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« The Precautionary Principle: An Economic Viewpoint »

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The Precautionary Principle

- The Precautionary Principle (PP) at Rio Conference (1992)
  - *“Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation”*

- Similar definitions of the PP:
  - Convention on Climate Change (1992), Maastricht treaty (1995), Protocol on Biodiversity (2000), Charte de l’Environnement (2005)

- The ambition of precaution:
  - Rebut the claim that uncertainty justifies inaction
  - Empower policymakers to take anticipatory action (despite uncertainty)

Motivation for the talk

- An observation:
  - Many qualitative discussions about the PP, both in academia and in practice, but few formal/quantitative approaches
- Key questions:
  - Can we give an economic interpretation to the PP?
  - Does scientific uncertainty justify more investments in safety?
- This lecture is mostly a reflection about our economic models
  - What do they mean? What do they imply?

A preview

- Dealing with risk is not the same as dealing with uncertainty
- The PP is related to a situation of uncertainty
- Two main approaches in economics for dealing with uncertainty:
  - One is based on the standard expected utility model
  - The other is based on ambiguity (aversion) models
- Both approaches are problematic

Outline

1. Background on risk regulation and the PP

2. The expected utility model
    - Risk aversion, prudence, VSL, information value
    - Option values
    - Difficulties with the EU model

3. Ambiguity (aversion) models
    - The Ellsberg paradox
    - An ambiguity (aversion) model, and an application
    - Difficulties with ambiguity (aversion) models

1. Background on risk regulation and the PP

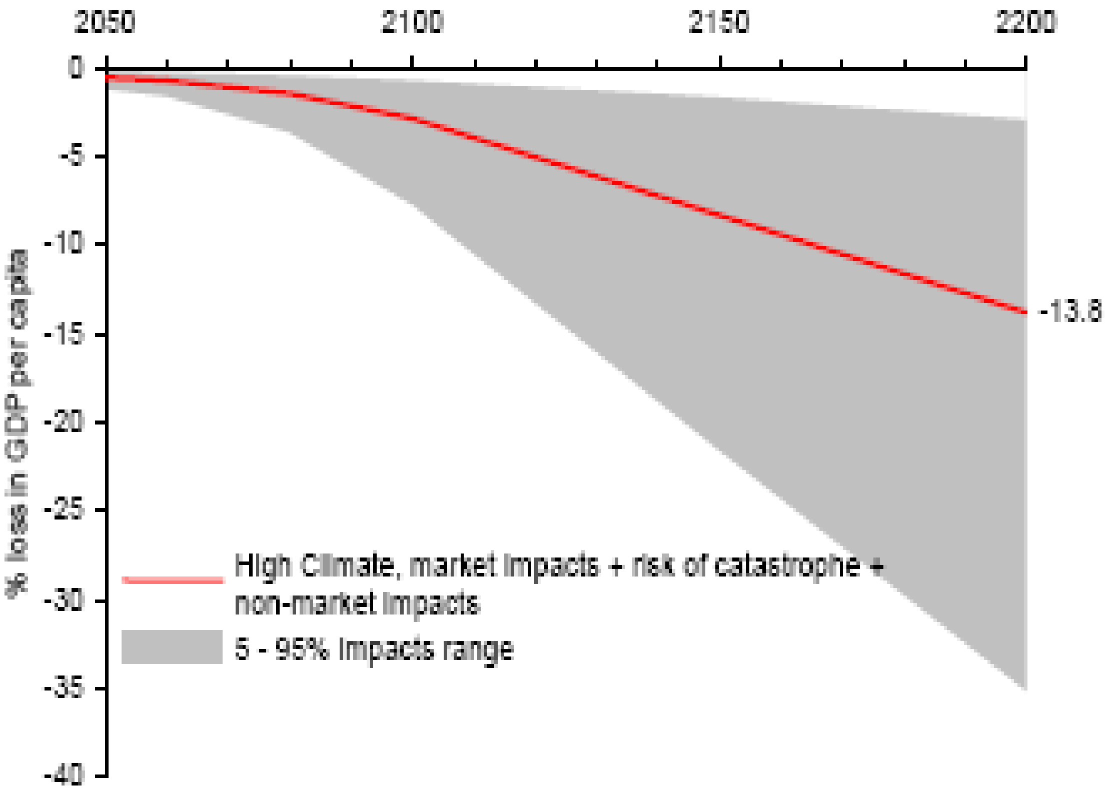
PP: Why so much fuss about a simple idea?

- Precaution => be cautious
  - « Better safe than sorry », « Look before you leap », « First do no harm », « Take care »
- However, controversies :
  - European Commission (2000, first sentence): « The issue of when and how to use the PP, both within the European Union and internationally, is giving rise to much debate, and to mixed, and sometimes contradictory views. »

Why do we need the PP now?

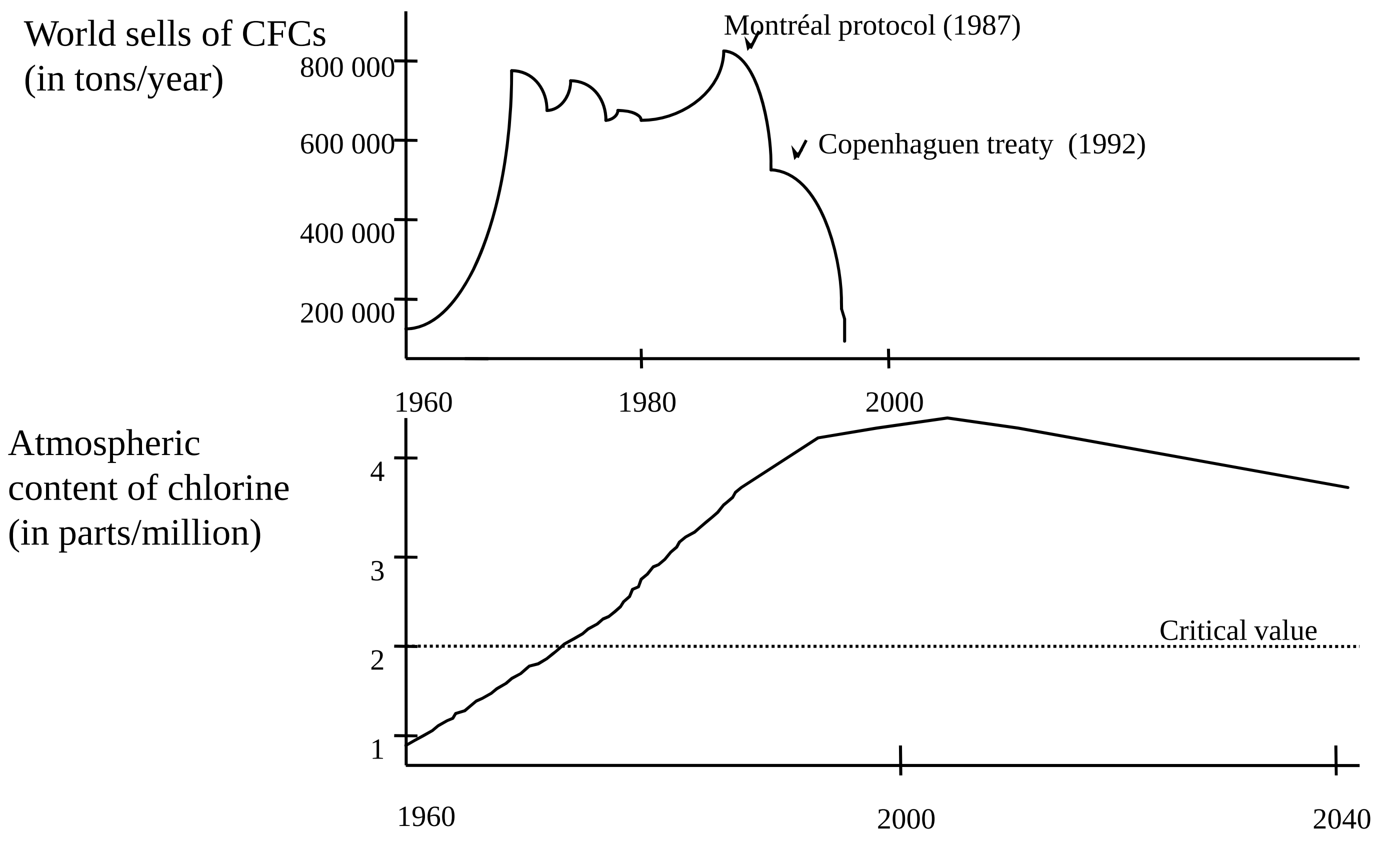
- The effects of careless and harmful activities have accumulated over many decades of economic development
- Earth limited capacity to absorb pollution
- Plenty of warnings that suggest that we should now proceed with caution

