Cross-cutting theme of my work:

Measuring & Integrating Economic Values in Interdisciplinary Management of Natural Resources & other Public Goods: The Role of Information & Risk.

Prof. Phoebe Koundouri *et al.*
Athens University of Economics Business, School of Economics
ICRE8: International Center for Research on the Environment & the Economy
London School of Economics, Grantham Institute
ATHENA Research and Innovation Center

RESEARCH FOCUS: *Research towards achieving* ***Natural Resources, Economic & Social Sustainability****:* ***Methodologically Sound Approach*** *to recognizing, demonstrating and capturing the* ***Total Economic Value*** *of public goods and services, integrating them in* ***Social Cost Benefit Analysis****, to inform sustainable* ***management tools and policy making****, while recognizing the* ***interdisciplinary*** *nature of the challenge.*

STAGES OF ANALYSIS:

–Characterization: Natural Resources, Socio-Economic, Institutional

–Mathematical Modelling

–Empirical/Econometric Models

–Data Collection (revealed/stated preference data)

–Empirical Models Application & Estimation

–Analysis of Results

–Policy Recommendations

International Centre for Research on the Environment and the Economy- ICRE8

www.icre8.eu

- **International Centre focused on Interdisciplinary Research on:**

  Environment **Economy**

  Energy **Eco-innovations**

  + electronic versions (hence E8)

Founder and Scientific Director: Phoebe Koundouri

Strategic Management Board: Prof. Bateman, Prof. Chichilnisky, Prof. Dasgupta, Prof. Gollier, Prof. Hasapis, Prof. Koundouri, Prof. Markandya, Dr. Tsichritzis.

Scientific Collaborators: 40 core researchers at ICRE8 premises in Athens, network 90 established researchers (Europe, USA, Asia, Australia)

A layman's introduction to ICRE8's framework of analysis

2030 Agenda for **Sustainable Development**
Adopted 193 Heads of State
UN Summit, New York, September 2015

Development that meets human needs **NOW** while preserving the environment so that **future generations** can meet their own needs.

ICRE8 Hosts
United Nations SDSN-Greece

SUSTAINABLE DEVELOPMENT SOLUTIONS NETWORK
A GLOBAL INITIATIVE FOR THE UNITED NATIONS

Website: *unsdsn.org*

The **UN Sustainable Development Solutions Network (SDSN)** was launched in 2012, to mobilize global scientific and technological expertise to promote practical problem solving for sustainable development, including the design and **implementation of the Sustainable Development Goals (SDGs).**

The organization and governance of the SDSN aims to enable a large number of leaders from all regions and a diverse backgrounds to participate in the development of the network, while at the same time ensuring effective structures for decision making and accountability.

The **SDSN Leadership Council** acts as the board of the SDSN. A smaller **Executive Committee** oversees financial, programmatic, and other operational matters. Twelve Members of the SDSN are part of the SDSN Assembly and can participate in National or Regional SDSNs. The SDSN Secretariat is hosted by Columbia University with staff in Paris and New York.

