmatic criteria (namely, what works and what does not work). Statistics applied to quality management provides the best way to give evidential support to partial descriptions of these distributions.

Remark (8.1)

Nonetheless, the quality concept is useful and important. Many people are concerned in improving reproducible types of things, in how well these things work, and in how these things can be better done to achieve some ends; they unavoidably need the notion of quality to conceptualize what they do.

OPEN PATHS TO FURTHER RESEARCH

The economic literature about themes that are merely pointed out in this thesis is immense: vertical product differentiation, quality uncertainty, learning by doing, entry barriers, and so on. This thesis focuses on a theory of quality and it only sketches its relation with topics in economics and industrial organization. A more systematic examination of how the notion of

quality (as used in quality management) relates to economic theory is a pending work.

Likewise, I've focused on the proper core of quality management. A more detailed analysis of which portions of quality management actually go far beyond managing quality (and which do not) is also a pending work.

In this thesis I have not been interested in actual applications of quality measures as I have defined them (as multi-attribute utility functions)—actually, I have criticized the concept. However, some work on the issue perhaps could be interesting.

Obviously, my treatment of the topic of information flows' quality is not exhaustive. I have taken it just as an example of the amplitude and variety of the quality concept beyond products and services to sell. Much more work can be done.[33]

[33] Some of the outcomes from this thesis' research process are about information flows' quality:

Camps, O. and Tort-Martorell, X. (2010) Information quality for process improvement, ICOTS8 Conference, Ljubljiana, Slovenia, available at: www.stat.auckland.ac.nz/~iase/publications/icots8/

Camps, O. (2010), Una aplicación multidisciplinar del análisis de flujos de información al aseguramiento, admisibilidad e impugnación de la prueba electrónica en el juicio civil, in: Richard, M., Abel, X., & Picó, J. (Eds.) (2010). *La prueba judicial*, La Ley – Wolters-Kluwer (Proceedings of UNIJES 2010 Conference at ESADE Law School, Barcelona).

The courses I take at ESADE Law School in 2009 about evidence in law (as a part of procedural law) were of remarkable importance not only concerning my view of information flows but also concerning some other points in this thesis.

The rest of relevant research outcomes are two papers, the first one about the issues in Chapters 1-4 of this thesis (entitled "An analysis of the quality concept") and the second one about the issues in Chapter 7 (entitled "Quality, customer satisfaction, and business success"); both have been read by some colleagues but remain unpublished.

Appendix 1

A Simple Static Model of Means-Ends Relationships

Remark (App1.1) [Preliminary remark]

Previous versions of this thesis did not contain this appendix, despite its content (originally in the form of unstructured notes) was relevant for the research process. Thus its details are not strictly necessary to understand the main points of the dissertation. It can be skipped in a reading focused on general issues—the last section provides a summary of conclusions without too many technical details.

Nonetheless, the appendix shows some insights for a deeper understanding of Chapter 2—even though it lacks of genuine rigor in its formulation. It can be taken as a free exploration of some concepts that are relevant to the research. Specifically, it builds a simple model (almost a "toy" model) to explore some concepts which we use in thinking about means, ends and partial ends. Formal elegance and accuracy were not the primary criteria in its original development, but mainly the search of insights for the concepts' analysis.

In Chapter 2 I stated the following informal definitions of end, partial end, action and means:

Definition (2.3) [End]

An end is what an action purports to achieve. So to speak, an end is an action conceived in terms of what to do.

Definition (2.4) [Partial end]

A partial end is simply an end to be achieved as a part of a primary end's achievement.

Definition (2.5) [Action]

An action is defined by an end plus the way to achieve it.

Definition (2.6) [Means]

A means is an action such that its end is a partial end to a primary action.

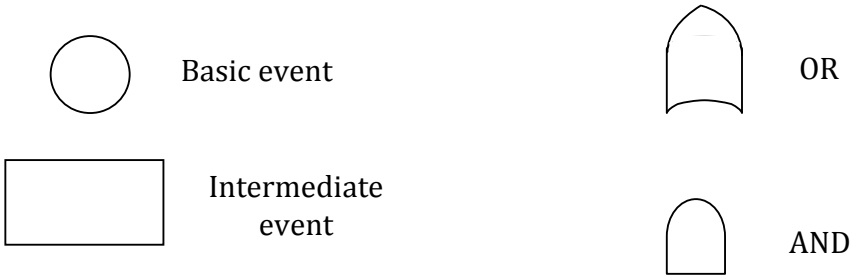
Our main objective is to describe actions as pairs $\langle w, h\rangle \in W \times H$ (actually, belonging to a suitable subset of $W \times H$), where W is a set of ends and H is a set of moves. Thus an action would be regarded as a binary relation such that a pair of ends and moves belongs to the relation if and only if the move yields the end in some given circumstances.

AN INTUITIVE ANALOGY (FTA FOR SABOTEURS)

Even though the model I am going to present is an abstract simplification, I would like to begin with an intuitive image of the general concepts I am going to discuss. I guess abstract notions will be easier to understand with some initial intuition associated to them. I will build this intuition on the basis of reliability theory and fault tree analysis—albeit the model did not originally come from that analogy, I believe it fits quite well to it.

Fault tree analysis (FTA) is a technique to represent and analyze failures in a system. Roughly speaking, it represents the logical dependencies between several events, depending on whether they occur or not—actually, depending on the probability of occurrence, but I will not take that into consideration.

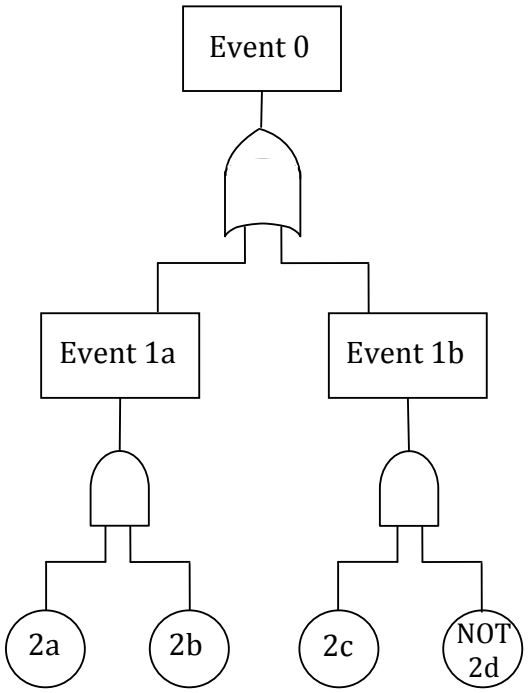
In its simplest version, the technique builds diagrams depicting some basic events (taken as irreducible), intermediate events, and a top event. The links between these sorts of events are modeled by two logical operations: Y_1 OR Y_2 (an event X occurs if an event Y_1 occurs or another event Y_2 occurs, or both), Y_1 AND Y_2 (X occurs if Y_1 and Y_2 occur). I will add, as sometimes it is done in fault tree analysis, the possibility to negate or not an event: NOT Y_1 (X occurs if Y_1 does not occur). Some standard symbols are used:



I will write the NOR simply before the name of the event (intermediate

or basic). The top event is depicted as an intermediate event with no further consequences.

Let us assume that there is an event 0 to analyze (top event). Event 0 occurs if an event 1a occurs or another event 1b occurs (or both). Event 1a occurs if basic events 2a and 2b occur. Event 1b occurs if basic event 2c occurs and basic event 2d does not occur. The diagram that represents that situation is:



This is an extremely simple example of fault tree analysis, but I guess it will work to illustrate the point. In the standard interpretation, events 0, 1a, 1b, 2a, 2b, and 2c would be failures to avoid—NOT 2d would be a part of the system working correctly, a failure that does not occur. Let us think about that from a different point of view—recalling that our purpose is to analyze the concepts of end, partial end and means.

Let us imagine that we are saboteurs that have the mission to cause event 0 in the system. Causing event 0 is our end. Which means can we use to do that? Well, we have two options: to accomplish 1a or 1b (or both). To accomplish them, several requirements have to be fulfilled: achieving 2a and 2b to accomplish 1a, or achieving 2c and keeping 2d working (avoiding failure 2d to occur) to accomplish 1b. Any of these options or requirements (from 1a or 1b to 2a, 2b, 2c or avoiding 2d) are partial ends to 0—namely, ends to be achieved as a part of 0's achievement.

The available means to achieve our end will be any different set of moves and available resources to achieve the partial ends (options and requirements). An important point of this appendix will be avoiding the confusion between partial ends and means: means are alternative ways to achieve partial ends. Thus, to sum it up:

(i) Top events can be interpreted as ends.

(ii) Intermediate and basic events (modified or not by the operator NOT) can be interpreted as partial ends; i.e., options or requirements—depending on whether they are components of an OR operator or components of an AND operator, respectively.