Stern review (2007)



- Global warming equivalent to an immediate and permanent reduction of 5% of world GDP
- Considerable uncertainties: GDP loss can go up to more than 20% of GDP

CFC regulation: Waiting increases damages



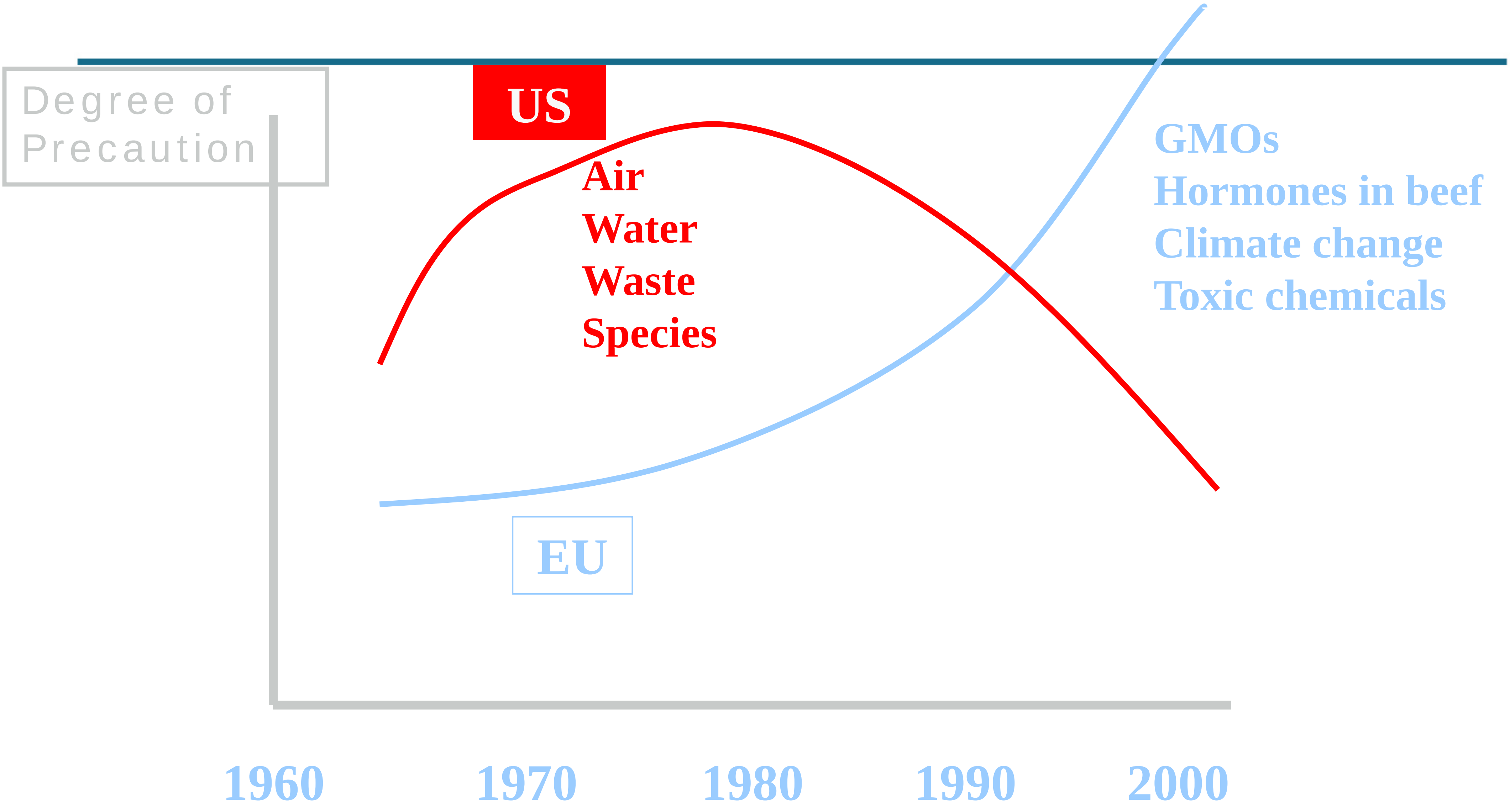
Emerging risks

- High uncertainties
- Large-scale effects
- Long term effects
- Stock and hysteresis effects
- Physical irreversibilities
- Socio-economic inertia
- Scientific progress

Historical background on the PP

- The PP has its roots, some believe, in the German Democratic Socialism in the 1930s, centering on the concept of good household management (O'Riordan and Cameron 1994)
- A precursor of the PP is known to be the German principle of « Vorsorge », or foresight, that was introduced in the early 1970s as an interventionist guideline for German environmental policy (Morris 2000, Sunstein 2005, Randall 2011)
- It is often said that the PP was first applied in 1984 at the International Conference on Protection of the North Sea
- Popular belief suggests that Europe is pro PP, and the US is against

The volte-face hypothesis



Source: Wiener (2008)

Precaution is costly

- An early example: the Superfund program in the US
- Love Canal - Hazardous waste risk was ranked first concern by US citizens (but was ranked medium or low risk by experts)
- Superfund: 36,000 sites, $50 billions, 50% of EPA budget in the 80s
- Importance of political factors (Viscusi and Hamilton 1999, AER) and of “ad hoc” policy rules
    - On some sites, 5% of expenditures eliminated 99.5% of the risk (Hird 1994)
- Cost per avoided cancer: >$1 billion!
- Inefficient since much larger than $1-10 million value-of-statistical-life (VSL) usually found in individual studies

VSL from a sample of wage differential studies

Author(s)	Year	Value of a statistical life USD Million (2000 prices)	Country
Thaler-Rosen	1975	$1.7-$1.9	US
Viscusi	1978-79	$5.5-$15.2	US
Dillingham	1977	$3.2-$6.8	US
Marin et al.	1982	$4.2	UK
Moore-Viscusi	1988	$3.2-$6.8	US
Berger-Gabriel	1991	$8.6-$10.9	US
Gegax et al.	1991	$2.7	US
Cousineau et al.	1992	$2.2-$6.8	Canada
Leigh	1995	$8.1-$16.8	US
Baranzini et al.	2001	$6.3-$8.6	Switz.
Kim	1993	$0.8	India
Liu et al.	1997	$0.2-$0.9	Taiwan

Source : Viscusi and Aldy (2003)

VSL from road safety studies

Table 1: Empirical estimates of the value of a statistical life in road traffic, in US$ 2005 (×1000)[a]

Authors	Country	Year of data, Study type	No. of estimates[b]	Range of VSL estimates Single	Lowest	Highest
Andersson (2005a)	Sweden	1998, RP	1	1,425		
Andersson (2007)	Sweden	1998, SP	8		3,017	15,297
Atkinson and Halvorsen (1990)	US	1986, RP	1	5,521		
Beattie et al. (1998)	UK	1996, SP	4		1,510	17,060
Bhattacharya et al. (2007)	India	2005, SP	1	150		
Blomquist (1979)	US	1972, RP	1	1,832		
Blomquist et al. (1996)	US	1991, RP	4		1,434	7,170
Carthy et al. (1999)	UK	1997, SP	4		4,528	5,893
Corso et al. (2001)	US	1999, SP	2		3,517	4,690
Desaigues and Rabl (1995)	France	1994, SP	6		1,031	23,984
Dreyfus and Viscusi (1995)	US	1987, RP	1	4,935		
Ghosh et al. (1975)	UK	1973, RP	1	1,901		
Hakes and Viscusi (2007)	US	1998, SP	5		2,396	6,404
	US	1998, RP	6		2,288	10,016
Hojman et al. (2005)	Chile	2005[c], SP	1	541		
Hultkrantz et al. (2006)	Sweden	2004, SP	2		2,192	5,781
Iragüen and Ortúzar (2004)	Chile	2002, SP	1	261		
Jara-Diaz et al. (2000)	Chile	1999, SP	1	4,555		
Jenkins et al. (2001)	US	1997, RP	9		1,350	4,867
Johannesson et al. (1996)	Sweden	1995, SP	4		5,798	6,981
Jones-Lee et al. (1985)	UK	1982, SP	1	4,981		
Kidholm (1995)	Denmark	1993, SP	3		898	1,338
Lanoie et al. (1995)	Canada	1986, SP	2		1,989	3,558
Maier et al. (1989)	Australia	1989[c], SP	6		1,853	5,114
McDaniels (1992)	US	1986, SP	3		10,131	36,418
Melinek (1974)	UK	1974[c], RP	1	881		
Persson et al. (2001)	Sweden	1998, SP	1	2,551		
Rizzi and Ortúzar (2003)	Chile	2000, SP	1	486		
Schwab Christe (1995)	Switzerland	1993, SP	1	1,094		
Vassanadumrongdee and Matsuoka (2005)	Thailand	2003, SP	2		3,208	5,458
Viscusi et al. (1990)	US	1991[c], SP	1	11,091		
Winston and Mannering (1984)	US	1980, RP	1	2,315		

VSL estimates in US$ 2005. Values transformed using purchasing power parities (PPP) and consumer price indices (CPI) from http://stats.oecd.org, 09/02/07. (For Chile and Thailand PPP and CPI from http://www.imf.org/external/data.htm were used.)

a: Many of the VSL estimates from de Blaeij et al. (2003).

