subjective part. In sum, economic analysis must rest on uncertainty as its principle foundation. Decision making under uncertainty is a good starting point in that respect.

2.2.2 Decision making under uncertainty

The concepts of uncertainty and rationality add up to a decision making framework. Rationality maintains the classical assumption about the most plausible behaviour of humans. In neoclassical economics, this assumption translates into the model *homo oeconomicus*. However, in connection with uncertainty the usual chain of reasoning for decision making lacks an important link. In general, we would use the following algorithm for evaluating the available choices (options):

$$\text{option(i)} \rightarrow \text{outcome(i)} \rightarrow \text{utility(outcome(i))}.$$

This evaluation process results in a set of projected utilities and the option referring to the maximum utility will then be favoured due to the rationality principle.

Uncertainty destroys this chain because the mapping from options to outcomes is fundamentally impaired. This is due to the fact that uncertainty involves not-knowable outcomes. With at least one outcome remaining unknown, the ordering of the implied utilities becomes unidentified. It is an empirical fact, however, that individuals make decisions despite the lack of identification. The challenge, therefore, is to understand how people nevertheless arrive at choices at all.

In order to establish the actual decision making process under uncertainty, two important observations have to be made. First, rational humans do account for the not-knowable when making decisions. Second, and probably more strikingly, only uncertainty turns the choice between options into an actual decision problem.

The first observation follows directly from the definition of rationality. It states that people choose “systematically and purposefully”, which excludes the possibility that people ignore uncertainty. The second observation follows from the fact that some aspects of individual choice remain obscure because of uncertainty. Owed to this obscurity, an objective solution for finding “the best they can to achieve their objectives” would entail perfectly copying humans, a possibility that has been excluded in the beginning. If, however, the decision making problem could be reduced to a tractable optimisation problem, humans would not actually be required to make decisions, or, more plainly, humans would not be needed at all. In that sense, without uncertainty, humans would be the slaves of the optimisation algorithm but not actually have a choice (see the interview of Ebeling, 1983, p. 7 with George Shackle, for example).

Suppose now that we would entertain an economic model that ignored uncertainty. What would be the result?

An iconic economic model is the random walk model for asset prices in complete and efficient markets. It basically says that rational individuals who process all available information cannot predict the change in the price of a liquid asset. Therefore, the best guess of a share price tomorrow is its value today. In the absence of uncertainty, we would therefore obtain a time series of asset price changes that looks like a series of independent data points drawn from a mean zero-probability distribution. Such a series provides no information whatsoever about future prices.[9]

When allowing for uncertainty, note first that asset prices too are the sole result of human negotiation. If it was true that the random walk would perfectly describe human behaviour, then human intervention would be unnecessary and we would run into a contradiction to the assumption that human behaviour cannot be exactly emulated. As a consequence, the empirical properties of asset prices will systematically deviate from the random walk properties. Time and again patterns will emerge and – by the principles of reflexivity and transformativity – disappear, change and re-emerge.

However, the direction of change of existing patterns and the features of the emerging patterns are all unknown in advance. Therefore, the key insight of the efficient market hypothesis also prevails under uncertainty: asset prices are not systematically predictable. Retrospectively, however, observed times series of asset price changes may very well exhibit autocorrelation and all sorts of dependency between these increments. Uncertainty also explains why, despite this systematic unpredictability, countless numbers of the brightest minds restlessly engage in forecasting asset prices. All these efforts are directed at discovering the emerging pattern in order to advise trading strategies based on these patterns. Trading on these patterns eventually changes them, giving rise to new features and so on. The research into and the exploitation of asset prices' properties, therefore, is nothing but applying the principles of reflexivity and transformativity in practice.

Two more remarks are in order. First, an interesting further implication of uncertainty is that an observer who *does not act* on the observation may well be able to discover a persistent pattern that looks like a profitable arbitrage opportunity. In such a situation, transformativity does not kick in, however, and as long as the observer stays inactive, the pattern may well survive giving rise to a "puzzling" deviation from the efficient market model.