(iii) Means can be defined as partial ends together with the particular moves to achieve them. If event 2a can be achieved doing two significantly different moves, at least we have these two different means (in this case to be combined with others) to achieve the primary end.

The model that follows is a more sophisticated (though not entirely rigorous) version of this basic idea.

ENDS

Definition Let us define recursively the notion of an end from a set of basic ends V. Basic ends in V can be regarded as irreducible descriptions of states in a given environment—true if they occur and false if they do not; somehow like basic events in FTA. Further along I comment on how to conceive basic ends, but anyway we shall not dwell on that and it is not actually important for this model's purposes. In particular, the cardinality of V is not important either; we shall assume it is finite.

(a) Every $v \in V$ is an end (every simple end is an end)
(b) If α is an end, then $\neg\alpha$ is an end
(c) If α, β are ends, then $(\alpha \vee \beta)$ is an end
(d) If α, β are ends, then $(\alpha \wedge \beta)$ is an end
(e) All ends are defined in accordance with rules (a) – (d)

As it is apparent, ends are taken to be propositions and modeled by standard propositional logic. Thus the representation I am describing takes the structure of a Boolean algebra. In accordance, the interpretation of our expressions is quite standard:

(f) $\neg\alpha$ occurs $\Leftrightarrow$ α does not occur
(g) $(\alpha \vee \beta)$ occurs $\Leftrightarrow$ α occurs or β occurs (or both)

(h) $(\alpha \wedge \beta)$ occurs $\Leftrightarrow$ α occurs and β occurs

According to these rules, $\big((\alpha \vee \beta) \vee \gamma\big)$ has the same meaning that $\big(\alpha \vee (\beta \vee \gamma)\big)$, as $\big((\alpha \wedge \beta) \wedge \gamma\big)$ has the same meaning that $\big(\alpha \wedge (\beta \wedge \gamma)\big)$. In addition, external parentheses do not cause different possible readings. Thus we adopt two parentheses omission rules:

(i) $\big((\alpha \vee \beta) \vee \gamma\big)$ and $\big(\alpha \vee (\beta \vee \gamma)\big)$ will be written as $(\alpha \vee \beta \vee \gamma)$. Likewise, $\big((\alpha \wedge \beta) \wedge \gamma\big)$ and $\big(\alpha \wedge (\beta \wedge \gamma)\big)$ will be written as $(\alpha \wedge \beta \wedge \gamma)$.
(j) External parentheses will be omitted: we write $(\alpha \vee \beta)$ and $(\alpha \wedge \beta)$ simply as $\alpha \vee \beta$ and $\alpha \wedge \beta$.

Of course, $\alpha \vee \beta \vee \gamma$ or $\alpha \wedge \beta \wedge \gamma$ are ambiguous expressions, but this is not an actual problem given the meanings assigned in (f)–(h).

Let W be the set of all ends; that is, the set of all simple ends and all the (compound) ends generated from them using rules (a)–(e); alternatively, W is the smallest set satisfying rules (a)–(d).

As it is well-known, any end can be regarded as a Boolean function $w: \mathcal{B}^n \to \mathcal{B}$, where $\mathcal{B} = \{0,1\}$. Given the occurrence of some basic ends (0 if they do not occur, 1 if they occur), the function returns whether some compound end occurs (1) or it does not occur (0). Therefore, the expressions:

$$w_1 = \neg(v_3 \wedge v_1) \vee v_2 \vee \neg v_1$$
$$w_2 = v_3 \wedge v_1 \wedge \neg(\neg v_2 \vee \neg v_4)$$

could be regarded in the following way:

$$w_1 = w_1(v_1, v_2, v_3) = \neg(v_3 \wedge v_1) \vee v_2 \vee \neg v_1$$
$$w_2 = w_2(v_1, v_2, v_3, v_4) = v_3 \wedge v_1 \wedge \neg(\neg v_2 \vee \neg v_4)$$

We say that two ends w_1 and w_2 are equivalent if they represent the same Boolean function. That is, if for any $\boldsymbol{v} \in \mathcal{B}^n$, $w_1(\boldsymbol{v}) = w_2(\boldsymbol{v})$. An example of equivalent ends may be $w: \mathcal{B}^2 \to \mathcal{B}$ and $w': \mathcal{B}^2 \to \mathcal{B}$ such that:

$$w(v_1, v_2) = v_1 \vee v_2$$
$$w'(v_1, v_2) = \neg(\neg v_1 \wedge \neg v_2)$$

The reader may check that if v_1, v_2 do not occur we have $w(0,0) = w'(0,0) = 0$. The same holds if both v_1, v_2 occur: $w(1,1) = w'(1,1) = 1$. Likewise, it can be easily checked that if one basic end occurs and the other does not, we have $w(1,0) = w'(1,0) = 1$ and $w(0,1) = w'(0,1) = 1$.

Note that if we have $|V|$ basic ends, each possible end is equivalent to one of $2^{|V|}$ configurations of basic ends.

Interesting Ends

The obvious fact that expressions such as $\neg\neg\neg\neg v \wedge \neg\neg\neg\neg v$ are perfectly well formed (and equivalent to v), shows that not all well formed ends are actually interesting: we would want to focus our attention only on equivalent interesting ends. This is the theme of the following definitions.

A literal is any element of V or its negation. That is, if $v_1, v_2, \in V$ the following ends are literals:

$$v_1$$
$$\neg v_1$$
$$v_2$$
$$\neg v_2$$

An end of the form $\alpha \wedge \beta \in W$ is called a conjunction; α and β are said to be components of the conjunction. An end of the form $\alpha \vee \beta \in W$ is called a disjunction; α and β are said to be components of the disjunction.

Definition (App1.2) [Negative normal form]

An end $w \in W$ is in negative normal form if negations ($\neg$) only modify basic ends, not conjunctions, disjunctions or already negated basic ends. That is, w is in negative normal form if negation only appears in literals—if the symbol '$\neg$' never appears behind a parenthesis or another symbol '$\neg$'.

Most of what we want to do would only require ends in negative normal form. However, in order to exploit some important theorems on Boolean functions (useful to avoid uninteresting ends), this model will work with two more restrictive normal forms:

Definition (App1.3) [Disjunctive normal form]

An end $w \in W$ is in disjunctive normal form (DNF) if negations only apply to basic ends (negations only appear in literals) and if no component of a conjunction contains a disjunction. That is, an end in DNF is a disjunction of conjunctions of literals.

Definition (App1.4) [Conjunctive normal form]

An end $w \in W$ is in conjunctive normal form (CNF) if negations only apply to basic ends (negations only appear in literals) and if no component of a disjunction contains a conjunction. That is, an end in CNF is a conjunction of disjunctions of literals.

The following elements of W correspond to ends in disjunctive normal form:

$$w_1 = (v_1 \wedge v_2 \wedge v_3) \vee (v_3 \wedge \neg v_4)$$
$$w_2 = v_1 \vee (v_2 \wedge v_3)$$
$$w_3 = (\neg v_1 \wedge \neg v_2) \vee v_3 \vee (v_1 \wedge \neg v_4 \wedge v_5)$$

These elements of W are in conjunctive normal form:

$$w_4 = (v_1 \vee v_2 \vee v_3) \wedge (v_3 \vee \neg v_4)$$
$$w_5 = v_1 \wedge (v_2 \vee v_3)$$
$$w_6 = (\neg v_1 \vee \neg v_2) \wedge v_3 \wedge (v_1 \vee \neg v_4 \vee v_5)$$

It will be important to bear in mind that the following ends are both in disjunctive and conjunctive normal forms (just add $\wedge$ 1 or $\vee$ 0 after them in the suitable way, reinserting external parentheses if necessary):

$$v_1$$
$$v_1 \wedge v_2$$
$$v_1 \wedge v_2 \wedge \neg v_3$$
$$v_1 \vee v_2$$
$$v_1 \vee v_2 \vee \neg v_3$$

With the notions of normal form and equivalence we can state the following well-known result:

Remark (App1.5)

Any end in W is equivalent to at least one end (also in W) in DNF (disjunctive normal form) and to at least another end in CNF (conjunctive normal form), all containing the same basic ends. In general, a DNF or CNF equivalent is not unique.

The proof appears in many standard textbooks on Boolean functions and/or propositional logic; Crama and Hammer (2011) is particularly suitable.

However, this doesn't make too much to avoid uninteresting ends. The end $(v \wedge v) \vee v$ is one of the DNF equivalents to v. In order to avoid this, we need some definitions which were mostly developed during the 1950s (Quine 1952, 1955; Nelson 1954; Ghazala 1957).