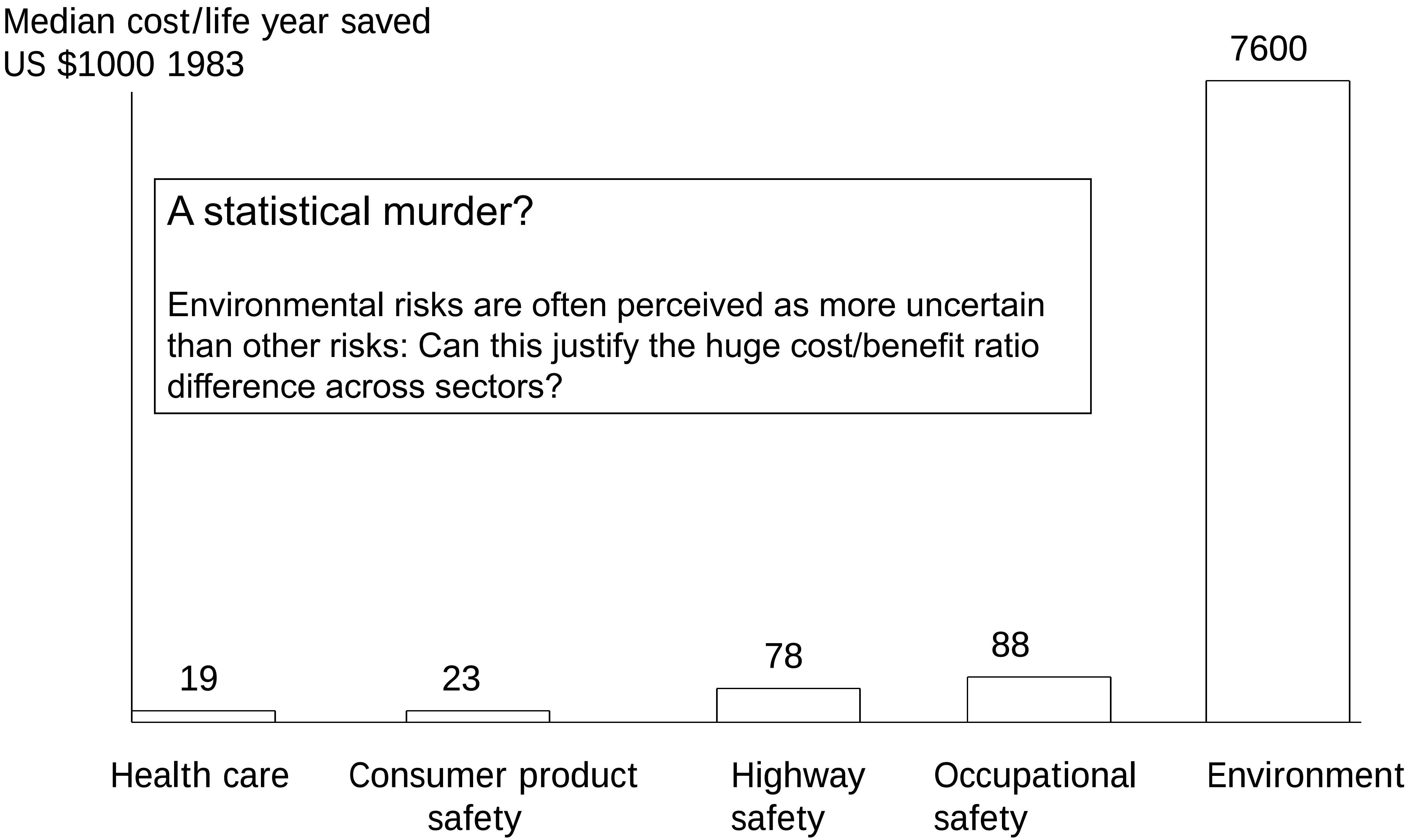
b: Several studies contain more estimates that stated here. When available, "preferred" values have been used.

c: Refers to year of study rather than data, since the latter not available.

Some ex post analyses of US public programs

Programs (Agency)	Estimated cost per avoided death – US $ Million ($1990)
Underground construction standards (OSHA)	0.1
Auto passive restraint/ seat belt standards (NHTSA)	0.1
Auto fuel-system integrity standard (NHTSA)	0.5
Crane suspended personnel platform (OSHA)	0.7
Children’s sleepwear flammability ban (CPSC)	0.8
Low altitude windshear equipment (FAA)	1.3
Arsenic/copper smelter (EPA)	2.7
Grain dust explosion prevention standards (OSHA-S)	2.8
Ethylene dibromide drinking water standard (EPA)	5.7
Arsenic emission standards for glass plants (EPA)	13.5
Ethylene oxide (OSHA)	20.5
Uranium mill tailings (EPA)	31.7
Abestos ban (EPA)	110.7
Diethylstillbestrol cattlefeed ban (FDA)	124.8
Dichloropropane drinking water standard (EPA)	653.0
Hazardous waste land disposal ban (EPA)	4,190.4

Source: Viscusi (1998), Sunstein (2001)



Source: Tengs and Graham (1996, RA)

