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The Order of Knowledge and Robust Action. How to Deal with Economic Uncertainty?

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Abstract

Economic uncertainty has to do with the consequences of actions under different circumstances. This raises two questions: First, how sensitive are the outcomes of actions to variations in the environment? Second, how clearly can we distinguish between environments? Robustness comes at the price of targeting actions less narrowly to specific conditions, so we lose gains from specialization. Need for robustness comes from our limited knowledge. Rational dealing with uncertainty requires to accord the degree of specialization to the reliability of knowledge about the relevant circumstances. In practical terms, under such an approach acting under uncertainty is related to guidelines for strategic thinking: Focus on priorities on a broader scale; the most refined set of actions is not always the best one.

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1 Introduction

Uncertainty arises from limited knowledge. Knowledge can be limited in the sense that we do not know things precisely, or that “we simply do not know” as Keynes (1937, p.214) has put it. In the latter case we may speak of radical uncertainty or Keynesian uncertainty. In contrast, not knowing things precisely means, we have knowledge which is somehow imperfect. Several proposals have been made to formalize imperfection of knowledge – from Shackle’s (1949) contributions to Fuzzy logic. I will use the probabilistic language for talking about things that are known more or less precisely, yet not for sure. In this language probability measures are assigned to possible realisations of events. We speak of risk if there is precise knowledge about the probability distribution of the uncertain states. Knowledge, however, may be more uncertain than described by risk. For instance, we are not sure about which probability distribution describes possible realisations of events accurately. Having knowledge about a set of distributions rather than a specific distribution, is usually addressed as Knightian uncertainty – after Knight (1921). One may ask then, do we really know the set of distributions from which the relevant distributions are drawn?

This paper points to a even more fundamental point. Probability measures can only be assigned to distinguishable events. So the question is, what is the appropriate state space on which measures are formed and actions are conditioned. The goal of the paper is to establish an order on the set of possible state spaces and to give guidance on the choice of a space, in a way such that deceptions arising from actions conditioned on the states in the chosen space are kept within tolerable bounds.

2 Modelling the uncertain future

The future world is partly “men made” and partly determined by “nature”. That is, the events realized in the future result on the one side from exogenous factors, which may be called luck or fate. On the other side, they are an endogenous outcome of past or present day human actions. Modelling the future therefore involves two model components: The “nature” of the future and the “production” of the future.

Human actions are guided by the perceptual and cognitive framework in which we deal with the future, in particular, by the way in which we reflect what we know and what we do not know. As a consequence, “limited knowledge” about the “nature” and the “production” of the future is the third model component we have to consider. As a metaphor, I think of the future as a partially unknown land for which we have to draw a map to guide tours to specific targets.¹ On the one side, one would like a map with a fine grid that covers the entire terrain. On the other side, the information for filling the fine grid with correct details may be missing so that a more coarse or incomplete map gives better guidance. The metaphor suggests that two characteristics are important for a good map: First, that the coverage of the map shows the boundary of the terrain for which more or less details are known. If any terrain lies outside this boundary, one knows that there no details can be distinguished at all. Second, that in the covered part of the map the granularity of the grid is in line with the details that can be reliably

¹As Hirshleifer (1971) emphasized, “discovery” is to be distinguished from “foreknowledge”. A map expresses the “foreknowledge” we have accumulated from past experience. Agents who plan tours are aware that they may discover things on which the map is silent. What would be more awkward is if the map shows unreliable details.

distinguished.

2.1 “Nature” of the future

By the word “nature” I address the elements of the future world that cannot be influenced by current action. Let Ω be the set of all possible realisations of exogenous factors. At present time, $t = 0$, it is not known which condition $\omega \in \Omega$ is realized in the future, $t = 1$. I assume that in ideal circumstances, the language of probability theory is appropriate to describe possible future outcomes. That is, if there were no further limitations of knowledge, an adequate representation of the future is a probability space $(\Omega, \mathcal{A}, \pi)$, where \mathcal{A} is a σ -field in Ω and π a probability measure on \mathcal{A} . $A \in \mathcal{A}$ is a possible future event. We may call an agent with precise knowledge of this probability space *quasi-omniscient*. Then, by definition, for quasi-omniscient agents, dealing with the future boils down to a calculus of risks. Real agents, however, are subjected to limitations of knowledge which go beyond probabilistic calculus. In particular, the probability measure for future events may be unreliable or they may have no measure at all.