Mediterranean Climate Change Initiative

SDSN Greece

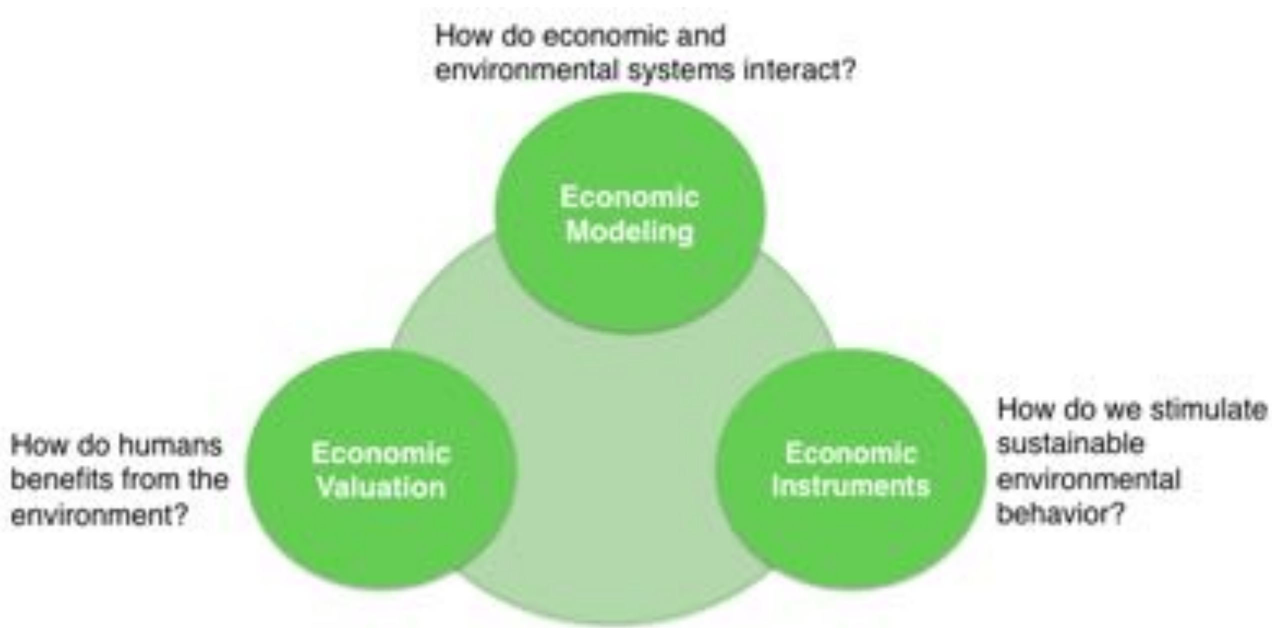
Action Plan

- SDSN Greece Website
- Research e-library
- SDSN MED Conference
- Youth SDSN Greece
- Corporate training in SD
- EAERE and SDSN

Economics?

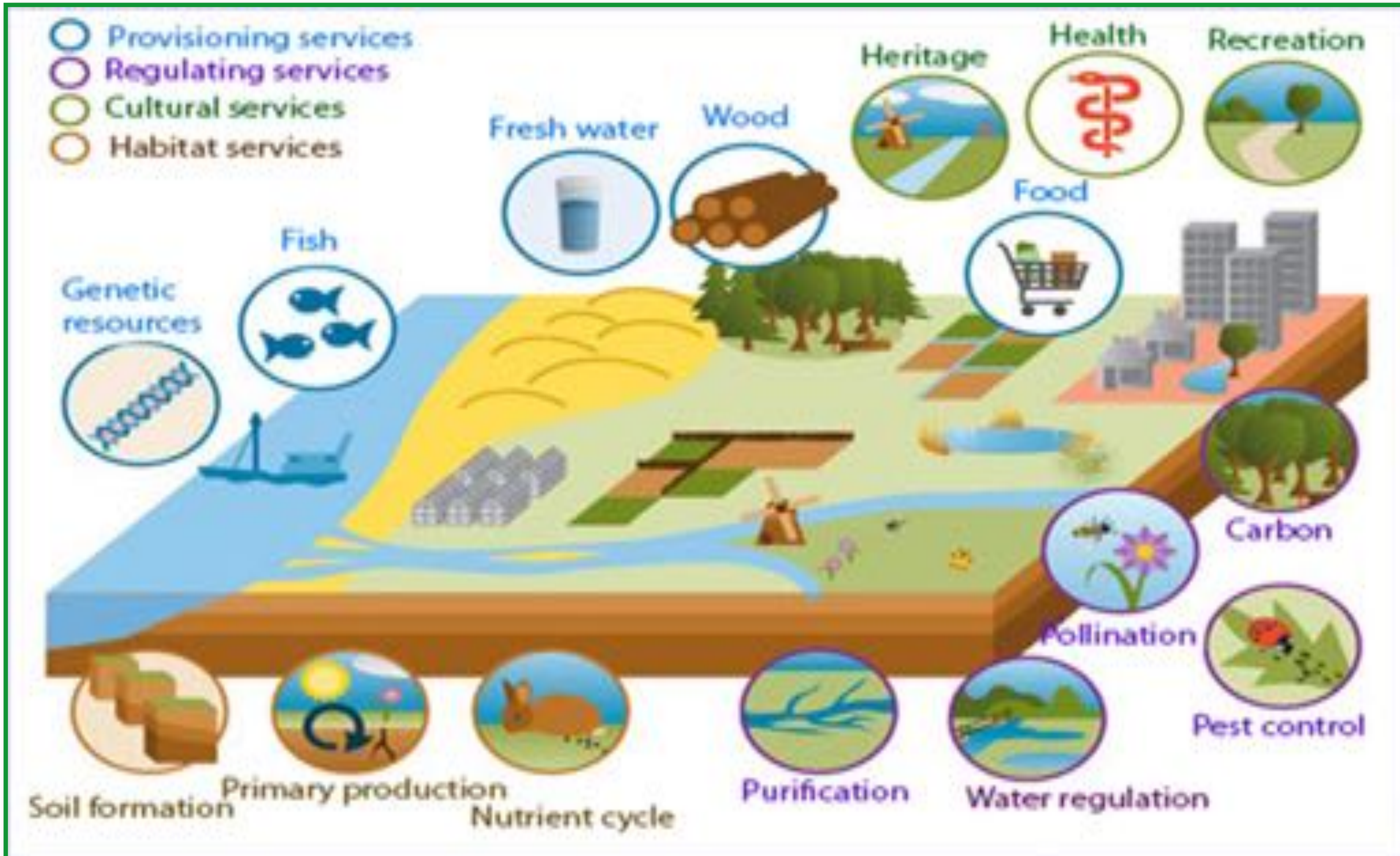
Allocation of
scarce stocks & flows
across people
over time and space
in a way that social welfare is maximized.