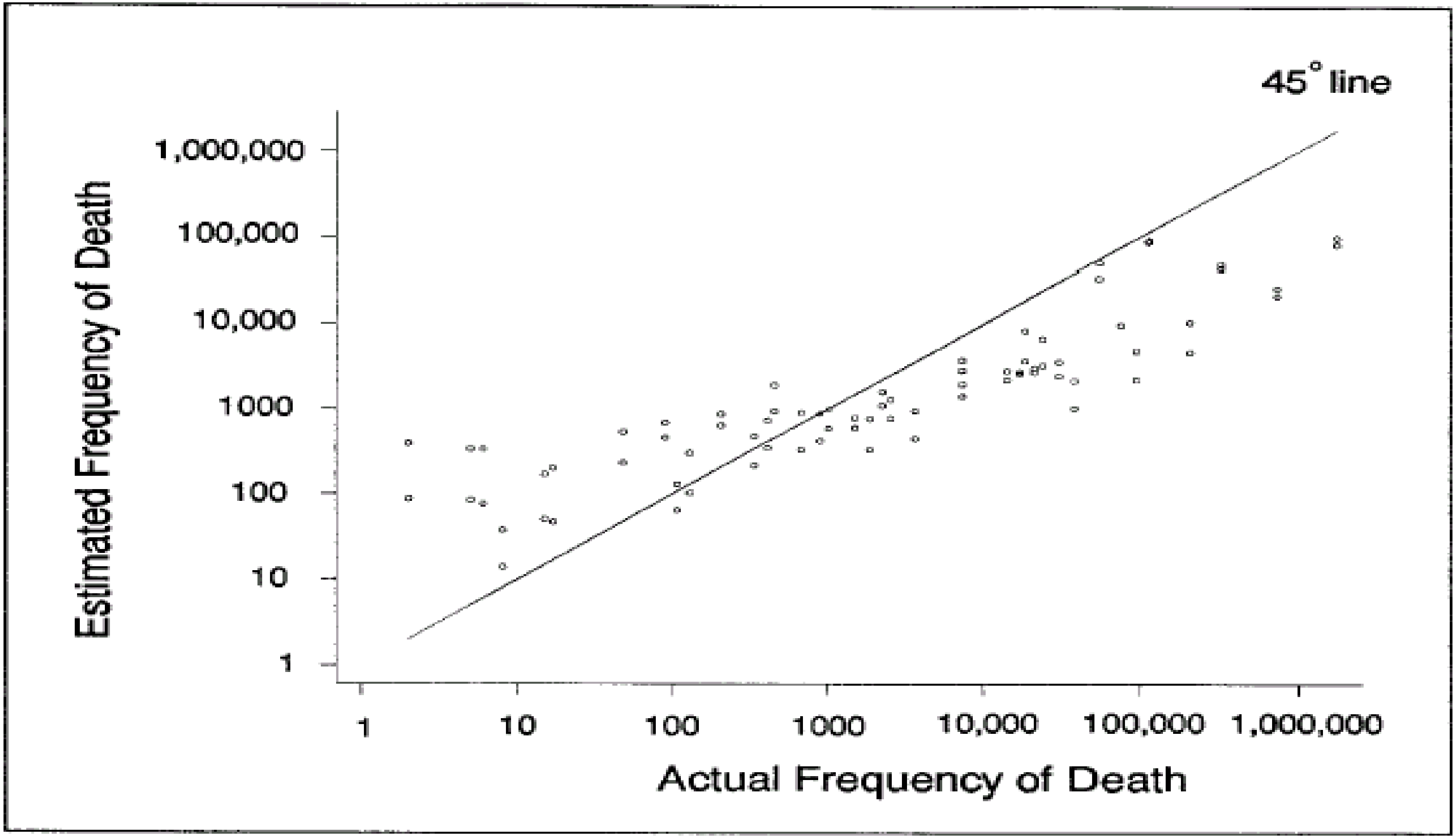
The PP = Laws of fear

- Sunstein (2000) argues that policy-makers focus too much on the worst-case scenario, and the PP is mostly a demagogic response to citizens' beliefs

- People overestimate small risks

- There is an uncertainty premium embodied in policy making (Viscusi 1998; Sunstein 2000)

Mortality risk (mis-)perceptions



Are risk assessment practices too conservative?

- **Zero-risk**: target an unrealistic « zero risk » level (Travis et al. 1987), e.g., an ideal of 10^{-7} absolute risk for Superfund risk (Breyer 1993)
- **Cut-off values**: define focal cut-off values, like the 1-in-1-million lifetime excess cancer risk, or 100-year flood, or 475-year earthcake (see the Adler (2007)'s critiques of the « de minimis » risk)
- **Use of percentiles**: Do not reflect mean values or overall distribution. Due to the use and the compound of 95% percentiles, Belzer (1991) showed that US EPA overestimated dioxine mean risk by a factor 5,000 and perchloroethylene mean risk by a factor 35,000
- **Individual risk**: Population risk not accounted – Risk assessment computations are typically based on a « virtual » individual: with maximal exposure and ingestion rates, low body weight…
- **Safety factors**: Use a safety (or blow up, or disproportionate) factor (equal to 10,100 etc.), that is hardly justified

The European Commission approach to the PP

- European Commission, "Communication on the Precautionary Principle" (February 2000): measures based on the PP should be:
  - *proportional* to the chosen level of protection,
  - *non-discriminatory* in their application,
  - *consistent* with similar measures already taken,
  - *based on an examination of the potential benefits and costs* of action or lack of action (including, where appropriate and feasible, an economic cost/benefit analysis),
  - *subject to review,* in the light of new scientific data, and
  - *capable of assigning responsibility for producing the scientific evidence* necessary for a more comprehensive risk assessment.

2. The Expected Utility Model

- Risk versus uncertainty
- The Savage Framework
- Risk aversion, and prudence
- Models of option values

Knight and Keynes' early contributions

- Knight (1921) is often credited as the first writer to make a distinction between risk and uncertainty

« Uncertainty must be taken in a sense radically distinct from the familiar notion of Risk, from which it has never been properly separated. . . A *measurable* uncertainty (i.e. risk) . . . .is so different from an *immeasurable* one that it is not in effect an uncertainty at all. »

- Keynes (1921 – initiated in his master thesis 1908)

Argues that propositions and events vary in their « appropriate degree of rational belief ». Keynes discusses the concept of « confidence in beliefs » and, although he did not believe that this need to be numerically scaled, he was concerned in the comparison of « degrees of beliefs ». See discussions in Jones and Ostroy (1984) and O'Donnell (1989).

Financial crisis and Knightian uncertainty

Economics focus

(Nearly) nothing to fear but fear itself

In a guest article, Olivier Blanchard says that policymakers should focus on reducing uncertainty

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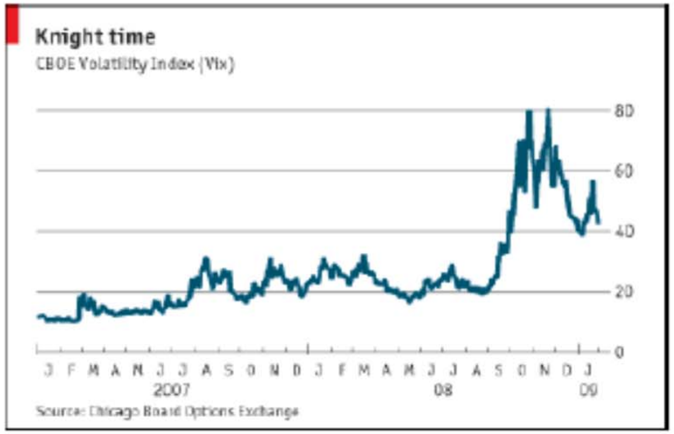
CRISES feed uncertainty. And uncertainty affects behaviour, which feeds the crisis. Were a magic wand to remove uncertainty, the next few quarters would still be tough (some of the damage cannot be undone), but the crisis would largely go away.



From the Vix index of stockmarket volatility (see chart), to the dispersion of growth forecasts, even to the frequency of the word "uncertain" in the press, all the indicators of uncertainty are at or near all-time highs. What is at work is not only objective, but also subjective uncertainty, or what economists, following Chicago economist Frank Knight's early 20th-century work, call "Knightian uncertainty". Objective uncertainty is about what Donald Rumsfeld (in a different context) referred to as the "known unknowns". Subjective uncertainty is

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What is a probability?

- Traditionnally, three views of a probability:
  - frequentist
  - logical
  - subjectivist

- The subjectivist's view can be summarized by the famous De Finetti (1928)'s sentence: « *probability does not exist* »
  - This sentence means that an « objective » probability does not exist, a probability only exists in the mind of individuals, it is a « degree of belief », and is thus subjective

- De Finetti as well as Savage (1954) propose a behavioral definition of probability, measured by the willingness to bet

The Savage expected utility (EU) framework

- The von Neumann-Morgenstern EU framework is based on objective probabilities, so it is implicitly « frequentist » or « logical »,
- Savage (1954) axiomatize EU with subjective probabilities
- In the Savage framework, there is no difference between risk and uncertainty
- In the Savage framework, probabilities can be anything (since they are subjective)
  - There is thus no sense to talk about « right » or « wrong » beliefs, more pessismistic, or biased beliefs
  - This view has been criticized: *"[U]tilities directly express tastes, which are inherently personal. It would be silly to talk about impersonal tastes, tastes that are objective or unbiased. But it is not at all silly to talk about unbiased probability estimates, and even to strive to achieve them."* (Aumann 1987)

The expected utility (EU) model

d: decision

- $\text{Max}_d \, E_X \, U(d, X)$

E: Expectation operator (i.e. the beliefs)

U(.): vNM utility function

X: risk

- Normative foundations of EU (vNM 1944, Savage 1954)
- Related fundamental concepts: economics (e.g., risk aversion), statistics (e.g., stochastic dominance), decision theory (e.g., information value)

Example 1: Risk premium and risk aversion

- Risk premium: monetary cost of risk

- Risk premium $p(k)$ in face of a zero-mean risk X:
  - $u(w-p(k)) = Eu(w+kX)$ where w is wealth, and u is an increasing utility function
  - A second-order approximation gives: $p(k)$ # EX^2 $A(w)$
  - $A(w)=-u''(w)/u'(w)$ is the Arrow-Pratt index of risk aversion (which depends on the curvature of u and on w)
  - Key concept in risk theory: u concave means « risk aversion », et $A(w)$ measures the degree of risk aversion
  - Example: $u(w)=(1-a)^{-1}w^{(1-a)}$, $a>0$ (i.e., u power form) => $A(w)=a/w$

Example 2: The standard portfolio model

- An agent maximises EU. He has a strictly increasing, strictly concave utility function u(.) of wealth.