The approach of this paper is guided by the following idea. We look at Ω with a frame of mind. The frame may be structured in a more or less sophisticated way, where the degree of sophistication is a choice we make. For a quasi-omniscient agent the probability space $(\Omega, \mathcal{A}, \pi)$ is the best frame. Choosing actions optimally, conditional on this frame, yields the best future world that is possible under calculable risk. Under limited knowledge about the measure π on \mathcal{A} , a cruder frame $\Theta \subset \mathcal{A}$, in which possible future events are distinguished in a less differentiated way, may be a more reliable guide for

actions. Hence, rational dealing with uncertainty involves two steps: First, choosing an appropriate frame for thinking about the future and, second, making right decisions conditional on the chosen frame. My contribution focusses on the first step, assuming that the second step follows standard procedures of optimal allocation of resources.

Before coming back to the question how to choose frame Θ , accounting for the limitations of knowledge, we have to clarify how present human action impacts on the future.

2.2 “Production” of the future

The “men-made” part of the future is an outcome $y \in Y$, resulting in $t = 1$, which is endogenously related to a portfolio of actions chosen in $t = 0$. The portfolio of actions is an allocation $x_I = \{x_I(i)\}_{i \in I}$ of a given resource \bar{X} on a set of instruments I . In general, the relationship between actions and consequences will not be deterministic but depend on the exogenous conditions realized in $t = 1$. Under a given portfolio, each instrument generates, conditional on $\omega \in \Omega$, an outcome which is an increasing function of the part of resources allocated to the instrument:

$$y = f_i(x_I(i)|\omega), \quad i \in I.$$

Instruments can be more or less sensitive to variations in the exogenous environment. To address the relevant sensitivity, the following definitions are useful.

Definition 1. *Instrument i is robust with respect to $\omega, \omega' \in \Omega$ if and only if*

for all feasible $x(i)$

$$f_i(x(i)|\omega) = f(x(i)|\omega').$$

An instrument is called (globally) robust if it is robust with respect to ω, ω' for any $\omega, \omega' \in \Omega$.

Definition 2. Instrument i is targeted to environment $A \in \mathcal{A}$ if and only if there exists a function f_A so that

$$f_i(x(i)|A) = \begin{cases} f_A(x(i)) & \text{if } \omega \in A, \\ 0 & \text{otherwise.} \end{cases} \quad (1)$$

An instrument with high and robust outcomes clearly dominates instruments which work only under rare conditions and even then show poor performance. A non-trivial economic problem arises if high productivity can only be achieved at the cost of robustness. We can capture such trade-offs by assuming that feasible instruments are bounded by an efficiency frontier that satisfies the following property:

Assumption 1. There exists $G > 0$ so that for any $A \in \mathcal{A}$ with $\pi(A) > 0$ the productivity of the efficient A -specialized instrument, f_A , is inversely related to $\pi(A)$:

$$f_A(x) = \frac{G}{\pi(A)}x. \quad (2)$$

The assumption can be interpreted as follows. At $t = 0$, there exists a certain stock of general knowledge, G , how future outcomes can be generated by actions today. From the general knowledge, specific Know-how about production in specific circumstances can be derived. If, for a specialized instrument, robustness is required only under a small set of conditions, then a highly productive instrument can be generated from G .