Natural Resources, Environmental and Energy Economics?

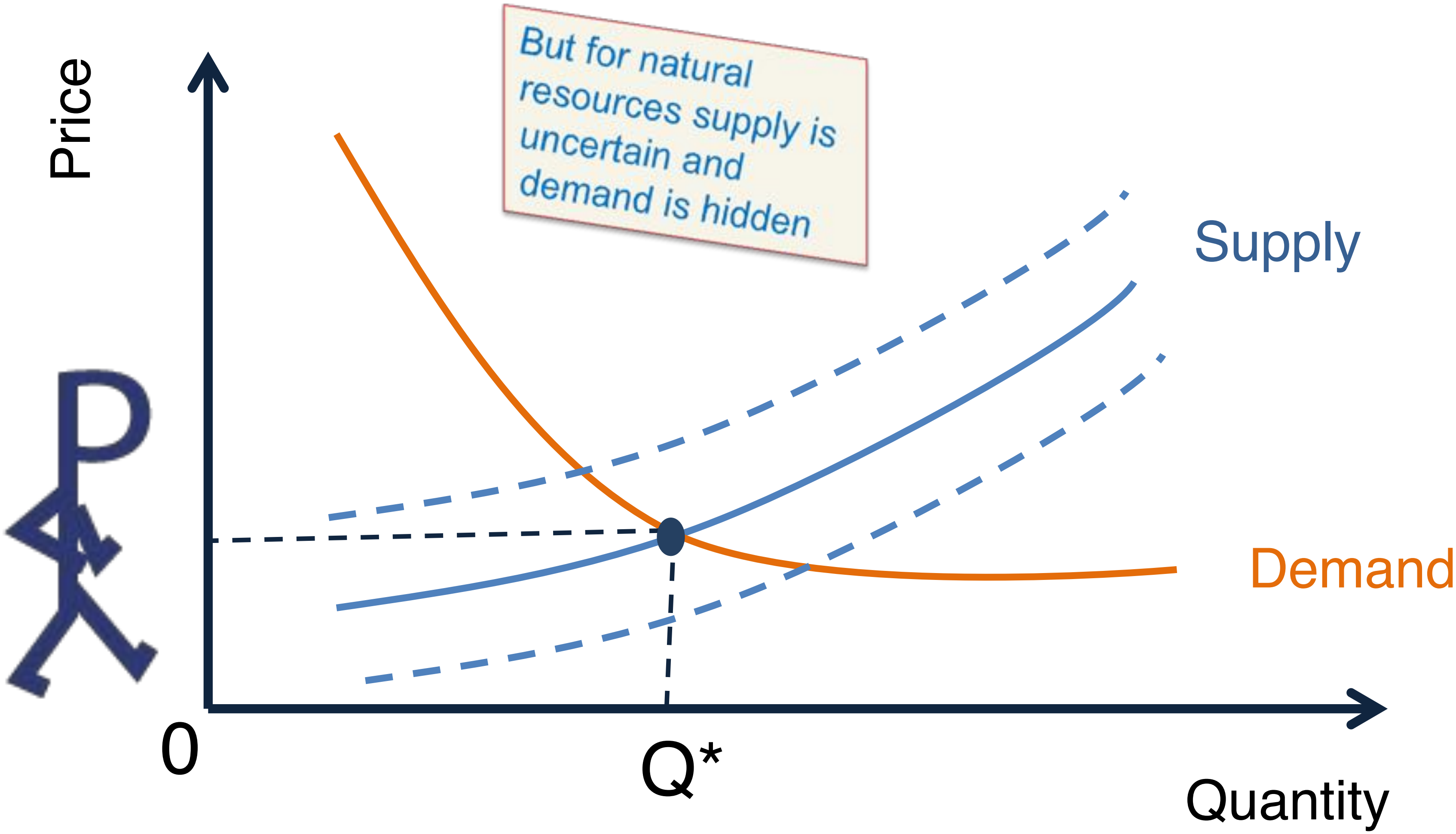


Social Welfare is