- He can invest an amount d in a risky asset with random rate of return R, and (w-d) in a riskless asset with rate of return r.
  - $\text{Max}_d\ Eu((w-d)(1+r)+d(1+R))$
  - Notation: $U(d,X) = u(w(1+r)+dX)$ where $X=R-r$ is excess return

- A result: As soon as $EX>0$, and despite risk aversion (u concave), the optimal demand for the risky asset is always strictly positive, i.e. $d>0$.

- Intuition: Risk aversion is only a second order effect

Example 3: The VSL

- Let the state-dependent EU: $U = (1-p_0)u(w) + p_0 v(w)$
- u (resp. v) is the utility if alive (resp. dead), w is wealth and p_0 is probability of death
- Assume u>v, and u'>v'≥0, we obtain:

$$VSL = \frac{dw}{dp_0} = \frac{u(w)-v(w)}{(1-p_0)u'(w)+p_0 v'(w)} > 0$$

- The VSL increases with w and with p_0
  - Example: Let $u(w)=(1-a)^{-1}w^{(1-a)}$, and $v(w)=0 \Rightarrow VSL= w((1-a)(1-p_0))^{-1}$

Example 4: Precautionary savings

- Two-period model with wealth w1 and w2 in each period. How to allocate consumption across periods?
- $d^* = \arg \text{Max}_d \; u(w1-d) + v(w2 + d(1+r))$
- $d^{**} = \arg \text{Max}_d \; u(w1-d) + Ev(w2 + d(1+r) + X)$ with $EX=0$ (future income is risky)
- Precautionary savings iff $d^{**}>d^*$. Induced by risk aversion?
- No! For all X, we have $d^{**}>d^*$ iff $v'''(.)>0$ (Leland 1968, Kimball 1990). Condition $v'''(.)$ is coined « prudence ».

Example 5: Information value (IV)

- Simple investment decision problem under risk neutrality (i.e. linear utility function)
- U(d,X)= d (X-c) with d in {0,1} [interpretation: c is cost and X is unknown benefit]
- Investment rule: invest (i.e., d=1) iff EX>c. Expected profit: **max(EX-c, 0)**
- Suppose now perfect information is expected (i.e., a message will give perfect information about the realization of X).
- Investment rule: invest iff X=x>c. Expected profit: **Emax(X-c,0)**
- Information Value: **IV=Emax(X-c,0) - max(EX-c, 0) ≥0**
- Example:

  Take: c=100, X=(50%, 200, 50%, 50). IV= 50-25=25

  Take: c=100, X=(50%, 140, 50%, 50). IV= 20-0=20

An exercise: Park vs. parking

- Consider the choice between i) preserving a park or ii) building a parking
- There are two periods (present and future), and the discount rate is assumed to equal zero (to simplify)
- The costs and benefits have been estimated by our best experts
- The parking yields $40 benefit in each period, and the construction cost is $25
- The park yields $0 benefit in period 1, and either $100 or $0 in period 2 with equal probability
- Based on benefit cost analysis (BCA), the parking is built (since it yields $55 net benefit > the net expected benefit of the park $50)
- Do you agree with this choice in favor of the irreversible decision?

The option value

- The value of preserving the park is in fact $57.5, and is therefore the best decision
- Compared to standard BCA, there is an additional value of $7.5, coined the (quasi-)option value, that leads to preserve the park
- This is the value of flexibility: building the parking is **irreversible** while preserving the park is flexible since it maintains both options in the future
- The option value is consistent with the PP: scientific uncertainty should lead to preserve flexibility
- Early contributions on option values: Arrow and Fisher (1974, QJE), Henry (1974, AER), Epstein (1980, IER), Jones and Ostroy (1984, RES)

Modeling irreversibility

- Decision problem with perfect information

$Max_{d1}\ u(d_1) + EMax_{d2}\ u(d_2,X)$

with the following choice sets: d_1 in $D_1=\{0,1\}$ and d_2 in $D_2(d_1)=\{d_1,1\}$

- D_2(d1) represents irreversibility

If $d_1=0$ then $D_2=\{0,1\}$

If $d_1=1$ then $D_2=\{1\}$ => irreversible choice

- Numerical values in the park/parking example:

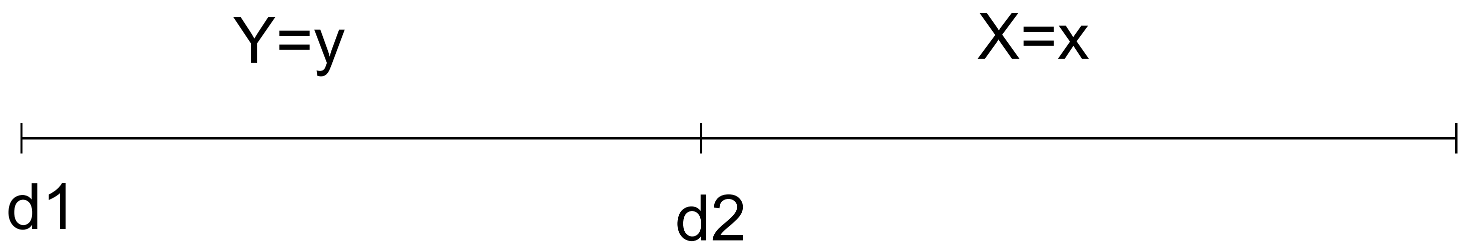
u(d1)= d1(40-25); u(d2,X)=d2(40)+(1-d2)X with X=(100, ½; 0, ½)

Information and optimal timing in policy-making

- Information/timing is critical for policy-making:
  - What should I do today given that I will have better information in the future? Should I delay decisions? Should I be more cautious?
  - *« The challenge is not to find the best policy today for the next 100 years, but to select a prudent and flexible strategy and to adjust it over time »* (IPCC 1995)
  - *« Measures should be periodically reviewed in the light of scientific progress, and amended as necessary" »* (European Commission 2000)

A more general sequential EU model

- $\text{Max}_{d1}\ E_Y\ \text{Max}_{d2}\ E_{X/Y}\ u(d1, d2, X)$
- Timing:



- Beliefs updated using Bayes' law (Y is correlated with X)
- Notion of « better » information structure Y (Blackwell 1953)

Risk vs. uncertainty

- Risk: X / Uncertainty: Y
- Interpretation:
  - Uncertainty means that the probability distribution of X is expected to vary over time due to the observation of Y
  - In other words, Y represents scientific discoveries/progress
- Leads to a distinction: Prevention vs. Precaution
  - Prevention: The beliefs over X do NOT vary over time (risk)
  - Precaution: The beliefs over X do vary over time (uncertainty)
- Therefore, situations of uncertainty can be captured by the standard EU model, just « need » to compute option values

Let us summarize

- Remember the definition of the PP

  "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation" (Rio Conference 1992)

- We have shown:

  That the *lack of full scientific uncertainty* can be modeled within an EU bayesian model by the prospect to receive information over time (i.e. Y).

  Key question in order to justify the PP: Does the prospect to receive information should always lead us to be more cautious in the short run?

An economic interpretation of the PP

- Gollier, Jullien and Treich (2000, JPubE)
  - U(d1,d2,X) = u(d1) + v(d2 – X (d1+d2))
  - Decisions d1 and d2 can be interpreted as the consumption of a toxic product (e.g., consumption of energy emitting CO_2 emissions)
- Includes stock/hysteresis effects in the simple option value model => much more compelx

An economic interpretation of the PP (cont'd)

- The model shows that it is justified to reduce the first-period decision d1 with a better information Y only for specific utility functions; namely, only when v is « sufficiently prudent »
- Scientific message: The PP is not always justified economically; this depends on risk preferences
- Intuition: Two opposite effects, i.e.,
  - i) better to wait for information before acting,
  - ii) better to act early to maintain « cheap » options available

Option value in benefit-cost analysis (BCA)

- Can the option value make a difference in practical BCA?
  - « *Potentially, yes. (…) Delay can improve the quality of the decision. Further study is needed* » Pearce et al. (2006)
  - An example is Nordhaus (1994) for climate policy, but showing that the option value of delaying abatement is small

- Note that it is difficult to compute option values:
  - Requires a full representation of uncertainties, and of how they might be resolved over time
  - Requires to capture the various degrees of flexibility/irreversibility

Difficulties with this standard EU approach

- In practice

  Technically difficult to compute option values. « *Examples to date are limited* » (Pearce et al. 2006, OECD).