An immediate consequence of (2) is that among efficient instruments the globally robust instrument is the least productive one. At the same time, however, the more productive specialized instruments possibly don't work in the future, according to (1). The insights of standard portfolio theory tell us that it would be desirable to have targeted instruments for all environments, to exploit specialization advantages fully and without risk. In the limit, this would mean $I = \Omega$. Yet, appropriate targeting requires that environments can be clearly distinguished and accurately measured. If knowledge about future conditions is limited, it may be better to target instruments on a more coarse frame of conditions. In view of the uncertain nature of the future, the basic trade-off we face is the following: On the one side, a higher degree of sophistication allows more fine-tuned preparation for specific realizations of possible future conditions. On the other side, a finely structured frame demands more information so that, for a given basis of experience, a more sophisticated frame may be less reliable.

2.3 Limited knowledge

In an economy, in which agents approach the relationship between present action and future outcome with the outlined cognitive framework, according to (1) and (2), knowledge about three types of objects is required for making rational choices: The possible future environments $A \in \mathcal{A}$ to which an instrument can be targeted, their measure $\pi(A)$ and the productivity level G that can be achieved by the given stock of general knowledge. Conceptually, G is not affected by the uncertainty about the specific future circumstances. Rather it assesses our general ability to shape the future. The assessment may be biased in an optimistic or pessimistic way and is of a similar nature

as Keynes' "state of expectations".

The fact that measure π on \mathcal{A} may not be known precisely is addressed in the literature about Knightian uncertainty. Following the seminal contributions of Gilboa and Schmeidler (1989) and Bewley (2002), limited knowledge about π can be modeled by assuming that the true π^* belongs to a set of measures $\pi \in \Pi$, where possibly the distribution of $\pi \in \Pi$ is known but not the true π^* itself.

There is however a more fundamental form of uncertainty. A measure can only be assigned to events which are distinguishable from other events. Moreover, for targeting actions to specific circumstances, the consequences of actions under their circumstances must be distinguishable from the consequences of actions targeted to other circumstances.² The fact of limited distinguishability of future events can be modeled in the following way: Denote by $\Omega_K \subset \Omega$ the more or less explored terrain, whereas $\bar{\Omega}_K \equiv \Omega - \Omega_K$ is unexplored. Let, for an index set $N = \{1, \dots, n\}$, $\Theta := \{\vartheta_\nu \in \mathcal{A} \text{ and } \pi(\vartheta_\nu) > 0\}_{\nu \in N}$ be a decomposition of $\Omega_K \subset \Omega$ (that is: ϑ_ν and $\vartheta_{\nu'}$ are disjoint if $\nu \neq \nu'$ and $\bigcup_{\nu \in N} \vartheta_\nu = \Omega_K$). I call n the granularity of Θ and $\mu_\Theta = \pi(\Omega_K)$ the coverage of Θ .³

Definition 3. *An economy is Θ -constrained if the class of distinguishable environments is Θ and the set of targeted instruments is given by $F = \{f_\vartheta | \vartheta \in \Theta\}$.⁴*

²As Diamond (1967) pointed out the ultimate limit of diversifying risk under technological uncertainty is "an inability to distinguish finely among the states of nature in the economy's trading" (p.760).

³In Falkinger (2014) I used this approach to discuss the role of uncertainty in a general equilibrium model with financial markets.

⁴Since F contains only targeted instruments, each ν addresses exactly one ϑ so that

In a Θ -constrained economy, agents can use a portfolio $\{x_\Theta(\vartheta)\}_{\vartheta \in \Theta}$ of targeted actions. For the (possibly empty) unknown terrain $\bar{\Omega}_K$ no targeted instruments exist so that only a globally robust instrument, f_Ω , can be used to prepare for events there. Let $x_\Theta(\Omega)$ denote the resource allocated to this instrument. For allocating a total resource \bar{X} on a portfolio $x_\Theta = \{x_\Theta(\vartheta_1), \dots, x_\Theta(\vartheta_n), x_\Theta(\Omega)\}$, in a reasonable way, the part of measure π one needs to know is $\pi_\Theta = \{\pi(\vartheta)\}_{\vartheta \in \Theta}$. Actually, agents may not know the measure correctly but only the set of measures to which it belongs:

$$\Pi(\Theta), \quad \pi_\Theta \in \Pi(\Theta).$$

Apart from uncertainty about π_Θ , coverage μ_Θ may be uncertain, too. Yet the information basis about the boundary between territory Ω_K , known at scale Θ , and the unknown terrain $\bar{\Omega}_K$ outside is of a different nature than the knowledge within Ω_K . Either one has information on the size of the whole world Ω or one has not. In the first case, we know μ_Θ for sure; in the second case, we have to choose a weight that expresses our subjective view on the importance of the unknown terrain relative to the terrain which we know at least to some extent.⁵ In both cases μ_Θ is exogenous – as an observed measure in the first case or as a belief in the second case. We have

we can skip index ν . Here instruments are fully specialized to a particular environment. A looser form would be that instruments work best in the targeted environment but to some extent also perform in other environments. In this case, the correlation between instruments could be used as a measure of (non-)distinguishability. See Studer (2015) for an analysis of financial innovations based on correlated underlying projects.

⁵If one thinks it is unreasonable to put a positive weight on something we do not know (though we know there may be something) the appropriate weight is $\mu_\Theta = 1$. To require from the user of a model to take a stand on $1 - \mu_\Theta \in [0, 1)$ mirrors the conviction that it is reasonable to be aware that there may be regions of events outside the familiar terrain.

the restriction

$$\mu_{\Theta} = \sum_{\vartheta \in \Theta} \pi_{\Theta}(\vartheta)$$

on π_{Θ} .

3 The order of knowledge

3.1 Granularity and coverage

In a Θ -constrained economy, the possibility to prepare for the uncertain future by sophisticated actions are limited by the granularity, n_{Θ} , and the coverage, μ_{Θ} , of distinguished environments. Since targeted actions are more productive than a robust one, a finely differentiated grid Θ covering many events is preferable to coarse granularity and low coverage. The following definition characterizes decompositions of Ω along this line of reasoning.

Definition 4. *i) Θ' is a refinement of Θ if and only if for all $\vartheta' \in \Theta'$ there exists $\vartheta \in \Theta$ so that $\vartheta' \subset \vartheta$. ii) Θ' is an extension of Θ if $\bigcup_{\vartheta \in \Theta} \vartheta \subset \bigcup_{\vartheta \in \Theta'} \vartheta$.*

By definition, for any strict refinement: $n'_{\Theta} > n_{\Theta}$, and for a strict extension: $\mu'_{\Theta} > \mu_{\Theta}$. Thus, restricting the discussion to decompositions of Ω which can be ordered as refinements and extensions of other decompositions, we can capture the advantages of a more differentiated or extended grid for targeting actions by assigning to a Θ -constrained economy a differentiation (or sophistication) value:

$$D(n_{\Theta}, \mu), \tag{3}$$

where D is increasing in both arguments.

So far, space Θ has been considered as exogenously given. Yet, distinguishability of environments is a cognitive frame that might be worth to change. In view of (3), it would always be worth to approach the future with the most refined grid covering all future conditions. But, this may come at a cost. To focus on the role of uncertainty, suppose that designing targeted instruments is costless. Then, framing the future in a more sophisticated way is unambiguously good for omniscient agents. Yet, for agents whose knowledge is limited, it usually implies to base actions on unreliable assumptions and to experience deception by unintended consequences in the future. Therefore, choosing an optimal set of actions conditional on frame Θ solves only part of the problem of uncertainty. The more fundamental problem is the adoption of an appropriate frame. For a reasonable solution of this problem, the differentiation advantages captured by (3) must be weighed against costs of deception.