Let $w: \mathcal{B}^n \to \mathcal{B}$ and $w': \mathcal{B}^n \to \mathcal{B}$ be two Boolean functions, with $\mathcal{B} = \{0,1\}$. We say that w *implies* w' when for any $\boldsymbol{v} \in \mathcal{B}^n$, if $w(\boldsymbol{v}) = 1$ then $w'(\boldsymbol{v}) = 1$. Note that if w implies w' then $w \wedge w' = w$ and $w \vee w' = w'$.

An *implicant* for a Boolean function $w: \mathcal{B}^n \to \mathcal{B}$ is any conjunction of literals C such that C implies w. A *prime implicant* of w is any implicant of w that does not imply any other implicant of w.

Let us comment an additional definition of prime implicant. Let C_1 and C_2 be implicants of w. We say that C_1 *absorbs* C_2 if $C_1 \vee C_2 = C_1$. Recall that for any literals or conjunctions of literals $\alpha_1, \ldots, \alpha_M, \beta_1, \ldots, \beta_N$:

$$(\alpha_1 \wedge \ldots \wedge \alpha_M) \vee (\alpha_1 \wedge \ldots \wedge \alpha_M \wedge \beta_1 \wedge \ldots \wedge \beta_N) = \alpha_1 \wedge \ldots \wedge \alpha_M$$

A prime implicant for w is an implicant that is not absorbed by any other implicant of w. Therefore, a prime implicant for w is an implicant that ceases to be an implicant for w if any literal is deleted.

Now let us see the dual concepts for the case of disjunction. An *implicate* for a Boolean function $w: \mathcal{B}^n \to \mathcal{B}$ is any disjunction of literals D such that w implies D. A *prime implicate* of w is any implicate of w that it is not implied by any other implicate of w.

As in the previous case, let D_1 and D_2 be implicates of w. We say that D_1 absorbs D_2 if $D_1 \wedge D_2 = D_1$. Again, recall that for any literals or disjunctions of literals $\alpha_1, \ldots, \alpha_M, \beta_1, \ldots, \beta_N$:

$$(\alpha_1 \vee \ldots \vee \alpha_M) \wedge (\alpha_1 \vee \ldots \vee \alpha_M \vee \beta_1 \vee \ldots \vee \beta_N) = \alpha_1 \vee \ldots \vee \alpha_M$$

A prime implicate for w is an implicate that is not absorbed by any other implicate of w. In other words, a prime implicate for w is an implicate that ceases to be an implicate for $w(\cdot)$ if any literal is deleted.

A disjunctive normal form (DNF) is prime if all its terms $C_1 \vee \ldots \vee C_M$ are prime implicants. A conjunctive normal form (CNF) is prime if all its terms $D_1 \wedge \ldots \wedge D_M$ are prime implicates. Now I state a well-known result which is relevant to our purposes:

Remark (App1.6)

Any end has at least one equivalent prime DNF that is irredundant—in the sense of Quine (1952); i.e., it has no superfluous disjunctions and no disjunction has superfluous literals. An irredundant prime DNF is its shortest possible DNF representation. Likewise, any end has at least one prime irredundant CNF equivalent that is its shortest possible CNF representation (it has no superfluous conjunctions and no conjunction has superfluous literals).

As in the case of Remark (App1.5), the proof appears in many standard textbooks. See Crama and Hammer (2011). Quine (1952) contains the initial discussion and the proof of some related theorems.

Definition (App1.7) [Short equivalent]

An end $w \in W$ in prime irredundant DNF or in prime irredundant CNF will be called 'a short equivalent end' of any end $w' \in W$ such that $w' = w$ (any end equivalent to w; i.e., when w represents the same Boolean function that w').

Albeit that they are irredundant (hence interesting in the sense previously used), short equivalents are not unique in general. I am not saying they are unique up to the order of the terms. Short equivalents are not necessarily unique in the sense that they can contain different literals. For instance, these two ends are short equivalents one of each other:

$$w = (v_1 \wedge v_2) \vee (\neg v_2 \wedge v_3) \vee (\neg v_1 \wedge \neg v_3)$$
$$w' = (v_1 \wedge v_3) \vee (v_2 \wedge \neg v_3) \vee (\neg v_1 \wedge \neg v_2)$$

Just as a side issue: the only case of necessary uniqueness of short equivalents (up to the order of the terms) holds for ends $w: \mathcal{B}^n \to \mathcal{B}$ such that for any $\boldsymbol{v}, \boldsymbol{v}' \in \mathcal{B}^n$, if $\boldsymbol{v} \leq \boldsymbol{v}'$ (coordinate-wise) then $w(\boldsymbol{v}) \leq w(\boldsymbol{v}')$. However, this is not the general case in our model.

PARTIAL ENDS, PLANS AND LISTS OF OPTIONS

Using the notion of short equivalent, prime implicants and implicates, and implicit end, I am going to re-state the definition of partial end.

Definition (App1.8) [Partial end]

Roughly speaking, the end w is said to be a *partial end* of w^* if w is a subset of terms of any short equivalent representing w^*. By 'subset' I mean a collection of terms picked up from a short equivalent of w^*. Accordingly, one of the following conditions hold:

(a) w is a disjunction of prime implicants or a conjunction of prime implicates of w^*. In particular, this condition holds if w is a prime implicant or a prime implicate of w^*.
(b) w is a conjunction of literals in a prime implicant or a disjunction of literals in a prime implicate of w^*. In particular, this condition holds if w is a literal in some prime implicant or prime implicate of w^*.

Roughly speaking, a partial end to w^* is any expression appearing in one of its short equivalents—of course, several conditions apply on how they can be combined in order to accomplish the primary end.

Definition (App1.9) [Options and requirements]

When needed, I will distinguish two sorts of partial ends. An *option* to w^* is a partial end that works as a component of a disjunction. A *requirement* to w^* is a partial end that works as a component of a conjunction.

We can see DNF short equivalents as lists of options and CNF short equivalents as lists of requirements (or *plans*). Note that:

(1) Each option in a list of options contains a plan (perhaps with only one requirement) to perform it.

(2) Each requirement in a plan contains a list of options (perhaps with only one option) to fulfill it.

To Mix or Not to Mix

To the extent that they are equivalent, plans and lists of options are alternative views on how to achieve the same end. We have two remarks valid in our static model:

(3) Do not mix plans. Taking a requirement of a plan and combining it with a requirement of another plan does not guarantee that the end is achieved.

(4) On the contrary, options can be combined. Taking two options of different but equivalent lists of options allows achieving the end.

Albeit this is quite intuitive, let us see the reason in our model. The following ends are two short equivalents, both in DNF:

$$w = (v_1 \wedge v_2) \vee (\neg v_2 \wedge v_3) \vee (\neg v_1 \wedge \neg v_3)$$
$$w' = (v_1 \wedge v_3) \vee (v_2 \wedge \neg v_3) \vee (\neg v_1 \wedge \neg v_2)$$

The following ends (created using building blocks from w and w'), are not equivalent to w and w', but it doesn't matter because when one of them is achieved, w and w' are achieved as well:

$$(v_1 \wedge v_2) \vee (\neg v_2 \wedge v_3) \vee (\neg v_1 \wedge \neg v_2)$$
$$(v_1 \wedge v_3) \vee (v_2 \wedge \neg v_3) \vee (\neg v_1 \wedge \neg v_3)$$
$$(v_1 \wedge v_2) \vee (v_2 \wedge \neg v_3) \vee (\neg v_1 \wedge \neg v_3)$$

When they are not achieved, w and w' can be achieved; but if they are achieved, w and w' are achieved as well. They are not equivalent, but are equisatisfiable. Therefore, they are suitable ways to combine partial ends to w and w'.

However, consider the case of the following two short equivalents, this time in CNF (not equivalent to the previous ones):

$$w'' = (v_1 \vee v_2) \wedge (\neg v_2 \vee v_3) \wedge (\neg v_1 \vee \neg v_3)$$
$$w''' = (v_1 \vee v_3) \wedge (v_2 \vee \neg v_3) \wedge (\neg v_1 \vee \neg v_2)$$

The following ends (created as before using building blocks from w'' and w''') are not equisatisfiable between them and are not equisatisfiable with w'' or w''':

$$(v_1 \vee v_2) \wedge (\neg v_2 \vee v_3) \wedge (\neg v_1 \vee \neg v_2)$$
$$(v_1 \vee v_3) \wedge (v_2 \vee \neg v_3) \wedge (\neg v_1 \vee \neg v_3)$$
$$(v_1 \vee v_2) \wedge (v_2 \vee \neg v_3) \wedge (\neg v_1 \vee \neg v_3)$$

When they are achieved w'' and w''' are not necessarily achieved. If w'' and w''' are achieved, they are achieved as well, but this is not of much help. They are not suitable ways to combine partial ends to w'' and w'''.