It is thus understandable that several hotly debated stock market anomalies such as the weekend effect, the January effect or the momentum strategy have eventually disappeared or decayed (Malkiel, 2003; Schwert, 2003; McLean and Pontiff, 2016).[10] Once these anomalies were brought to light, people started to act upon them and thus triggered the transformation of the market. In the future, it is plausible to expect fewer such anomalies to be published because covertly acting upon them is certainly more profitable than publishing them. Covert action will delay the spread of the discovery and thus copying behaviour which eventually lead to the transformation of the market process nonetheless.[11]

As a second example, consider the risk assessment problem discussed earlier. Experiments have often shown that individuals are on average not able to provide a proper evaluation of the risk presented to them. In the best of cases, subjects are able to learn how to evaluate and consequently improve their performance (see Hommes, 2013, for example). Uncertainty helps to reconcile these results with rationality.

The argument goes as follows. Suppose that an individual is faced with uncertainty. Suppose further that, as a rule, it is impossible to quantify the various utilities of the outcomes of the individual's choice. This impossibility will usually arise because one or more final states of the options are not knowable. Add to this the empirical fact that individuals nevertheless do make decisions and we can conclude that somehow humans are able to choose even in the absence of quantifiable utilities.

Let us denote the decision making process under uncertainty d_u and the actual elementary choices, c, among the set of options, O, with $c \in O$ such that $c = d_u(O)$. The key difference between decision making under uncertainty and decision making in the actual experiment is now handily characterised by introducing an alternative decision making process that covers the domain of risk, d_r. This decision making process applies to the experiment that is set in a probabilistic framework. A possible interpretation of the "irrational" behaviour observed in the Asian disease experiment (see p. 20) then simply is that participants apply rule d_u to a risk problem for which d_r would have been more appropriate since $c \neq c' = d_r(O)$.

Hence, the finding that people decide irrationally to a large part follows from the experimenters' observation of $c \neq c'$ with c representing the objectively rational solution. The whole experiment, therefore, must be based on knowing the correct outcome beforehand. But in the presence of uncertainty such superior knowledge is unavailable, which restricts any such analysis to the domain of risk.

With this restriction in place, experimental rationality tests essentially only challenge the individuals' ability to recognise that a certain decision problem is a problem of risk rather than one of uncertainty. If we assume, however, that humans are most of the time faced with uncertainty rather than with risk, it is logical to expect respondents to "automatically" apply the decision making process under uncertainty even though the easier risk approach would be more appropriate.[12]

This having been said, under rationality, respondents in experiments of the Asian disease kind must be expected to reflect on the problem and by the principle of transformativity be able to adapt to the actual circumstances in the experiment. And indeed, according to List (2004), Thomas and Millar (2012) or Hommes (2013), learning in repeated experiments takes place with respondents showing a tendency to provide the objectively correct answers.

The same learning process can also be observed in real-life situations. Thaler (2016) offers a telling anecdotal evidence. He observes that investors continuously converge to the rational price of a derivative (which is its underlying asset) once they are made aware of the technically determined relationship between the derivative and the asset. His specific example draws on a fund called "Cuba" that tracks the evolution of some listed companies. For some reasons, the price of the fund stays below the underlying assets' values. In the wake of the Obama administration's lifting of sanctions against Cuba (the country), the funds' prices first strongly overshoot before converging to the value of the underlying stocks.

The question thus remains what can be learned from experiments set in the context of risk while in reality many decisions involve uncertainty.[13] Contrary to what some experimenters claim, not much can obviously be learned about the degree to which people act rationally beyond, of course, respondents' ability to switch from d_u to d_r.

Nonetheless, those experiments are invaluable in determining the tools humans use for decision making when facing uncertainty. Remember that this task is extremely difficult if not impossible to shoulder with mathematical precision because it involves not-knowables. On the upside, however, we must conjecture that all those factors that determine the difference between c and c' are also linked to the differences between d_r and d_u. Since economists and others have already studied and understood d_r (decision making under risk) very well, a careful analysis of the factors linked to the differences between d_r and d_u will eventually reveal the mechanisms of decision making under uncertainty.