3.2 Reliability

Targeting actions to environments $\vartheta \in \Theta$ on the basis of a belief $\tilde{\pi}_\Theta \in \Pi(\Theta)$ leads to deception in the future if $\tilde{\pi}_\Theta$ deviates from the true measure π_Θ^* . For instance, in the expected utility framework agents choose a portfolio x_Θ in such a way that $EU[x_\Theta, \tilde{\pi}_\Theta, \mu_\Theta] = \int_\Theta u[f_\vartheta(x_\Theta(\vartheta)) + f_\Omega(x_\Theta(\Omega))] d\tilde{\pi}_\Theta(\vartheta) + (1 - \mu_\Theta) u[f_\Omega(x_\Theta(\Omega))]$ is maximal. As a result an optimal portfolio of actions $x_\Theta^*[\tilde{\pi}_\Theta, \mu_\Theta]$ is obtained. The choice is sensitive to $\tilde{\pi}_\Theta$. If the true measure is π_Θ^* , then the correct expected utility generated by $x_\Theta^*[\tilde{\pi}_\Theta, \mu_\Theta]$ is $EU[x_\Theta^*[\tilde{\pi}_\Theta, \mu_\Theta], \pi_\Theta^*, \mu_\Theta]$ rather than $EU[x_\Theta^*[\tilde{\pi}_\Theta, \mu_\Theta], \tilde{\pi}_\Theta, \mu_\Theta]$. Agents can base their decisions on more or less erroneous beliefs about the true measure. So how can we keep deceptions within tolerable bounds?

For a given set $\Pi(\Theta)$ of imprecise measures, the literature on Knightian uncertainty has proposed several approaches to choose the portfolio of actions x_Θ more cautiously. For instance, to maximize the outcome in the worst case or to apply more general concepts of uncertainty aversion.⁶ I want to emphasize a different aspect: Whatever is the rule guiding the allocation of resources, the possible deceptions implied by an optimal choice depend on frame Θ . Would it not be reasonable to keep deceptions within tolerable bounds by restricting targeted actions to sufficiently reliable decompositions Θ ? Under such a perspective, an important primitive of thinking about uncertainty is the ordering of decompositions along some notion of reliability.

Let, for a Θ -constrained economy and a given decision rule, $\{x_\Theta^*(\vartheta)\}_{\vartheta \in \Theta}$ and $x_\Theta^*(\Omega)$ be the optimal allocation of resource \bar{X} on the targeted instruments and the robust instrument, respectively. Then, according to (2), the possible outcomes from the resources allocated to the targeted instruments are given by

$$\left\{ \frac{Gx_\Theta^*(\vartheta)}{\pi_\Theta(\vartheta)} \right\}_{\vartheta \in \Theta}, \pi_\Theta \in \Pi(\Theta).$$

Suppose that the decision rule accounts for the productivity gains from targeted actions (relative to resources employed in a robust instrument), then the total volume of resources allocated to targeted instruments, $X_\Theta^* = \bar{X} - x_\Theta^*(\Omega)$, will be increasing in coverage μ_Θ . That is, there exists a function

⁶Suppose, for instance, that $\mu_\Theta = 1$ and $\Pi(\Theta)$ is a parametrized family $(\pi_\Theta(p))_{p \in P}$ of measures, where p is distributed over P according to a known measure χ . Then the expected utility approach can be extended to the risk of the π assessment by choosing a portfolio x_Θ that maximizes $\int_P v[\int_\Theta u(f_\Theta(x_\Theta(\vartheta)))d\pi_\Theta(\vartheta, p)]d\chi(p)$, where v represents the attitude towards uncertainty.