Negating Partial Ends

The relationship between ends and partial ends changes in a quite obvious way with the negation of some partial ends:

Remark (App1.10)

If w_1 is a requirement to w_2, then $\neg w_1$ is an option to $\neg w_2$. Likewise, if w_1 is an option to w_2, then $\neg w_1$ is a requirement to $\neg w_2$.

Sure enough if w_1 is an option to w_2, then $w_2 = w_1 \vee \alpha$ for some $\alpha \in W$. Since $\neg w_2 = \neg w_1 \wedge \neg \alpha$, then $\neg w_1$ is a requirement to $\neg w_2$. If w_1 is a requirement to w_2, then $w_2 = w_1 \wedge \alpha$ for some $\alpha \in W$. Since $\neg w_2 = \neg w_1 \vee \neg \alpha$, then $\neg w_1$ is an option to $\neg w_2$.

The basic intuition behind this proposition is clear enough: administrating a fatal dose of cyanide is an option to kill somebody; not to administrate any fatal dose of cyanide to anybody is a requirement to avoid killing somebody. Likewise, creating some kind of combustion is a requirement to light up a cigarette; not to create any kind of combustion is an option to do not light up a cigarette.

MOVES AND ACTIONS

Moves

Let M be a set of basic moves (or simple moves). We shall not dwell on that, but our model is loosely speaking confined to a given environment with undetermined actors and technology. Accordingly, circumstances are taken as given. We could think that actors and technology have properties and that every basic move implies some discrete change in a property.[34] This is not actually important for the point that the model wants to illustrate.

[34] A better way to think of this model is to think of a very simple board game with several pieces forming positions—the initial position is fixed, moves can be regarded as simultaneous changes of the different pieces in the board, ends are associated to the final position and partial ends are different aspects of this position (depending on how the different pieces have been moved).

The model is static not only in the sense that circumstances are taken as given and unchanging, but of course in the sense that moves are assumed as not having any dynamic dependence through several times. So to speak, they will occur at a unique and indeterminate time—note that the analogy with reliability theory and fault tree analysis is useful here: standard diagrams as the simple one showed above are also static. This point (of course, a simplification) is clarified later in this appendix.

Let H be an algebra on M. That is, H is a set of subsets of M such that:

(1) $M \in H$
(2) $h \in H$ implies $\bar{h} \in H$, where $\bar{h} = M \setminus h$ (the complement of h)
(3) If $h_1, h_2 \in H$ then $h_1 \cup h_2 \in H$

The set H is closed under finite unions and finite intersections. We do not need H to be closed under countable infinite unions (or countable infinite intersections).

We say that H is the set of moves. Let us give a standard interpretation to the elements of H.

(i) Any $h \in H$ is a set of basic moves.
(ii) $\bar{h} \in H$ is the set of basic moves that do not belong to h.
(iii) $h_1 \cup h_2 \in H$ is the set of basic moves that belong to h_1 or h_2.
(iv) $h_1 \cap h_2 \in H$ is the set of basic moves that belong to h_1 and h_2.

Actions

Putting together the notions of end and move we can treat the concept of action. This is a key step to our model, since means are actions to achieve an end.

Let $A \subseteq W \times H$. I will call A 'the set of actions'. I am going to define an action as a pair $\langle w, h \rangle$ that belongs to A if and only if h contains moves that achieve w. Therefore, the set of actions can be regarded as a binary relation such that a pair of end and move belongs to the relation if and only if the move yields the end.

The set of actions $A \subseteq W \times H$ is the set defined by the following condition, aimed at show when we would say that a move yields an end depending on whether we would say that some tied moves do not yield its negation:

Remark (App1.11)

For $w \in W$ and $h \in H$, we would say that $\langle w, h \rangle \in A$ if there is an existing $h' \in H$ satisfying $h = h' \cup h''$ for some h'', $h' \cap h'' = \emptyset$, such that we would say that $\langle \neg w, h' \rangle \notin A$.

Equivalently, we would say that $\langle w, h\rangle \notin A$ if for any $h' \in H$ such that $h = h' \cup h''$ for some h'', $h' \cap h'' = \emptyset$, we would say that $\langle \neg w, h'\rangle \in A$.

That is, h contains moves that achieve w if in some partition of h there is a part that does not contain moves that yield $\neg w$. Equivalently, h does not contain moves that achieve w if in any partition of h any part contains moves that yield $\neg w$. Recall that (a) circumstances are taken as given and unchanging and (b) any basic end takes values in $\mathcal{B} = \{0,1\}$, thus it occurs or does not occur (but neither both things at the same time nor a third possibility).

Remark (App1.11) only says that if we are willing to write $\langle w, h\rangle \in A$, then we are compelled to write $\langle \neg w, h'\rangle \notin A$ for some element h' of a partition of h. This is a mere instruction on how to manipulate symbols in our model. It happens that the symbols generated in such way arguably fit with the interpretation and objective that the model pursues.

Definition (App1.12) [Proper move, proper action]

In the particular case that $h' = h$ (thus $h'' = \emptyset$) and $\langle \neg w, h'\rangle \notin A$, we say that h is a *proper move* to w and that $\langle w, h\rangle \in A$ is a proper action.

Definition (App1.13) [Default end]

Let $w \in W$ be such that $\langle w, \emptyset\rangle \in A$. In that case, we say that w is a *default end*.

Definition (App1.14) [Reverser move]

Let $w \in W$ be a default end and let $h^* \in H$ be a move. If there is $h' \in H$ satisfying $h^* = h' \cup h''$ for some h'', $h' \cap h'' = \emptyset$, such that $\langle \neg w, h'\rangle \in A$, then h^* is called a *reverser move* of w—in the particular case that $h' = h^*$, we say that h^* is a proper reverser move to w.

If there is a reverser move of a default end w, then we say that w is an *avoidable default end*; if there is not, we say that w is an *unavoidable* (default) *end*.

MEANS

According to Definition (2.6), a means to carry out a primary action is another action that purports to achieve a partial end to the primary action; thus means are actions and also have the form $\langle w, h\rangle \in A$. Notice that according to our simple model means and partial ends are quite different entities: an end is an element $w \in W$. Let us explicitly define the concept of means:

Definition (App1.15) [Means, proper means]

A means (proper means) to an end w* is an action (proper action) $\langle w, h\rangle \in A$, with $A \subseteq W \times H$, such that w is a partial end of w^*.

Definition (App1.16) [Reverser means]

Let w^* be a default end. A reverser means to w^* is a means $\langle w, h\rangle \in A$ to $\neg w^*$ such that h is a reverser move to w^*.

Now I am going to consider how moves are combined when two means are combined to achieve a given end. Let $\langle w_1, h_1\rangle \in A$, $\langle w_2, h_2\rangle \in A$ be actions. From Remark (App1.11), we have:

(1) If $w^* = \neg w_1$ then $\langle w^*, \overline{h_1}\rangle$, if exists, is the action for w^* given $\langle w_1, h_1\rangle$.

(2) If $w^* = w_1 \wedge w_2$ then $\langle w^*, h_1 \cup h_2\rangle$, if exists, is the action for w^* given the means $\langle w_1, h_1\rangle, \langle w_2, h_2\rangle$.

(3) If $w^* = w_1 \vee w_2$ then, if they exist, there are three actions for w^* given $\langle w_1, h_1\rangle, \langle w_2, h_2\rangle$:

(a) $\langle w^*, h_1 \cup h_2\rangle$
(b) $\langle w^*, h_1\rangle$
(c) $\langle w^*, h_2\rangle$

(4) If $w^* = w_1 \wedge \neg w_2 = \neg w_2 \wedge w_1$ then $\langle w^*, (h_1 \setminus h_2) \cup \overline{h_2}\rangle$, if it exists, is the action for w^* given $\langle w_1, h_1\rangle, \langle w_2, h_2\rangle$.

(5) If $w^* = w_1 \vee \neg w_2 = \neg w_2 \vee w_1$ then, if they exist, there are three actions for w^* given $\langle w_1, h_1\rangle, \langle w_2, h_2\rangle$:

(a) $\langle w^*, (h_1 \setminus h_2) \cup \overline{h_2}\rangle$
(b) $\langle w^*, h_1\rangle$
(c) $\langle w^*, \overline{h_2}\rangle$

We shall not dwell on that, but with the rules (1)–(5) we could solve more complex situations such as $w^* = (w_1 \vee \neg w_2) \wedge w_3$ given $\langle w_1, h_1\rangle, \langle w_2, h_2\rangle, \langle w_3, h_3\rangle$. If they exist, there are two ways to achieve w^* with these means:

(a) $\langle w^*, h_1 \cup h_3\rangle$
(b) $\langle w^*, \overline{h_2} \cup (h_3 \setminus h_2)\rangle$

Remark (App1.17)

In general, even if $\langle w_1, h_1\rangle \in A$, $\langle w_2, h_2\rangle \in A$, and $w^* = f(w_1, w_2)$, the hypothetical action for w^* given $\langle w_1, h_1\rangle, \langle w_2, h_2\rangle$ may not belong to A. That is, given arbitrary means we could think of unachievable actions as a result of rules (1)–(5).