Thankfully, psychologists and economists have already identified a great number of factors that are related to $c - c'$. Assuming, for example, that humans have been faced with uncertainty ever since they have populated the earth, humans probably have developed efficient strategies to cope with it. It is therefore a matter of taste to refer to these empirical identifications as an evolutionary approach. Researchers, in turn, uncover those strategies and, potentially, improve upon them.

Without claiming completeness, the following list provides some of them. For reasons that will be explained below, we will call this list "decision enabling factors":

- emotions (Damasio, 1995; 2012)
- anchor values (Kahneman, Schkade and Sunstein, 1998)
- endowment (Tversky and Griffin, 1991)
- institutions
- belief
- credible information (Druckman, 2001)
- status quo (Samuelson and Zeckhauser, 1988)
- heuristics (Goldstein and Gigerenzer, 2002)
- uncertainty aversion (Ellsberg, 1961)
- inattention (Bacchetta and van Wincoop, 2005)
- deliberate ignorance
- science
- whim (Keynes, 1936, pp. 162–163)
- sentiment (Keynes, 1936, pp. 162–163)

- chance (Keynes, 1936, pp. 162–163)
- prejudice

In the presence of uncertainty these factors are not merely "explainawaytions" (Thaler, 2016, p. 1582) or stains on an otherwise-perfect *homo economicus*. Rather, they are indispensable tools for making decisions in most circumstances because they help to bridge the gap between the not-knowable outcome of a certain choice and its utility for the individual.

A striking example that underlines the importance of emotions, for instance, is owed to Damasio (1995). Damasio tells the story of a patient called Elliot who had lost parts of his brain due to a surgery that removed an aggressive brain tumour. Crucially, however, with the tumour some frontal lobe tissue of the brain had also be to be removed. This region of the brain is known to be the region where emotions are controlled.

The operation was a "success in every respect", Damasio (1995, p. 36) reports and adds, "To be sure, Elliot's smarts and his ability to move about and use language were unscathed". It later turned out that he also did well in standard tests of cognitive skills and analytical problem solution. And yet, something peculiar had changed:

> He needed prompting to get started in the morning and prepare to go to work. Once at work he was unable to manage his time properly; he could not be trusted with a schedule. [...] One might say that the particular step of the task at which Elliot balked was actually being carried out *too well*, and at the expense of the overall purpose.
>
> Damasio (1995, p. 36), emphasis as in the original

Elliot, moreover, showed "superior scoring on conventional tests of memory and intellect" which apparently "contrasted sharply with the defective decision-making he exhibited in real life", (Damasio, 1995, p. 49). Even more strikingly, Elliot was very well aware of himself and his excellence at testing as well as of his inability to cope with real life. Damasio (1995, p. 49) gives the patient's own account of his situation as follows.

> At the end of one session, after he had produced an abundant quantity of options for action, all of which were valid and implementable, Elliot smiled [...] but added: "And after all this, I still wouldn't know what to do!"
>
> Damasio (1995, p. 49)

It might be noteworthy that Elliot seemed to command all the required skills, knowledge and wits of a rational man, quite like economists imagine the perfect decision maker. But still, he was not up to the challenge of being a functioning member of society.

This dis-functionality shows as an inability to choose, as Damasio (1995, p. 50) observes: "The defect appeared to set in at the late stages of reasoning, close to or at the point at which choice making or response selection must occur. [...] Elliot was unable to choose effectively, or he might not choose at all, or choose badly."

What is probably most remarkable of all is the underlying reason Damasio discovers for Elliot’s behaviour. Damasio (1995, p. 51): “I was certain that in Elliot the defect was accompanied by a reduction in emotional reactivity and feeling. [...] I began to think that the cold-bloodedness of Elliot’s reasoning prevented him from assigning different values to different options, and made his decision-making landscape hopelessly flat.”

After having studied twelve patients with similar damages to frontal lobe tissue and similar changes in personality that turned individuals from affectionate, emotional beings into rather “cold-blooded” rational men, Damasio (1995, p. 53) summarizes that in none of the twelve cases “have we failed to encounter a combination of decision-making defect and flat emotion and feeling. The powers of reason and the experience of emotion decline together.”