Maximized When Value is Maximized

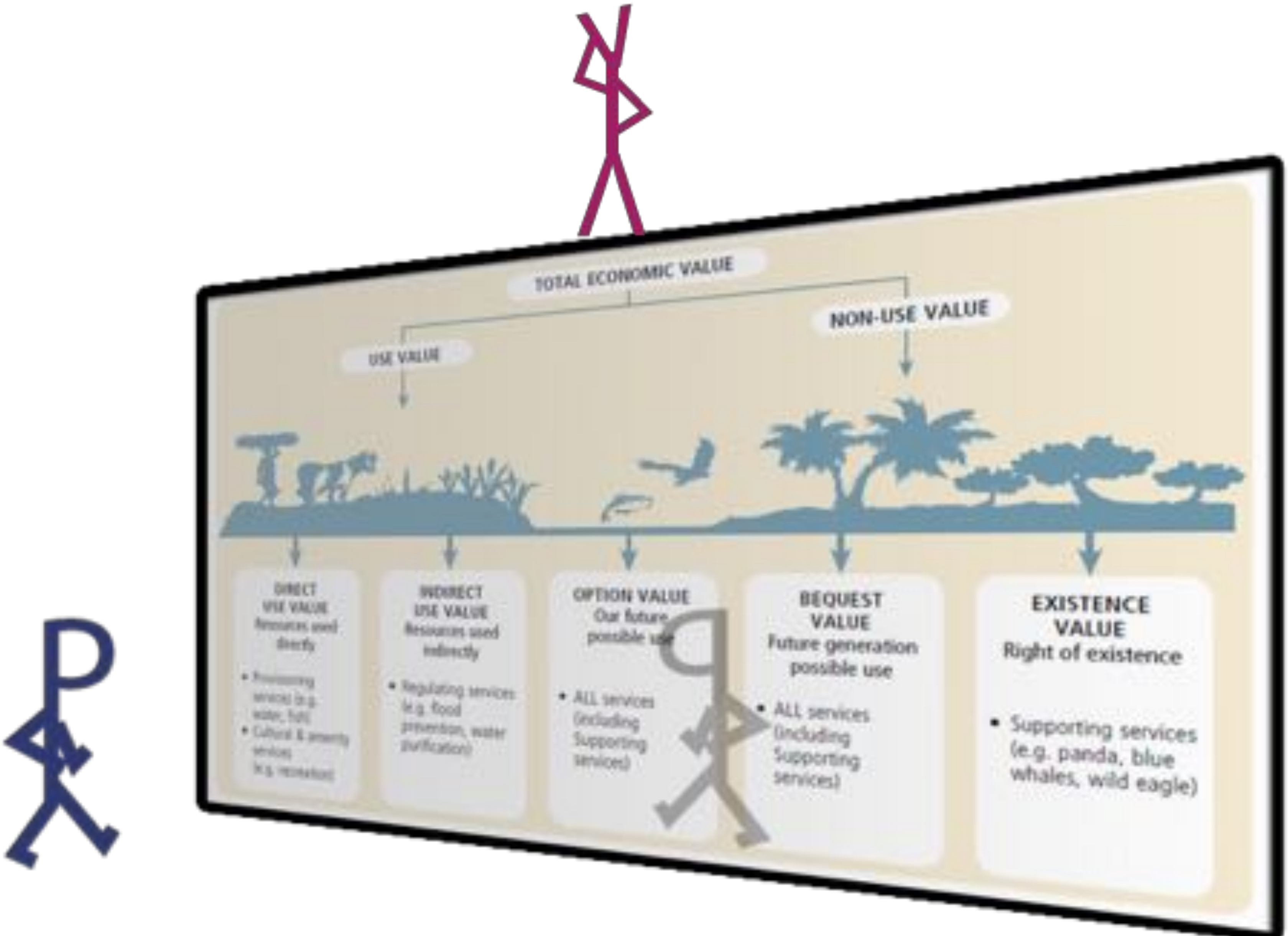
Value of what? Value of Ecosystem Services