X^* on $(0, 1)$ so that

$$X_{\Theta}^* = X^*(\mu_{\Theta}), \quad \frac{dX^*}{d\mu_{\Theta}} > 0. \quad (4)$$

Moreover, if the decision rule accounts for the desire to smooth outcomes, then

$$x_{\Theta}^*(\vartheta) = \tilde{\pi}_{\Theta}(\vartheta)X^*(\mu_{\Theta}) \quad (5)$$

where $\tilde{\pi}_{\Theta} \in \Pi(\Theta)$ is the decision maker's belief.⁷

Under decision rules satisfying (4) and (5), the planned output from targeted actions is $GX^*(\mu_{\Theta})$ for all $\vartheta \in \Theta$. Actually, however any outcome $GX^*(\mu_{\Theta}) \left\{ \frac{\pi_{\Theta}(\vartheta)}{\tilde{\pi}_{\Theta}(\vartheta)} \right\}_{\vartheta \in \Theta, \pi_{\Theta}, \tilde{\pi}_{\Theta} \in \Pi(\Theta)}$ is possible. Thus, we can assign to any Θ a set

$$\Delta(\Theta) \equiv X^*(\mu_{\Theta}) \left\{ \frac{\pi_{\Theta}(\vartheta)}{\tilde{\pi}_{\Theta}(\vartheta)} \right\}_{\vartheta \in \Theta, \pi_{\Theta}, \tilde{\pi}_{\Theta} \in \Pi(\Theta)} \quad (6)$$

of potential deceptions.

Now, the valuation of the costs from potential deceptions is a normative issue so that there is no undisputable way of ranking the sets $\Delta(\Theta)$. A plausible assumption seems to me that larger deception sets are considered as less reliable than smaller ones.

Assumption 2. Θ' is less reliable than Θ if $\Delta(\Theta')$ is a strict superset of $\Delta(\Theta)$.

Another plausible assumption is that, given the experience at $t = 0$, our measure $\tilde{\pi}$ of future events becomes blurred if we distinguish future events more finely.

⁷Properties (4) and (5) apply for instance to the portfolios in Acemoglu and Zilibotti (1997) and Falkinger (2014).

Assumption 3. *i) There exists a maximal Θ_0 so that experience at $t = 0$ suffices to assess π_{Θ_0} correctly. ii) If Θ' is a refinement or extension of Θ , then $\Pi(\Theta')$ is a strict superset of $\Pi(\Theta)$.⁸*

Combining the two assumptions, we conclude that reliability decreases if the decomposition of the uncertain future in distinguishable environments is refined or extended beyond a certain scale. Using the fact that granularity $n_{\Theta'}$ is larger than granularity n_{Θ} if Θ' is a strict refinement of Θ , and that coverage $\mu_{\Theta'}$ is larger than μ_{Θ} if Θ' is a strict extension of Θ , we can assign to a Θ -constrained economy a reliability value:

$$R(n_{\Theta}, \mu_{\Theta}), \quad (7)$$

starting at $R(n_{\Theta_0}, \mu_{\Theta_0}) = R_0 > 0$ and decreasing in both arguments.

4 Choosing robust productive actions

In view of the differentiation advantages summarized by (3), without limitations of knowledge any increase in the granularity and coverage of targeted actions would be a good thing. This reflects the common view among economists that innovation and specialization are beneficial. Obviously, the benefits must be weighed against the costs of innovation like R&D efforts.

⁸ Θ_0 is maximal in the sense that for any strict refinement or extension Θ of Θ_0 , $\Pi(\Theta)$ is a strict superset of $\{\pi_{\Theta_0}\}$. For ii) note that any measure $\pi_{\Theta'}$ defines a measure π_{Θ} . Θ_0 is not fixed for ever but depends on the accumulated experience with the world we face. Keynes (1921, p.28) said: “As the relevant evidence at our disposal increases,...—we have a more substantial basis upon which to rest our conclusion” so that the “weight of an argument” increases. In the approach of this paper a more substantial experience basis expands the space of events that we can accurately distinguish.