There still remains one riddle to be resolved. How is it possible that a smart, knowledgeable man does perfectly well in the laboratory but still cannot prevail in life? Damasio’s (1995) simple answer is: uncertainty.

> Even if we had used tests that required Elliot to make a choice on every item, the conditions still would have differed from real-life circumstances; he would have been dealing only with the original set of constraints, and not with new constraints resulting from an initial response. [...] In other words, the ongoing, open-ended, **uncertain evolution** of real-life situations was missing from the laboratory tasks.
>
> Damasio (1995, p. 49f), emphasis added

Thus, once we shift the focus of the analysis of decision making away from laboratories (and mathematical models) to real-life problems where decisions have to be made under uncertainty, *emotions* apparently do not impair but *enable decisions*. In the words of Damasio (1995, p. 49f): “***Reduction in emotion may constitute an [...] important source of irrational behavior***” (bold face and italics in the original).

Using the above notation, it seems that Elliot had lost his ability to make decisions using d_u but retained d_r. When going through standard testing procedures, d_r was fully sufficient for gaining high scores but these scores were meaningless, when d_u was needed in real life and hence under the conditions of uncertainty. It follows that emotions are an essential, distinctive element of d_u that is not part of d_r.

To sum up, emotions *enable* decision making; they are not merely confounding factors or causes of “irrational” behaviour. Quite to the contrary, emotions are a pre-condition for rational choice under the conditions of uncertainty.

We may also consider deliberate ignorance. In the presence of uncertainty, the common expected utility approach does apparently not work. A workaround in this situation is to simply ignore this fact. For example, central banks including the European Central Bank and the Federal Reserve nowadays require the commercial banks to calculate their individual value at risk. The value at risk is then compared to the banks’ equity in order to assess the banks’ resilience to adverse shocks. Obviously, due to the many subjectively determined asset prices on the banks' balance sheets and the fundamentally unknown future, these value-at-risk calculations can only be stochastic approximations of uncertain, i.e., not-knowable outcomes. Nevertheless, by deliberate ignorance, a judgement of the banks' resilience can be made, irrespective of how "wrong" these judgements may turn out in the future.

Finally, let us consider science and belief. Science helps mankind to draw a distinction between uncertainty and risk. Earlier, people would consider thunder as the result of their own misconduct. This reasoning was perhaps enshrined in beliefs or religion[14] and offered a way of dealing with the (unknown) cause-effect relationship. Scientists have, however, later proved that it is the result of exogenous, natural forces instead. Therefore, human decision making with respect to the thread of thunder, or lightning for that matter, has fundamentally changed. It is now referred to the domain d_r while it used to be part of the d_u rules. On a deep, very fundamental level, it is as yet an open question, whether all decision making problems can – in violation of the key assumption – eventually be referred to the domain of risk instead of uncertainty.

Models of decision making that aspire to also account for uncertainty, therefore, must include the actual determinant of decision making into a coherent framework. Furthermore, interpreting the experimental or empirical evidence requires an inversion of Friedman's (1953a) notion of "as if"-behaviour. In experiments that are restricted to the stochastic or risk domain, one must assume that participants usually behave "as if" they make their decision under uncertainty, yet not "as if" the economic theory or their assumptions were true. Their decisions must be considered to reflect rationality and potential deviations between the experimenter's rational solution and actual decisions must first of all be accredited to the difference between optimisation under risk versus uncertainty.

2.3 The epistemology of economics

Owed to human creativity, any economic model, law or constant must be considered historical in nature, or at best of transitory validity. It is impossible to discover fundamental or eternal laws because humans constantly create and change the society they are living in. The direction of change is genuinely unpredictable due to the impossibility to simulate the human brain which eventually gives rise to omnipresent uncertainty. This omnipresence of uncertainty, however, does not simply deal a blow to some economic methodologies, it also opens the scope for new research approaches. These new opportunities will be discussed in the following subsections. We start with a brief review of the dominant, current epistemology of economics.

2.3.1 A brief look in the rear mirror

As every science aims at uncovering the truth, each science has to answer the two basic questions as to what constitutes truth and how to find truth.