Market Interaction Makes Value Explicit

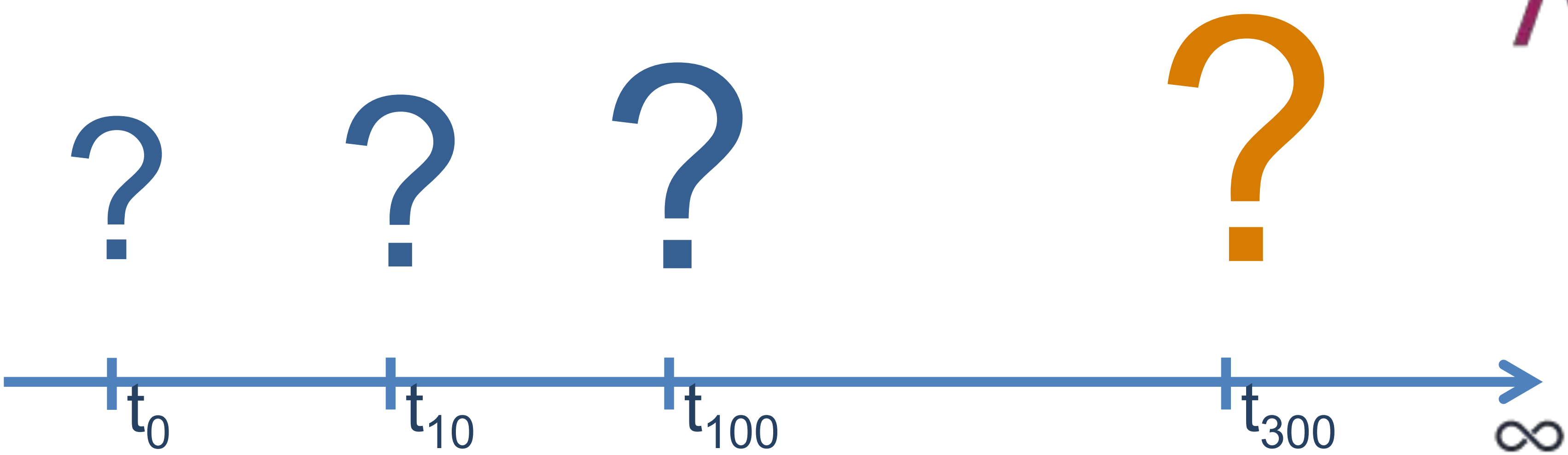


Price should mirror **Value**



We need  for EACH

- Resource $_{(r)}$
- Individual $_{(i)}$
- Space $_{(s)}$
- Time $_{(t)}$ from today till ∞