To see that, let us consider $\langle w, h_1\rangle \in A$ and $\langle w, h_2\rangle \in A$ to be such that $h_1 \cap h_2 = \emptyset$. Let $w^* = \neg w$. The action for w^* given $\langle w, h_1\rangle$ would be $\langle w^*, \overline{h_1}\rangle$, but $h_2 \subseteq \overline{h_1}$. Therefore, $\langle w^*, \overline{h_1}\rangle$ may be performed as $\langle w^*, h_2\rangle$ yielding w and hence $\neg w^*$.
Another counterexample would be $w^* = w_1 \wedge \neg w_2$ with $\langle w_1, h\rangle \in A$ and $\langle w_2, h\rangle \in A$ such that h is the unique proper move to w_1. The action would be $\langle w_1 \wedge \neg w_2, (h \setminus h) \cup \bar{h}\rangle$ which is equivalent to $\langle w_1 \wedge \neg w_2, \bar{h}\rangle$, that doesn't belong to A because w_1 couldn't be achieved.

An important point refers to the condition concerning whether two actions are independent one to each other:

Definition (App1.18) [Independent actions]
Two actions $\langle w_1, h_1\rangle$ and $\langle w_2, h_2\rangle$ are independent if $h_1 \cap h_2 = \emptyset$.

Quite intuitively, if two proper actions are independent then there is no conflict when accomplishing what the first one purports to achieve and avoiding what the second one purports to achieve. To be sure, if given two independent proper actions $\langle w_1, h_1\rangle$ and $\langle w_2, h_2\rangle$ we define $w^* = w_1 \wedge \neg w_2$ then we have $\langle w^*, (h_1 \setminus h_2) \cup \overline{h_2}\rangle = \langle w^*, h_1 \cup \overline{h_2}\rangle = \langle w^*, \overline{h_2}\rangle$; that is, avoiding w_2 suffices, since this implies that h_1 will be performed.

Transitivity

The transitivity of means mainly depends on the transitivity of partial ends. The property that if w' is a partial end to w'' then any means to w' is also a means to w'' is a critical feature for the quality concept. Intervening in quality basically implies to intervene in the quality of some means in order to impact on the quality of further means. In some sense, this is what quality management is about.

Remark (App1.19)
Let $\langle w_1, h_1\rangle$ be a means to w_2 and $\langle w_2, h_2\rangle$ a means to w_3. Then $\langle w_1, h_1\rangle$ is a means to w_3.

To see that, we have to see that if w_1 is a partial end to w_2 and w_2 is a partial end to w_3, then w_1 is a partial end to w_3. If w_1 is not a partial end to w_3, then it does not appear neither in any combination of implicants or implicates nor in any combination of literals in these implicants or implicates of any of its short equivalents. But if w_1 is a partial end to w_2 then it appears in at least one of its short equivalents; since w_2 is in its turn a partial end to w_3, then w_1 also has to appear in some combination of implicants or implicates (or in some combination of literals in these implicants or implicates) of some short equivalent of w_3.

Remark (App1.20)

Let $\langle w_1, h_1 \rangle$ be a means to $\neg w_2$ and $\langle w_2, h_2 \rangle$ a means to w_3. Then $\langle w_1, h_1 \rangle$ is a means to $\neg w_3$.

In order to justify this remark we have to see that the negation of a CNF scheme $\alpha \wedge (\beta \vee \gamma)$ is $\neg[\alpha \wedge (\beta \vee \gamma)] = \neg\alpha \vee (\neg\beta \wedge \neg\gamma)$ and that the negation of a DNF scheme $\alpha \vee (\beta \wedge \gamma)$ is $\neg[\alpha \vee (\beta \wedge \gamma)] = \neg\alpha \wedge (\neg\beta \vee \neg\gamma)$. In the negation of an end, negation symbols are reversed in literals and operators $\vee$ and $\wedge$ are interchanged. Accordingly, if w_2 is a partial end to w_3, then $\neg w_2$ has to appear in some combination of implicants or implicates of some short equivalent of $\neg w_3$ or in some combination of literals in these implicants or implicates.
However, if w_1 would not be a partial end to $\neg w_3$, then it would not appear neither in any combination of implicants or implicates nor in any combination of literals in these implicants or implicates. But since w_1 is a partial end to $\neg w_2$, it appears in some of its short equivalents; therefore, w_1 also has to appear in some combination of implicants or implicates (or in some combination of literals in these implicants or implicates) of some short equivalent of $\neg w_3$.

CONCLUSIONS FROM THE MODEL

The model presented in this appendix is almost literally a toy model, in the sense that it presents a very simple abstract simulation of ends achieved making moves; since moves actually accomplish partial ends, we are somehow modeling the notion of means.

Any model, and particularly toy models, has limitations as well as some argued benefits. This section presents a summary of both.

Limitations

Of course the main limitation of the model is that it is static: it makes abstraction of sequences of actions in time. As noticed before, the analogy with reliability theory and fault tree analysis (FTA) is suitable to understand what this means—in its most standard and widely used version, FTA is a static analysis; a dynamic FTA also exists. Therefore, it shows that it is not such an extravagant simplification. Nonetheless, the model is static also in the sense that circumstances in which moves and actions are carried out are considered as given and unchanging.

Many relevant issues depend on time in any realistic situation concerning means and ends. Importantly, means' availability sometimes depends on time. Our static model does not consider availability, because from the static viewpoint unavailable means simply do not belong to the set of actions. Changes in means are another relevant influence of time. Our means

have predetermined characteristics; actual means have changes during their lifetime. Finally, time is relevant mostly because one means used at a certain moment can have quite different consequences that the same means used later. Again, our model makes abstraction of these aspects.

The model is entirely "Boolean", meaning that everything takes values in $\mathcal{B} = \{0,1\}$. Actually, this is an important feature of its formulation—results on prime irredundant normal forms and the like apply to Boolean functions. Of course, our models of reality may be Boolean, but actual world is hardly "Boolean". In particular, ends and partial ends are barely achieved or not achieved. Nonetheless, it is a reasonable assumption, quite frequent in real life.

Sets V (basic ends) and M (basic moves) can be specified in many ways. However, actually we have no exhaustive knowledge of the basic events that shape our environments, or of the basic moves that actually constitute our actions. Again, FTA shows that, nonetheless, this abstraction is not so extravagant. FTA relies on Boolean algebras but nobody worries about the fact that sets of basic events are not predetermined and accurately specified. This fact does not lead to the conclusion that failures and dependencies between failures are not correctly conceptualized.

A related issue is that elements in sets M and V have to be basic in a strict sense. In general, this means that basic items are independent between them. In practice, it is not trivial how to define suitable sets M and V whose elements are strictly independent. This would mean that such items are not overlapped in any relevant sense, and this (in typical occasions) can barely be guaranteed.

Finally, prime and irredundant normal forms are not only hard to compute in most cases, but simply and obviously not computed by actual people. In addition, the model is confined to irredundant ends. Actually, redundancies probably abound in how we conceive complex ends—in fact, some degree of redundancy seems to be convenient.

Useful Results

Arguably these are some of the most relevant limitations of our toy model. In this subsection I am going to summarize the insights that I consider that can be obtained from it.

(1) The first point is that means and partial ends are different kinds of objects. In the model, partial ends belong to the set W though means are actions belonging to a relation $A \subseteq W \times H$.

(2) This has a notorious implication in transitivity. For the quality concept to make sense (and quality management to make sense at all), it would be desirable for means to show transitivity: if $\langle w_1, h_1 \rangle$ is a means to

w_2 and $\langle w_2, h_2\rangle$ is a means to w_3, then $\langle w_1, h_1\rangle$ is a means to w_3. This happens because moves to achieve an end can be merged with other moves in order to form more complex moves and means.

(3) A problem for the transitivity of means is that some moves can be incompatible. If moves are independent, there is no problem; if not, some hypothetical actions cannot actually be performed. Of course, this issue would be more complex in a dynamic model.

(4) In the model, the notion of equivalent ends is important. Ordinary language and everyday conventions do not make us actually efficient in detecting equivalent ways to carry out actions. We are not good at detecting unexpected implications of our complex ends either—probably because of that, not only because of randomness, our choices sometimes have unexpected consequences.

(5) Accordingly, we probably use redundant partial ends. I have referred to it as a sort of cognitive bias; however, the problem (provided there is a problem) is not redundancy in itself. Redundancy can be good, in principle. The problem would be double: (a) we do not know the degree of redundancy we are using, and (b) quite often we barely know the consequences of redundancies—i.e., two conflicting means due to their non-proper parts.