- In lab experiments

  Subjects do not maximize EU, and are not bayesian (Allais 1953, Kahneman and Tversky 1979, Camerer 1995)

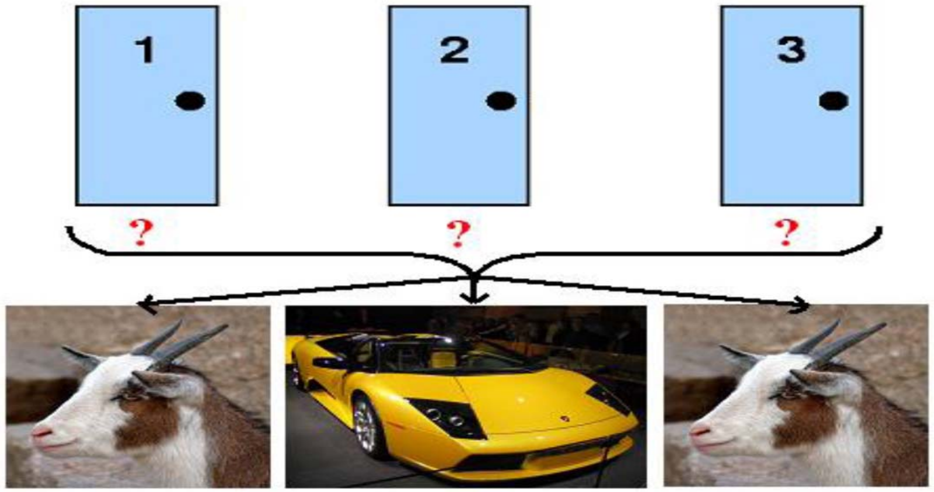
- On normative grounds

  EU does not seem to account well for the coexistence of multiple priors

Monty Hall paradox

The game (television show) :

- A gift (a car) is hidden behind a door, the two other doors have no gift (a goat)
- Step 1: choose a door
- Step 2 : After the choice, a door without gift (goat) is opened, should you switch?
- Answer: yes, because proba win is P=2/3 when switching, only P=1/3 when staying



Experimental studies :

- Only a minority of subjects (about 20%) switch
- Robust to repetition and feedback (Friedman 1999, AER)
- Combination of i) repetition, ii) group communication and iii) group competition needed to obtain high switching rate (Slembeck et Tyran 2004, JEBO)

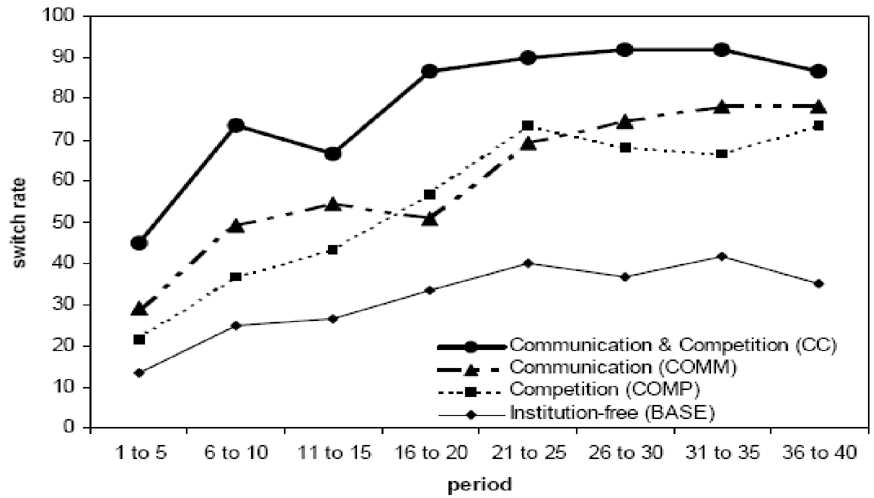


Fig. 1. Switch rates in blocks of five periods.

3. Ambiguity (Aversion) Models

- The Ellsberg paradox
- A model of ambiguity (aversion)
- An application: Ambiguity aversion and the VSL
- Difficulties with ambiguity (aversion) models

Ambiguity and climate sensitivity

EU predicts that individuals make choices « as if » there exists a unique probability distribution.
Is it reasonable?

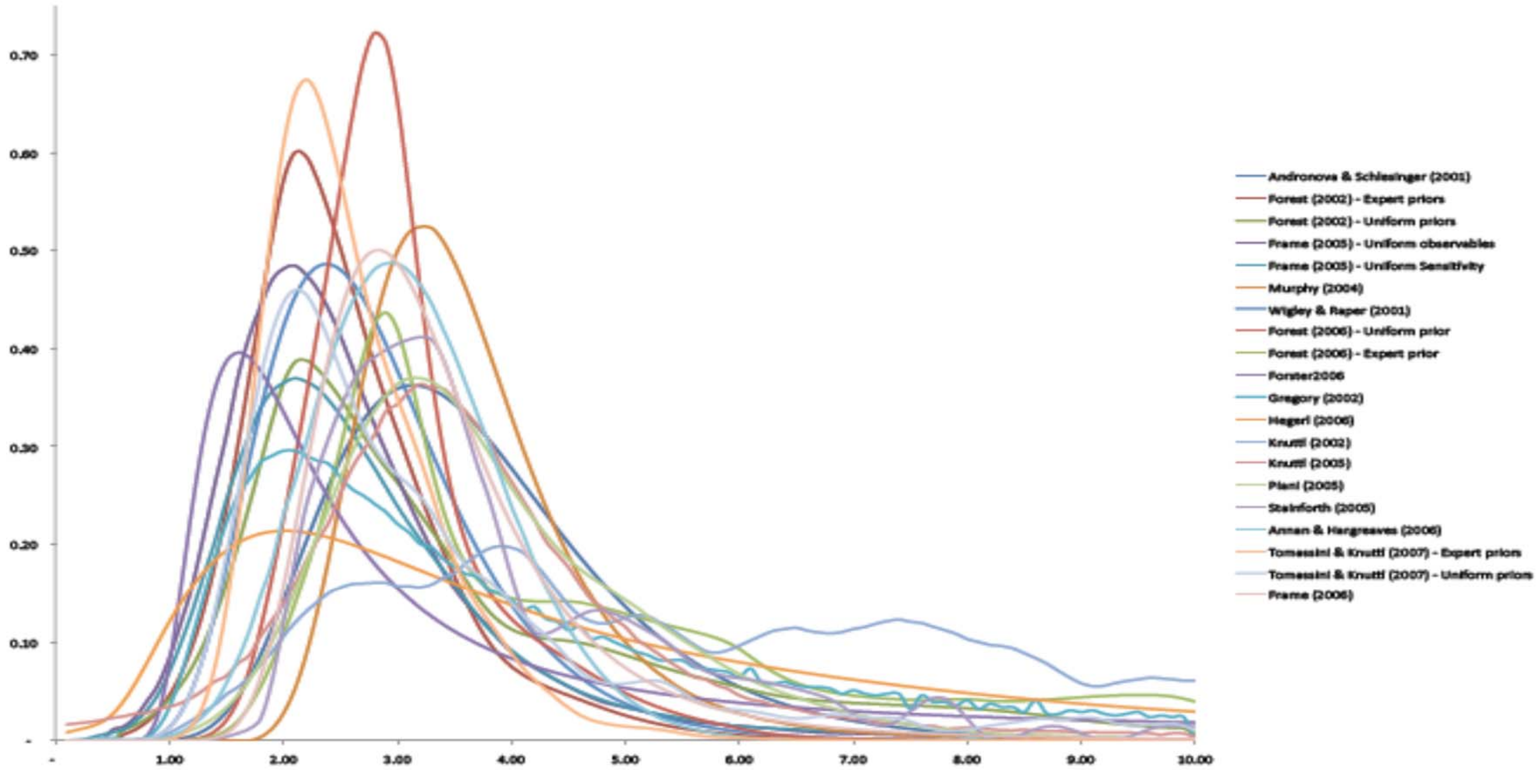
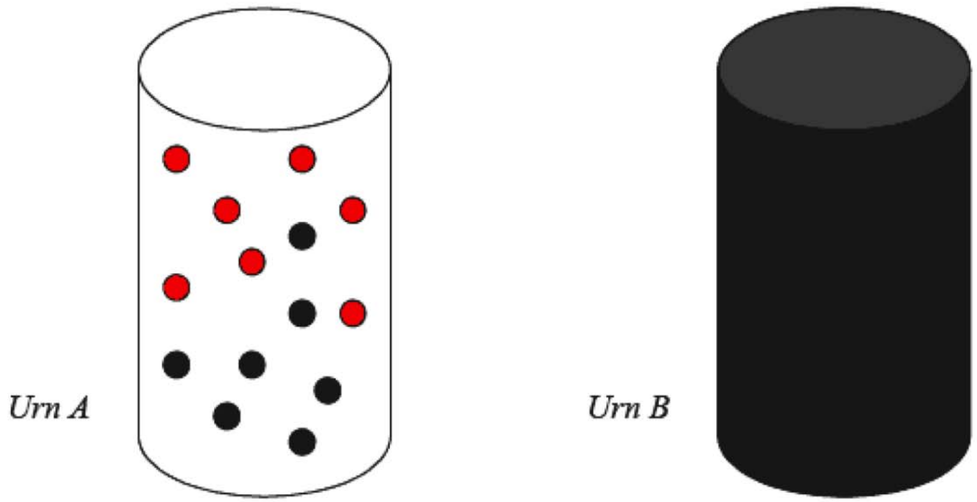