For instance, in Acemoglu and Zilibotti (1997) a fixed set up cost limits the range of financial innovations, that is, the set of states covered by Arrow securities. If we account for the true nature of uncertainty outlined in this paper, there is an additional type of cost: The deception of plans by reality. Falkinger (2014) has analyzed the implications of limited knowledge about the measure of future environments in the context of financial innovations. More generally, we have seen in the last section that decisions under uncertainty lead to deceptions if they are based on an unreliable decomposition of future events into distinguishable environments. This points to a fundamental difference between decision making under risk and decision making under uncertainty. In the former case, targeted actions are chosen in such a way that the net benefit of the expected value of the chosen actions minus their cost is maximal. In addition to that, in the second case, the reliability of the frame, on which the choice of targeted actions is conditioned, has to be taken into account. In other words, the art of decision making under uncertainty is to consider not only the productivity dimension of actions but also their robustness.

Deliberations about robustness require to order our knowledge according to its reliability. Starting from a known terrain, Θ_0 , any refinement or extension of the set of distinguishable future environments tends to lower the reliability of plans targeted to these environments. The purpose of conditioning decisions on a reliable frame is to avoid deceptions of plans based on the chosen frame. For an appropriate choice of the frame we have to make up our mind about what is a tolerable level of deceptions. At the level of society, deceptions of plans may concern many people so that unreliable frames lead to some form of crisis. Deciding about the tolerable level of deceptions or crises translates into setting a minimum reliability level $\bar{R} > 0$, which choices of an

appropriate frame have to take into account. That means, feasible choices of decompositions $\Theta \subset \mathcal{A}$ have to satisfy the condition

$$R(n_\Theta, \mu_\Theta) \geq \bar{R}. \quad (8)$$

Combining differentiation value (3) and reliability value (7) of a Θ -constrained economy, we obtain the following characterization for an optimal choice of the frame, within which plans for the uncertain future should be made:

$$\begin{aligned} \max_{n_\Theta, \mu_\Theta} \quad & D(n_\Theta, \mu_\Theta) \\ \text{s.t.} \quad & R(n_\Theta, \mu_\Theta) \geq \bar{R}. \end{aligned} \quad (9)$$

I argued why D is increasing and R is decreasing in both arguments. Yet, I have no arguments why they should satisfy usual convexity properties. Hence, program (9) determines for each n_Θ a unique μ_Θ and for each μ_Θ a unique n_Θ , but not a unique combination of the two. We may suppose, however, that feasible refinements and extensions of Θ_0 can be lined up in a sequence $(\Theta_\gamma)_{\gamma \in \Gamma}$ with increasing granularity $n(\gamma)$ and coverage $\mu(\gamma)$. Then program (9) becomes $\max_{\gamma \in \Gamma} D(n(\gamma), \mu(\gamma))$ subject to $R(n(\gamma), \mu(\gamma)) \geq \bar{R}$, which determines a unique $\gamma^*(\bar{R})$ for the optimal decomposition $\Theta^*(\bar{R}) = \Theta(\gamma^*(\bar{R}))$ of the space of uncertain future events. An optimal choice of targeted actions within the frame of a $\Theta^*(\bar{R})$ -constrained economy – with granularity $n^*(\bar{R}) = n(\gamma^*(\bar{R}))$ and coverage $\mu^*(\bar{R}) = \mu(\gamma^*(\bar{R}))$ – exploits the differentiation advantages to an extent that is in line with deceptions and crises considered as tolerable by the individual or social decision maker. In other words, the $\Theta^*(\bar{R})$ -constrained economy leads to actions which are reflective of productivity and robustness aspects in a rational way.

5 The dialogue between experts and decision makers in an uncertain world

Decision making is typically seen as an agent's choice how to allocate a resource or capability on different instruments for pursuing a goal. The role of an expert is then to check which choices are feasible, to calculate their consequences and to identify the best choice. Essentially, this boils down to an optimization-problem. As an input for solving this problem, the expert needs from the decision maker information on the volume of effort or resource he or she is able or willing to spend, and on the goal or valuation system by which the decision maker values outcomes. Under uncertainty, outcomes are state contingent and the expert needs in addition information on the agent's attitude towards risk or their capacity to bear risk. For instance, a firm that wants to take out a loan is checked with respect to its ability to bear risk. And a client who comes to the bank with his or her savings is asked about the size of wealth to be managed and the risk preference.