(6) The model also shows in a clear way a duality between options and requirements—and the associated duality between list of options and plans, respectively. This duality implies that both concepts switch in the case of negated ends: if w_1 is a requirement to w_2, then $\neg w_1$ is an option to $\neg w_2$; if w_1 is an option to w_2, then $\neg w_1$ is a requirement to $\neg w_2$. In our static context, we have seen that plans should not be mixed but that lists of options are equisatisfiable—this does not necessarily hold in a dynamic setting. The view in this thesis is that quality attributions may depend on whether an end is understood in terms of options or requirements—note that the same means can work in both cases: $\langle v_1, h\rangle$ in $w' = (v_1 \wedge v_2) \vee (\neg v_2 \wedge v_3)$ and $w'' = (v_1 \vee \neg v_2) \wedge (v_1 \vee v_3) \wedge (v_2 \vee v_3)$; it can be checked that $w' = w''$.

(7) Given a decision about how to define the set V of basic ends, in the model the question about the degree of complexity of an end is quite natural. I am not an expert on this issue—actually, I only know in some detail early papers by Nelson Goodman about simplicity; (Goodman 1943, 1949, 1955), among a few others. This question is merely a preliminary remark to the next point—concerning the complexity of means.

(8) Our way to conceive actions is that for $w \in W$ and $h \in H$, we would say that $\langle w, h\rangle \in A$ if there is an existing $h' \in H$ that satisfies $h = h' \cup h''$ for some h'', $h' \cap h'' = \emptyset$, such that we would say that $\langle \neg w, h'\rangle \notin A$. In this

definition, h is a proper move to w in the particular case that $h' = h$ and we would say that $\langle \neg w, h' \rangle \notin A$.

In general, we have a clear intuition of what is a proper move to achieve an end: a move that does not have superfluous parts. It is, so to speak, an efficient move to do something. The following question also arises quite naturally from the model: does a proper means have more quality than an equivalent non-proper means? The answer which is implicit in Chapters 1 to 5 is that this is not necessarily the case.

(9) A rather technical but quite interesting point is that in the general analysis of means-ends relationships, Boolean functions are not positive. A positive Boolean function $w: \mathcal{B}^n \to \mathcal{B}$ is one such that for any $\boldsymbol{v}, \boldsymbol{v}' \in \mathcal{B}^n$, if $\boldsymbol{v} \leq \boldsymbol{v}'$ (coordinate-wise) then $w(\boldsymbol{v}) \leq w(\boldsymbol{v}')$. As Crama and Hammer (2011) point out, this is a suitable assumption in voting applications or most applications in reliability theory: voting rules do not switch from 1 to 0 when a single voter switches from 0 to 1; a system in state 1 (functioning) do not switch to state 0 (not functioning) if an element of the system is repaired (switches from 0 to 1). However, in our model (as in more sophisticated applications in reliability theory) an end may not be achieved if a partial end switches from 0 to 1. We admit negative requirements—partial ends that have to be not achieved in order to accomplish the final end.

The model shows in a coherent way that ends expressed with negations (negative ends) have exactly the same status than positive ends: not to do something can be a suitable way to achieve an end. For instance, not to make a payment may be a means to reinforce a negotiating position. This is obvious and well known and acknowledged in many contexts. However, discussions about the quality concept usually do not refer to the quality of things that are not done. The problem is whether we have any good reason to not use the quality concept in negative means.

Appendix 2

On Reasoning in Science and Management

Allegedly, quality management should use the scientific method. The bottom left of the Joiner's triangle corresponds precisely to 'the scientific approach'. The heart of the scientific approach is collecting and using data to guide our thinking (Scholtes, Joiner and Streibel 2003). Since quality management, and significantly Six Sigma, make a broad use of data and statistical methods, "the quality movement can be seen as the analysis, institutionalization, and democratization of the scientific method, a tool for efficiently generating new knowledge" (Box 1997).

This appendix is aimed at presenting some straightforward differences between general patterns of reasoning in science and management. Above all, it is aimed at discussing some implications of these differences concerning the role of quantitative methods in management. Quantitative methods are very important in management but managers should realize that their role is not the same than in science. Their use necessarily responds to different criteria than in science and managers have to understand these differences in order to avoid analytic mistakes.

The issue is particularly relevant in the case of quality management, where statistical techniques necessarily play an outstanding role. Previously in this thesis I have argued that intervening on quality is mainly a matter of intervening on the shape of (multi-dimensional) joint probability distributions. Therefore, statistics is constitutive and essential to quality management; statistical thinking is inherent to what it does. Nothing in this appendix is against the use of statistics in quality management—actually, the core ideas in the thesis provide a justification to the use of data when intervening on the quality of what organizations use and provide. However, differences in patterns of reasoning with the scientific use of statistics are important in quality management as in any other managerial activity.

MONOTONIC AND NON-MONOTONIC REASONING IN SCIENCE AND MANAGEMENT

The only feature I want to assume about science is that it is an outstanding mechanism to protect monotonicity in reasoning based on scientific theories. I do not suggest that science always succeeds in doing so, but it does it in its normal functioning with noticeable reliability. Science is (among other things) a mechanism that is capable to add knowledge while protecting monotonic reasoning.

Monotonicity is a logical property captured by the so-called 'weakening rule'. If it is the case that a conclusion C can be deduced from a set of sentences Γ, then it is the case that C can be deduced from Γ and a new sentence α:

$$\frac{\Gamma \vdash C}{\Gamma, \alpha \vdash C}$$

Logical consequence is preserved when the number of premises increases. That is, let i, ii and C_1 be as follows:

i: Snow is white
ii: Snow is wet
C_1: Snow is white and wet.

Of course, C_1 can be deduced from i and ii. Let iii be an additional premise:

iii: Mickey Mouse is alive

There is no mystery in the fact that C_1 can be also deduced from i, ii and iii, because it can be deduced from i and ii. This is the weakening rule at work and an example of monotonicity.

Science is made in such a way that it minimizes non-monotonicity, in the sense that it minimizes failures of the weakening rule in reasoning with its accepted theories. Sciences provide explanations about types of phenomena in such a way that whenever an additional discovering contradicts an explanation we have to acknowledge that it was not actually correct. That is, whenever $\Gamma, \alpha \nvdash C$ then $\Gamma \nvdash C$:

Remark (App2.1)

Monotonicity implies that it cannot happen that a fact is incompatible with an explanation but the explanation is still correct.

The whole thing is allegedly about that. Monotonicity usually generates refinements: an explanation was correct but just under some particular

conditions; the new premise opens the path to discover a more general case.

However, management is not science. It does not properly make explanations of any type of phenomena—at best, it tries to understand particular situations which are subject to changing environments. Economics studies types of phenomena; management tries to understand how particular changing situations fit (or partially fit) with known economic patterns in order to make decisions. Management tries to obtain ideas to do things in complex environments under some multiple, changing and partial criteria. Therefore, management needs of partial, situated and mostly non-monotonic reasoning.

Non-monotonicity appears when a conclusion C can be deduced from a set of sentences Γ but it may be the case that C cannot be deduced from Γ and a new sentence α. This is quite usual in everyday reasoning and any kind of reasoning in which new information makes us update partial but correct inferences. The following conclusion C_2 can be derived from premises 1 and 2:

1: The opening time for the attention desk is 8 am.
2: It is 9 am.
C_2: The attention desk is open

People successfully make this kind of deduction every day; everyday life depends on the reliability of consequence relations like this. As actors, we move through our world making this kind of inference. In fact, action would not be possible without such inferences. However, C_2 cannot be deduced from 1, 2 and 3:

3: Mr. Smith, the man who has to open the attention desk, has not arrived yet

The weakening rule fails. Somebody would claim that C_2 cannot be deduced from 1 and 2, as premise 3 conspicuously demonstrates. Precisely this is the critical point:

Remark (App2.2)

The question is not that conclusion C_2 cannot be properly deduced from premises 1 and 2, and that our knowledge of some type of phenomenon advances by discovering the new fact stated in 3: the question is that action (i.e. go to the attention desk) is enabled and only can be enabled by inference from 1 and 2 to C_2.

Let me repeat it: simplest actions would not be possible without that kind of inference. Actors' life in any environment entirely depends on partial inferences that are subject to the emergence of new information, as AI

researchers discovered in the 1970s—see the initial chapter by Matthew L. Ginsberg in Gabbay, Hagger and Robinson (1994). Cognitive actors have no alternative to non-monotonic reasoning in actual situations.

The example of the attention desk is extremely simple. In more complex situations an actor may have not many elements to decide whether he is in front of an exception or a new stable constraint to what he can do.

Remark (App2.3)

This is not because of any defect in the method used to obtain premises or hypotheses, but because of the very nature of the context and purpose of the inference. Actors have to move on; they have to decide and to do things.