Figure 1: Estimated probability density functions for the climate sensitivity from a variety of published studies, collated by Meinshausen et al. (2009).

Source: Millner et al. (2010)

Ellsberg paradox (Ellsberg 1961, QJE)

- Two urns contain black and red balls:
  - Urn A: half red balls
  - Urn B: unknown proportion
- You must select a urn, and bet on a colour
- Win $100 if your colour is drawn (from the selected urn)
- Which urn do you choose?
- In experiments: usually subjects choose urn A
- This is NOT consistent with the assumption of a unique probability distribution in the Savage EU framework



Ellsberg's urn (with 90 three-color balls)

Act	30 blue balls	white balls	red balls
X	$100	0	0
Y	0	$100	0
X'	$100	0	$100
Y'	0	$100	$100

Subjects in experiments usually choose X>Y and Y'>X'
Again, this is inconsistent with Savage's subjective EU theory
May express a form of ambiguity aversion

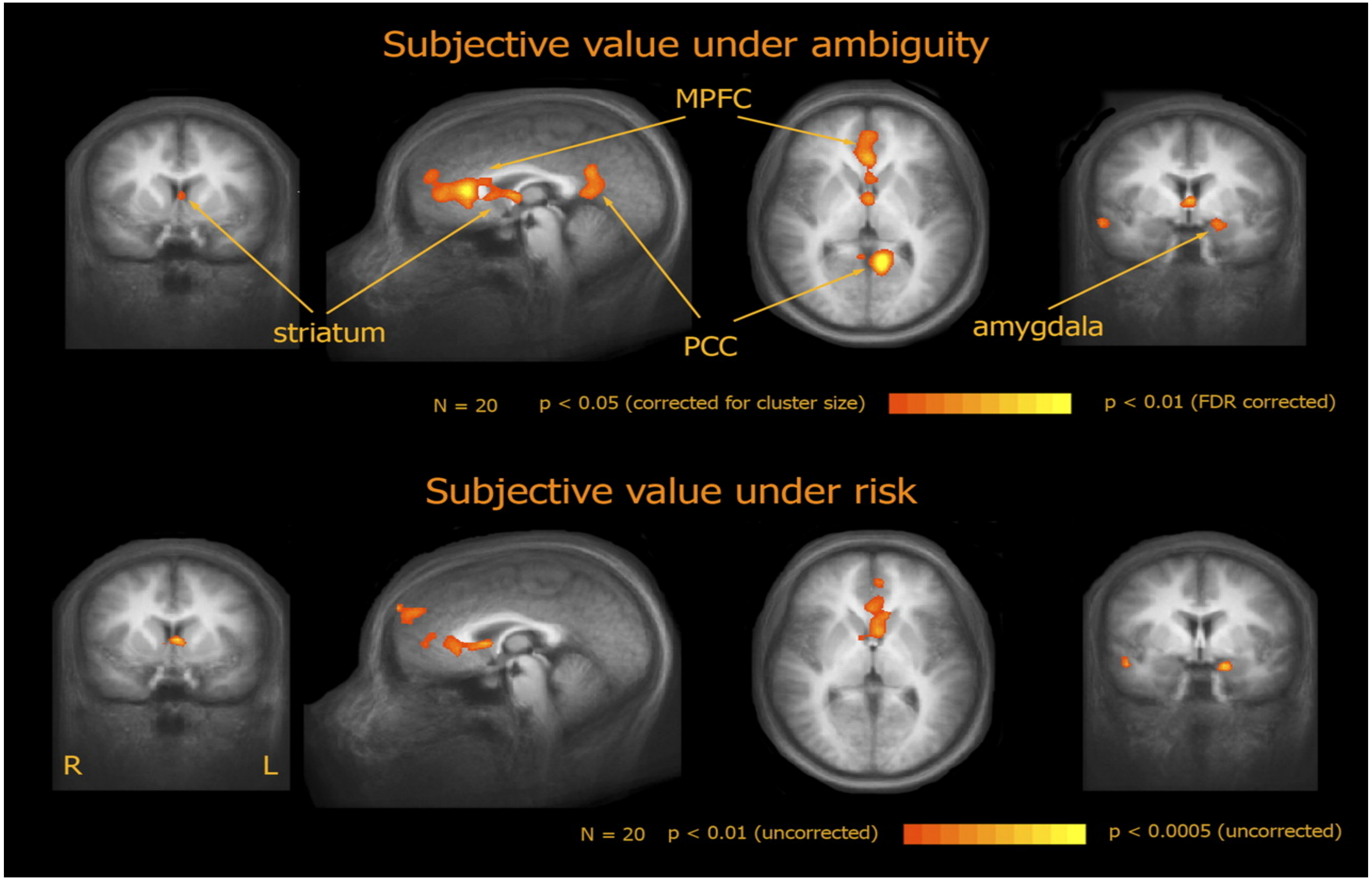
Ambiguity aversion literature

- Subjects have often been found to be averse to ambiguous probabilities
  - A wealth of experimental evidence (e.g., Camerer and Weber 1992)
  - Survey evidence (Hogarth and Kunreuther 1985; Viscusi et al. 1991; Chesson and Viscusi 2003; Burks et al. 2008)
  - Remark: almost no empirical evidence about ambiguity aversion
- Theoretical applications: ambiguity aversion may explain some empirical puzzle in finance (Dow and Werlang 1992; Mukerji and Tallon 2001; Chen and Epstein 2002; Ju and Miao 2009; Epstein and Schneider 2010)

Causes to ambiguity aversion?

- An deeper level of rationality in front of uncertainty: *"Agents can have different models (..) and be aware of the possibility that their model is mis-specified"* (Maccheroni et al. 1995)
- Paranoia: the decision-maker behaves as if a malevolent Nature changes the odds against him (Cerreia et al. 2008)
- Fear: Using brain imaging, Camerer et al. (2007) find evidence that the amygdala is more active under ambiguity conditions, and notice that the *"amygdala has been specifically implicated in processing information related to fear"*

Neuro-economics and ambiguity



Levy I et al. J Neurophysiol 2010;103:1036-1047

Journal of Neurophysiology

Modeling ambiguity aversion

- Let ***θ=1,…,n*** the number of white balls in the Ellsberg's urn, leading to the associated probability ***p(θ)*** of drawing a white ball
- Subjective expected utility: essentially assumes that only the subjective expectation ***Ep(θ)*** matters
- Maxmin: Gilboa and Schmeidler (1989, JME)'s proposes an axiomatics so that the decision maker maximizes expected utility under the « worst » probability ***p(θ)*** within a set
- Many variant versions of Maxmin theory (e.g., Epstein 1999; Ghirardato et al. 2003; Maccheroni 2006; Gajdos et al. 2009)

A popular model of ambiguity aversion

- Smooth ambiguity aversion (Klibanoff, Marinacci and Mukerji, hereafter KMM, 2005, Econometrica)

- Suppose θ is known. Let $U(\theta)= (1-p(\theta))u(w) + p(\theta)u(w+100)$ the expected utility reached ex post for a specific θ