In economics it often looks like solving optimization problems is the only role of experts, yet it is not. Another important role is to extend the set of feasible instruments by innovation. In this role, the message of decision makers to experts is: Search for more productive instruments. Raising productivity is closely related to specialization and differentiation. In particular, in a model of uncertainty with outcomes that are contingent on risky circumstances one wishes to have a richer set of instruments to be prepared for the different circumstances. For instance, in an incomplete market model innovation means to cover so far uncovered situations by new state-contingent securities.

Even if innovation is added to optimization the role of an expert is incompletely described. Expert systems use expert languages, whereas decision makers typically face a problem in a different language. A third and very crucial function of experts is therefore the translation of real world problems into the disciplined language they use for supporting decision makers with their expertise, as well as the inverse translation of their results into the language of the users. Essentially, this means an expert system is also responsible for appropriate modeling and communication. Appropriate modeling requires to check that primitives and assumptions on the primitives of the frame which the experts use, though abstract, capture in a reliable way the essential features of the problem facing the agents who have to decide.

A fundamental problem of economic modeling is that there is typically no unique model for a given real world situation. This brings us to the fourth task of expert systems: The choice or design of the model frame. In this respect, a problem to solve is the tension between sophistication and robustness. On the one hand, a more sophisticated model allows to give more specific and detailed advice. On the other hand, if specificities and details are very sensitive to assumptions they may give the wrong guidance. In dealing with uncertainty, the tension between sophistication and robustness is particularly pronounced. Keynes, for instance, argued that it is better to account for true uncertainty by conditioning a model on an exogenous state of expectations or confidence rather than endogenizing expectations in a calculus of probabilities which in fact are unknown. The approach sketched in this paper stresses the structuring of uncertain future terrain into distinguishable environments. On the one side, distinction of environments is crucial for targeted action. On the other side, unreliable distinction leads to deceptions. For the appropriate choice of frame, the task required from the

experts is to present their knowledge in a hierarchy ordered along the lines of sophistication and reliability, respectively. The decision makers' task is then to choose the reliability level which keeps deceptions within tolerable bounds.

6 Concluding remarks

Rational choice under uncertainty considers optimal decision making in a given framework, in particular, conditional on a given state space. From a more fundamental perspective, however, rationality implies to be aware of limitations of knowledge. Moreover, it requires to account for the fact that reasoning is conditional on the cognitive frame in which we analyze things. In dealing with an uncertain future, the critical element is: Which environments can we distinguish so that actions can be properly targeted to the environments? Therefore, separating distinguishable terrains from undistinguishable ones is important for reasonable dealing with uncertainty. In other words, the state space, on which decision making under uncertainty is conditioned from a conventional economic point of view, is endogenous and a matter of choice itself. The characteristics to be chosen are the granularity of the grid in which we distinguish and measure environments and the weight we assign to the area that is covered by the grid relative to the uncovered unknown terrain. Refined granularity and large coverage generate differentiation advantages. Yet, for a given base of experience, more coarse granularity and moderate coverage lead to more robust actions. To allow decision makers to keep actions in line with a tolerable level of deceptions or crises, experts need to present their knowledge about future events and the performance of

actions in a hierarchy ordered according to the reliability of their knowledge.

Reasonable dealing under uncertainty is therefore similar to strategic rationality. Choosing a strategy is not the same as acting according to a detailed optimal plan. Rather it means to focus on goals and to set priorities on broader scales; having thereby in mind that the strategic decision should be sustainable over a longer horizon, even though it may not be optimal under all specific conditions in the short run. It was said that appropriate reduction of complexity is an important component of good management. This is in contrast to the view that complexity is a fate to which we must react optimally by sophisticated actions. While the latter view is adequate in a given situation, it is less obvious for the framing of uncertain exogenous events; and in shaping the future complexity is definitely an endogenous outcome.

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