Science is able to keep at bay non-monotonicity in inferences with its accepted theories. It can achieve it not only because of how scientific discoveries are made, but because science is about law-like statements about types of phenomena. Management does not make law-like statements about types of phenomena. At best, it makes action-oriented statements about situations or elements in situations. In managerial contexts, non-monotonicity is the rule, not the exception to avoid.

Desirable features normally attributed to science largely relate to monotonicity: coherence, rationality (however interpreted), testability of its explanations, existence of falsifiability criteria, reproducibility of its results, ability to make highly accurate predictions, reliability, ability of reduction of some theories in terms of others, capability of knowledge addition, and so on. Science is a desirable model to other disciplines mainly because of these features—that is, mainly because of monotonic reasoning.

Measurement, observation, data analysis and the like will not provide comparable features in disciplines which are not focused on law-like statements about types of phenomena. That's not to say that they are useless, but that they do not play the same role than in science. Don't be confused by the fact that, of course, management can use results from science, particularly economics. In particular, results from applied science—the study of types of phenomena that are relevant to create technology in the broadest sense—are widely used in fields outside of the scientific inquiry. Science is about law-like statements concerning phenomena even when it is applied, not basic.

DECISION MAKING AND BELIEFS SUPPORTED BY EVIDENCES

Nonetheless, why is it so dangerous to act as if management could use the scientific method? In general, it is not dangerous. People use measure-

ments and quantitative analysis to figure out what is going on in a situation: e.g. how a process actually behaves, how an indicator changes or which is the distribution of some characteristic of an object or whatever. This is extremely desirable, even if it has little to do with the scientific method of reasoning and justification. It generates knowledge to be added to inferences about the situation in which we have to act—non-monotonic inferences, by the way.

However, in some occasions it can be dangerous: the danger appears when we do not realize that knowledge about situations is never the unique point to consider when making decisions and doing actions. In some occasions, it is not even the most important point—when there are no doubts about what is going on. In contrast, knowledge about phenomena is the unique point in basic science and at least the main point in applied science.

There exists a widespread idea according to which good decision making (not law-like knowledge about types of phenomena) should be mainly based on data and quantitative analysis. Claims attributed to Lord Kelvin express that idea: "to measure is to know" or "if you cannot measure it, you cannot improve it". I agree with such claims provided that we understand that they are merely a manner of speaking, a way to recommend avoiding commonsense or intuition in some occasions.

However, improving is much more than to improve a measurable indicator. This is not for the trivial reason that people improve things without managing any indicator; we could think of their deeds as if they were improving an implicit indicator. It is not for the reason that phenomena are multi-dimensional, and moving an indicator through its direction of improvement can imply moving another attribute to the contrary. The main reason is that any situation or process has a context of objectives, hypothesis, suppositions, preconceptions, conceptual schemes, questions, expectations and so on. These things can be revised and updated, and such revisions and updates can lead to actions and designs that *are* improvements:

Remark (App2.4)

Just changing the setting where previous performance indicators relied (independently of whether they have been improved or not), it is also possible to achieve genuine improvements.

Quantitative methods are not focused on unveiling, understanding and analyzing the relevance and suitability of objectives, hypothesis, suppositions, preconceptions, conceptual schemes, questions, expectations and the like. They are useful to check the evidential support of some beliefs that are associated to these aspects—particularly in the case of hypothesis. This is extremely important (provided there is enough time and resources to

gather and analyze data), but managers also need a broader perspective on the relevance and actual interest for analysis and decision making. They need that broader perspective because managerial reasoning has to deal with non-monotonicity: action-oriented statements (by contrast to law-like statements about type of phenomena) only are useful in the context of certain actions, purposes and circumstances.

Analytic rigor in decision making does not come from the use of premises obtained from data and quantitative methods. Measurement and data analysis only ensure evidential support to premises—I repeat, this is obviously important in most cases; it is just that it does not ensure their relevance or the interest of the whole inference. The rigor comes from the arguments' suitability—and this is particularly important in managerial decision making.

In the case of quality management, I repeat the claim that I have made at the beginning of this appendix: intervening on quality is mainly a matter of intervening on the shape of joint probability distributions. According to this idea, statistics is an essential set of techniques for quality management and statistical thinking cannot be separated of what it does. Nothing in this thesis recommends avoiding the use of statistics in quality management, quite the contrary: its core ideas provide a justification to its use.

Nonetheless, this use of statistics is different than in science (that does not have to deal with non-monotonic reasoning) and in quality management professionals also need a broader perspective on the relevance and actual interest of inferences in changing decision environments—they have to understand the actual role in decision making of the evidential support that statistics is able to provide.

AN ILLUSTRATIVE CASE

The Vietnam War ended in 1975 with the North Vietnamese final offensive against South Vietnamese forces and the resulting fall of Saigon.[35] Vietnam was reunified a few months later, and it was the end point of a history of foreign occupation (by French, Chinese, Japanese, British, and Americans) for more than a century.

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[35] I would like to acknowledge Professor Scott Sigmund Gartner, from the Department of Political Science at University of California, Davis, who kindly answered a question by email on my example about the Vietnam War. He neither is responsible nor necessarily agrees with any opinion expressed in this appendix about the Vietnam War or any other issue. Professor Gartner's *Strategic Assessment in War* (1997) is an interesting book on the subject.

About 20 or 25 years before, in the beginning of the Cold War, U.S. foreign policy in Southeast Asia was driven by the domino theory: if South Vietnam were lost to the Communists, the remaining states of the region would be incapable of resisting the Communist threat (Silverman 1975). In accordance with this theory, the U.S. Army significantly supported South Vietnamese against Communists since the early 1960's, with a hard involvement from 1965 to 1968 and a gradual withdrawn during the period 1969-73—the Nixon policy known as 'Vietnamization'. The final exit of the last troops in 1975 supposed, from the U.S. viewpoint, the end of a major military failure and, putting things simple, the end of an error—according to a leading decision maker from 1961 to 1968, Secretary of Defence Robert S. McNamara, "an error not of values and intentions but of judgment and capabilities" (McNamara 1995).

Especially in the period from 1965 to 1968 there are some interesting lessons about how an uncritical focus on performance indicators would pervert the balance between strategy and operations. The counterinsurgency policy during this period followed a cost-benefit or suppressive model: a strategy "predicated on the assumption that an insurgent conflict could be defeated through the capacity to harm insurgents (and their support system) at a level beyond their accepted 'cost-tolerance level' (beyond which pain and destruction are no longer acceptable)" (Shultz 1979). The suppressive model relied on decision-theoretic foundations, with a main assumption on the rationality of the enemy.

The adopted performance measures were coherent with the suppressive strategy, famously body counts, but also kill ratios, acres of crops destroyed and defoliated, and percentage of displaced populations (Shultz 1978). In fact, these performance measures were used in Vietnam even before 1965, and also in the Korean War (1950-53) (Gartner and Myers 1995). At least as soon as 1962, body counts not only dominated over all measures of performance, but also drove rewards with promotions, medals and time off from battlefield (Gartner and Myers 1995).

Body counts are an alternative to traditional geographical measures of military success, in the sense of positional possession of real state. When the strategic objective is not to invade or retake a territory, but to inflicting enough pain to the adversary to bring them to the negotiation table, then body counts are a much suitable performance indicator. A widely accepted opinion among militaries and scholars is that geographical measures of performance did not apply in Vietnam, due to its geographical and political terrain and the kind of guerrilla war performed in that terrain. Therefore, the performance indicators were coherent with the strategy, but probably they were intensively used before the official definition of this strategy, and anyway there were not many alternative measures.

A reasonable hypothesis is that (1) the context in Vietnam did not allow geographical measures, (2) previous experiences of not-entirely-geographical conflicts (i.e. Korea) derived in the use of body counts and similar performance indicators, (3) hence these indicators spread as measures of success and criteria for rewards, and (4) the very use of these assessment methods played in favor, some time after (in 1965), of the acceptability of a definite suppressive strategy—and the reinforcement of the performance measures.

Remark (App2.5)

Operational factors of information management can have an influence in strategic assessment when, for instance, not all performance measures are allowed, or when the inertia of the use of some assessment methods introduce biases in assessment criteria. Vice versa, strategic failures on informational aspects can have an impact on operations when, for example, some indicators are established as criteria for rewards (as Goldratt said, "tell me how you will measure me, and we will tell you how we will behave"), or when some problems of performance measures are reinforced with a strategic choice.

In this sense, dubious information supply from operations could "infect" strategic thinking, and vice versa, dubious information demand from strategic management could "infect" operations, usually by means of assessment and planning techniques.