- The ambiguity averse agent then evaluates his welfare ex ante by the certainty equivalent of the random expected utility:

Φ represents ambiguity aversion

$$\Phi^{-1}(E\Phi(U(\theta)) = \Phi^{-1}(\sum_{\theta} q(\theta)\ \Phi(U(\theta))$$

$q(\theta)$ is the subjective probability that the parameter value is θ; also coined the « second order belief »

KMM preferences

- Interpretation: two-stage lottery (first-stage determining probability distribution, and second-stage determining outcome)
- Axiomatics: unique second order belief giving rise to an expectation over EU
- Distinguish ambiguity, ambiguity aversion (a concave *ø)*, and Arrow-Pratt risk aversion – moreover defines an « index » of ambiguity aversion
- Two benchmarks: expected utility for ø linear, and MaxMin of Gilboa-Schmeidler (1989) for ø CARA with infinite absolute risk aversion
- Open to a violation of the axiom of reduction of compound lotteries for ø non-linear (see Segal 1987; see also Kreps and Porteus 1978)
- Preferences are not « kinked » (as with MaxMin) but are « smooth » when ø is differentiable, thus improving mathematical tractability

An application of ambiguity aversion: the VSL

- The value of statistical life (VSL)
- Within benefit-cost analysis, the VSL is instrumental to compute benefits from mortality risk reduction policies
- Regulatory agencies recommend using VSL values usually between $1 and $10 million
  - US EPA recommends a mean estimate of $6.2 million, and the European Union DG Environment a €1 million and €2.5 million for a high value (in 2000 prices)
- Should the VSL be adjusted when the regulatory policy concerns the reduction of « ambiguous » risks?

The VSL concept – introductory example

- Consider a society composed of 100,000 identical individuals
- They each face a (non ambiguous) 100 in 100,000 mortality risk - A project can reduce the risk from 100 to 80 expected fatalities
- Each individual has a willingness to pay for the project of WTP=$500
- Therefore VSL=$2.5 million – Indeed one can collect in this society $50 million to save 20 statistical lives
- VSL= $50 million/20 = $(N \times WTP)/(N \times \Delta p)$

  $= WTP/\Delta p = 500/(20/100{,}000)$

The VSL concept – underlying framework

- Let utility be $U = (1-p_0)u(w) + p_0 v(w)$
- u (resp. v) is the utility if alive (resp. dead), w is wealth and p_0 is probability of death (or the baseline risk) [remark: p_0 is denoted the baseline risk, equal to 100 in the previous example]
- Assume u>v, and u'>v'≥0

$$VSL_0 = \frac{dw}{dp_0} = \frac{u(w)-v(w)}{(1-p_0)u'(w)+p_0 v'(w)}$$

- Increases with w under concave utility functions (wealth effect) and increases with p_0 (« dead-anyway effect »)
- Intuition for the dead anyway effect: under u'>v', the opportunity cost of spending money is lower when the probability of death is higher

A VSL model with ambiguity aversion

- Let $\tilde{p}$ a random variable, representing (from now) the ambiguous baseline risk (e.g. in the previous example either a 50 or 150 in 100,000 mortality risk)

- Same mean baseline risk: $E\tilde{p} = p_0$

- Assume ambiguity aversion, i.e. ø concave (KMM, 2005)

- Utility becomes: $W = \phi^{-1}\{E\phi\{(1-\tilde{p})u(w) + \tilde{p}v(w)\}\}$

The VSL under ambiguity aversion

- The ratio between a change in wealth and an change in (the mean of the random) baseline risk:

$$\mathrm{VSL}_A = \frac{dw}{dp_0} = \frac{(u(w)-v(w))E\phi'\{(1-\tilde{p})u(w)+\tilde{p}v(w)\}}{E((1-\tilde{p})u'(w)+\tilde{p}v'(w))(\phi'\{(1-\tilde{p})u(w)+\tilde{p}v(w)\})}$$

- Which, for an ambiguity-neutral decision-maker (ø linear) reduces to:

$$\mathrm{VSL}_0 = \frac{(u(w)-v(w))}{E((1-\tilde{p})u'(w)+\tilde{p}v'(w))}$$

- Result: $\mathrm{VSL}_A > \mathrm{VSL}_0$ when u'>v' (see Treich 2010, JEEM). Therefore ambiguity aversion justifies more investments in safety expenditures

Difficulties with the ambiguity approach

- Portfolio of ambiguity (aversion) models – which one to choose?
- Few empirical evidence based on market data – can we test these models? what is a « proxy » for ambiguity? how to estimate ambiguity aversion?
- Ambiguity aversion theories introduce new anomalies, especially for sequential decision-making (e.g., Al-Najjar and Weinstein 2009, EP):

- Time-inconsistency

- Nonbayesian updating

- Negative value of information

Time-inconsistency: An intuition

- Consider the Ellsberg three-color urn, where the agent chooses X>Y and Y’>X’
- What happens if the agent is told whether or not the drawn ball is red?
- Ex ante, before information, he should prefer Y’>X’
- But once information reveals that the ball is not red, he should prefer X’>Y’

Act	30 blue balls	white balls	red balls
X	$100	0	0
Y	0	$100	0
X'	$100	0	$100
Y'	0	$100	$100

Reconciling the inconsistency?

- Sophistication (Siniscalchi 2006), but information aversion
- Distorting the updating rule (Hanany and Klibanoff 2007, 2009), but not bayesian updating
  - « Dynamic consistent beliefs must be bayesian » (Epstein & Le Breton 1993)
- Restricting information structures (Sarin & Wakker 1998, Epstein & Schneider 2003, Maccheroni et al. 2006), but one should not « choose » the economic environment so that it is not problematic for the theory

Ambiguity aversion: Is it mistake?

- Halevy (2007, Econometrica)'s experimental evidence
- The experiment: Four (two-colour) urns

1: 5 blue balls and 5 white balls

2: unknown proportion

3: number of blue balls uniform in {0,1,…,10}

4. either 10 blue balls or 10 white balls

- Urns 1 and 2 are Ellsberg's urns; Urns 1, 3 and 4 equivalent using reduction of objective compound lotteries (ROCL)
- 80% of subjects are ambiguity averse, and 86% fail ROCL
- But conditional on ROCL, 96% are neutral to ambiguity; and conditional on failing ROCL, 95% display Ellsberg's paradox

What is the status of ambiguity models?

- Either describe « rational behavior », but they induce other anomalies (i.e., time-inconsistency)
- Or describe behavioral choices, but there exist much simpler behavioral economics models
- Besides, ambiguity models are difficult to test empirically (what is a good proxy for ambiguity?), and are not easily tractable (almost no applications to game theory)

Take-home message

- The PP: An economic viewpoint

- Standard bayesian expected utility models may justify precaution based on the idea of option value
  - but needs a lot of data to compute option values in BCA practice
  - and does not account well for Knightian uncertainty

- Alternative ambiguity (aversion) models can account for Knightian uncertainty,
  - but have no or little empirical (i.e., nonexperimental) support,
  - and display unappealing normative properties, especially for sequential decision-making (e.g., time inconsistency)

Some references

- « The effect of ambiguity aversion on insurance and self-protection » 2012, *Economic Journal* , forthcoming. (with David Alary and Christian Gollier)
- « Option value and precaution » 2012, in *Encyclopedia of Energy, Natural Resources and Environmental Economics* edited by J. Shogren, forthcoming. (with Christian Gollier)
- « The value of a statistical life under ambiguity aversion », 2010, *Journal of Environmental Economics and Management,* 59, 15-26.
- « Precautionary Principle », 2008, *The New Palgrave Dictionary of Economics*, Second Edition (with Christian Gollier)
- « Uncertainty, learning and ambiguity in climate policy: Some classical results and new directions », 2008, *Climatic Change*, 89, 7-21. (with Andreas Lange)
- « Risk-aversion, intergenerational equity and climate change », 2004, *Environmental and Resource Economics*, 28, 195-207. (with Minh Ha-duong).
- « Decision-making under scientific uncertainty: The economics of the Precautionary Principle», 2003, *Journal of Risk and Uncertainty*, 27, 77-103. (with Christian Gollier).
- « Scientific progress and irreversibility: An economic interpretation of the Precautionary Principle », 2000, *Journal of Public Economics*, 75, 229-53. (with Christian Gollier and Bruno Jullien).