Planning and analytical techniques based on evidential performance measures were seen as the best way to conduct the war. This is the common view of the period of McNamara and his team ("the best and the brightest") in the Department of Defence (1961-68); see Enthoven and Smith (1971). In 1974, Lieutenant General Julian J. Ewell and Major General Ira A. Hunt wrote that "there is a tendency in the Army to distrust operations research due to some rather unpleasant experiences with its use (or misuse) during the Robert S. McNamara – Dr. Alain C. Enthoven regime" (Ewell and Hunt 1974). McNamara himself worked in statistical control tasks during the World War II (McNamara 1995). In fact, Ewell and Hunt's book contains a commented collection of actual applications of straightforward quantitative techniques.

What went wrong from the U.S. standpoint? In hindsight it is reasonable to think that a focus on performance indicators and analytical and planning techniques could have played against some necessary reflections on suppositions (i.e. the domino theory), enemy's objectives, U.S. own preconceptions (i.e. its military advantage), expectations (which radically changed after the Tet Offensive in 1968), and similar aspects beyond performance measures that shape their interpretation.

U.S. decision makers misunderstood the main objectives of the Vietnamese: primarily independence and unity, much more than a communist regime and the establishment of relations with USSR and China—and never at the price of a divided country (McNamara, Blight and Brigham 1999). U.S. strategy, inflicting enough pain upon communist forces to bring them to the negotiation table in order to return to the pre-war status quo (Gartner and Myers 1995), relied therefore in misconceptions.

In the Errol Morris' 2003 film *The Fog of War: Eleven Lessons from the Life of Robert S. McNamara*, McNamara himself explains a similar point:

McNAMARA: "In the Cuban Missile crisis, at the end we think we put ourselves in the skin of the Soviets. In the case of Vietnam, we didn't know them well enough to empathize. And there was total misunderstanding as a result. They believed we had simply replaced the French as a colonial power and we were seeking to subject South and North Vietnam to our colonial interests, which was absolutely absurd. And we, we saw Vietnam as an element of the Cold War. Not what they saw it as, a civil war."

In 1995 there was one of several meetings between McNamara, other U.S. decision makers, their Vietnamese counterparts, and military scholars from both countries. McNamara continues saying about that meeting:

McNAMARA: "The former foreign minister of Vietnam, a wonderful man named Thach said, "You're totally wrong. We were fighting for independence. You were fighting to enslave us." Do you mean to say it was not a tragedy for you when you lost 3,400,000 Vietnamese killed which on our population base is the equivalent of 27 million Americans? What did you accomplish? You didn't get more than we were willing to give at the start. You could've had the whole damn thing: independence, unification. [Thach said:] "Mr. McNamara, you must never have read a history book. If you had, you'd know we weren't pawns of the Chinese or the Russians. Did you know that? Don't you understand that we've been fighting the Chinese for 1000 years? We were fighting for independence, and we'd fight to the last man. We were determined to and no amount of bombing or U.S. pressure would've ever stopped us." (Morris 2003, minutes from 1:17:36 to 1:20:20)

The Vietnam War case is not intended to argue that quantitative methods are not important. Obviously they are. However, evidence-based approaches should be understood in their proper dimension.

Appendix 3

On Types

(This short appendix can be skipped by those readers who are not interested in philosophical subtleties; however, it explains without too much jargon a point about the thesis that can lead to confusion.)

The dissertation makes an intensive use of "type-talk"—that is, speaking as if there were not only particular units of iPhone but also as if there were a model. There is no need to say that this is the usual way to speak not only in everyday language but also in the languages of science, technology and almost any human inquiry (Wetzel 2009). It is also usual to speak of some models' properties (such as the sales numbers in a time period) and to speak of some units' properties, maybe different from those of models (such as being damaged or not)—note that units cannot have sales numbers and the model cannot be damaged in the same sense that tangible iPhones can be damaged.

Moreover, the concepts of type and token are critical to this thesis because the key distinction between reproducible and non-reproducible means is nothing more than a contextual distinction between relevant-as-type and relevant-as-token means in a given situation.

In philosophy, the matter of whether types exist constitutes a legitimate theme. To avoid misunderstandings:

Remark (App3.1)

The thesis does not assume that types exist, as it does not assume that they do not exist—strictly speaking, it does not assume that tokens exist as it does not assume that they do not exist, either.

The thesis does assume that in ordinary language we speak of concrete units (or occasions) and we make statements about them; it also assumes that we speak of types and we make statements about them. This is obviously true.

To be precise, it also assumes that we people do things according to what we have stated about tokens and types, and that we know when such things have correct consequences or not according to some criteria. This is obviously true as well.

Therefore, loosely speaking this thesis would admit at least two philosophical readings:

(1) It intends to be literally true about some abstract objects;

(2) It could be translated in such a way that all the predicates about abstract objects would be replaced by predicates about non-abstract objects; such a translation would intend to be literally true about such objects.

Certainly we have no guarantee that the translation procedure in (2) is actually possible—but it should be so to the extent that the original analysis is correct and adequate to our concept's usage (if it is not, probably the translation would fail). In summary:

Remark (App3.2)

The thesis, strictly speaking, does not favor any particular reading. Thus it can be read independently of any substantive philosophical discussion.

That said, it is probably intellectually honest to sketch my own views, since even though they can be justified independently of the thesis (and the thesis independently of them), they may have played some role in the genesis of its ideas.

Note that what people like or dislike of types sometimes depends on the activity in which they are primarily engaged—I do not suggest that there is something wrong about it. Typically, most mathematicians not only believe that abstract objects exist but also that entities that subsume other entities (sets, classes and the like) exist by their own right—e.g., any particular complex number exists and the set $\mathbb{C}$ of complex numbers exists as well (as an independent object, in a mathematically relevant sense; i.e., it can be used in impredicative definitions). Many experimental scientists (naturalistically inclined people in most cases) would not be comfortable with such views.

At any rate, people dislike types for two main reasons that do not necessarily come together. On the one hand, there are people who don't like abstract objects—types, in principle, are abstract objects. On the other hand, there are people who dislike entities that subsume other entities (i.e., sets, classes, or types that subsume elements, members, or tokens); that is, entities made up in some way on the basis of other entities—according to a rather reasonable idea, we think of the apple-type because we perceive, handle and eat apple-tokens.

In accordance, my position should take into account both aspects of the notion of type. As it will become apparent, probably my views also depend on the activity in which I am currently mainly engaged—namely, the anal-

ysis of concepts used in some practical activities, particularly in making and implementing improvement decisions.

On that basis, my own personal position is that types, in an important sense, do not exist—and that the "type-talk" is a mere manner of speaking. However, I do not see anything wrong in *pretending* to make reference to and to quantify over types.

Roughly speaking, given what we perceive, handle, transform and use *as tokens* in our activities (without giving too much relevance to which nature or essence they have), I believe that statements such as those contained in this thesis could be translated in the terms of the reading (2) above. Predicates about types could be translated, in principle, into different predicates about tokens. Nonetheless, I believe that such exercise would not give any advantage in general cases—we would obtain equivalent statements in a much more complicated, inelegant, and difficult form to handle. Moreover, I don't believe that a translation could be actually done in practice in most cases—for instance, for the case of quality it seems to me a rather difficult task.

I believe that things we say of types are mere convenient simplifications of statements about tokens—with such tokens determined in a merely pragmatic basis. Since our activities involve constraints as well as success and correctness criteria, we cannot say whatever we want about tokens—even though we have not assumed that they are objective (actually we have suggested that they are not); there are right and wrong things (statements, descriptions, examples) even if we deemphasize the role of truth as correspondence with an objective reference.

In short, (a) I don't have a particular aversion to abstract objects, (b) I believe that entities that subsume other entities are mere convenient devices (not entities that dictate what is right and true), and (c) I don't need to take tokens as objective things, but as particular items that we handle when we carry out actions in different contexts. Therefore, (d) tokens dictate what is right and true, not because they constitute the ultimate foundation of what there is, but because we become aware of constraints to what we do by gathering information from those tokens—this is what cognition is about.

Accordingly, in the particular activity of conceptual analysis in the broad sense described in the Preface, I believe that we can make use of any available conceptual device—including modal logic and any form of intensional logic, and of course set theory in its most exuberant version; classical nominalists like Quine and Goodman would proscribe all or some of them. However, we have to bear in mind that no analysis of applied concepts requires a literal commitment with the devices and objects it uses. Conceptual analyses are not true, just correct, convenient, useful or interesting in a pragmatic sense.

Related but not strictly equivalent views can be found (in partial aspects and with different emphases and approaches) in Goodman (1951, 1978, 1984), Field (1981) and Van Fraassen (1980). From a rather different perspective, some ideas by K. Jon Barwise can be linked (although some work is required) to the view sketched here (Barwise 1989, Barwise and Perry 1983). Barwise began with gibsonian premises, which do not fit in very well with this quite goodmanian perspective; see Gibson (1979), and complementarily Goodman (1971) as a response to Gibson (1971). The possible link is more apparent in Barwise and Seligman (1997).

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