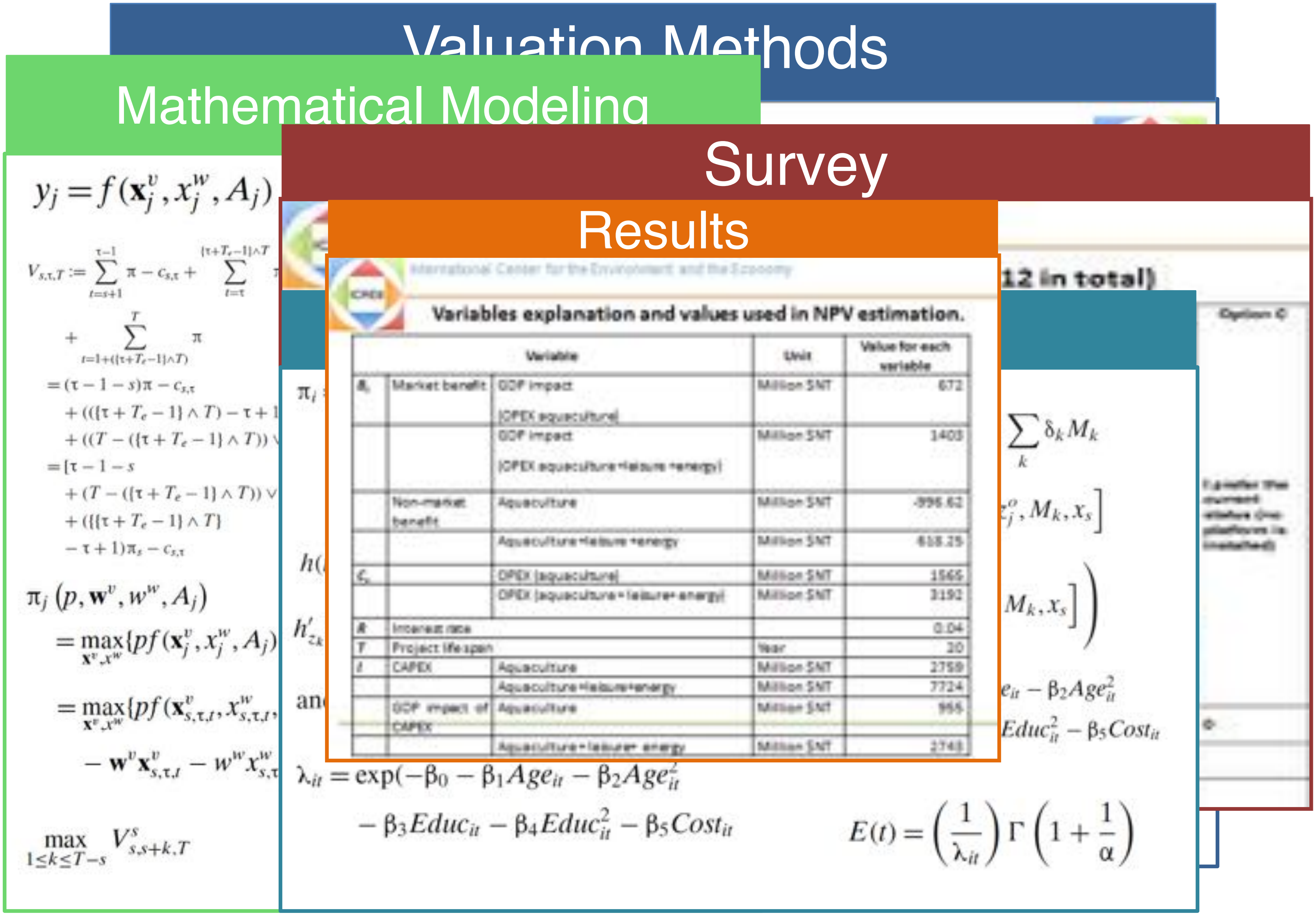


Tragedy of the Commons

Unsustainable Rotation

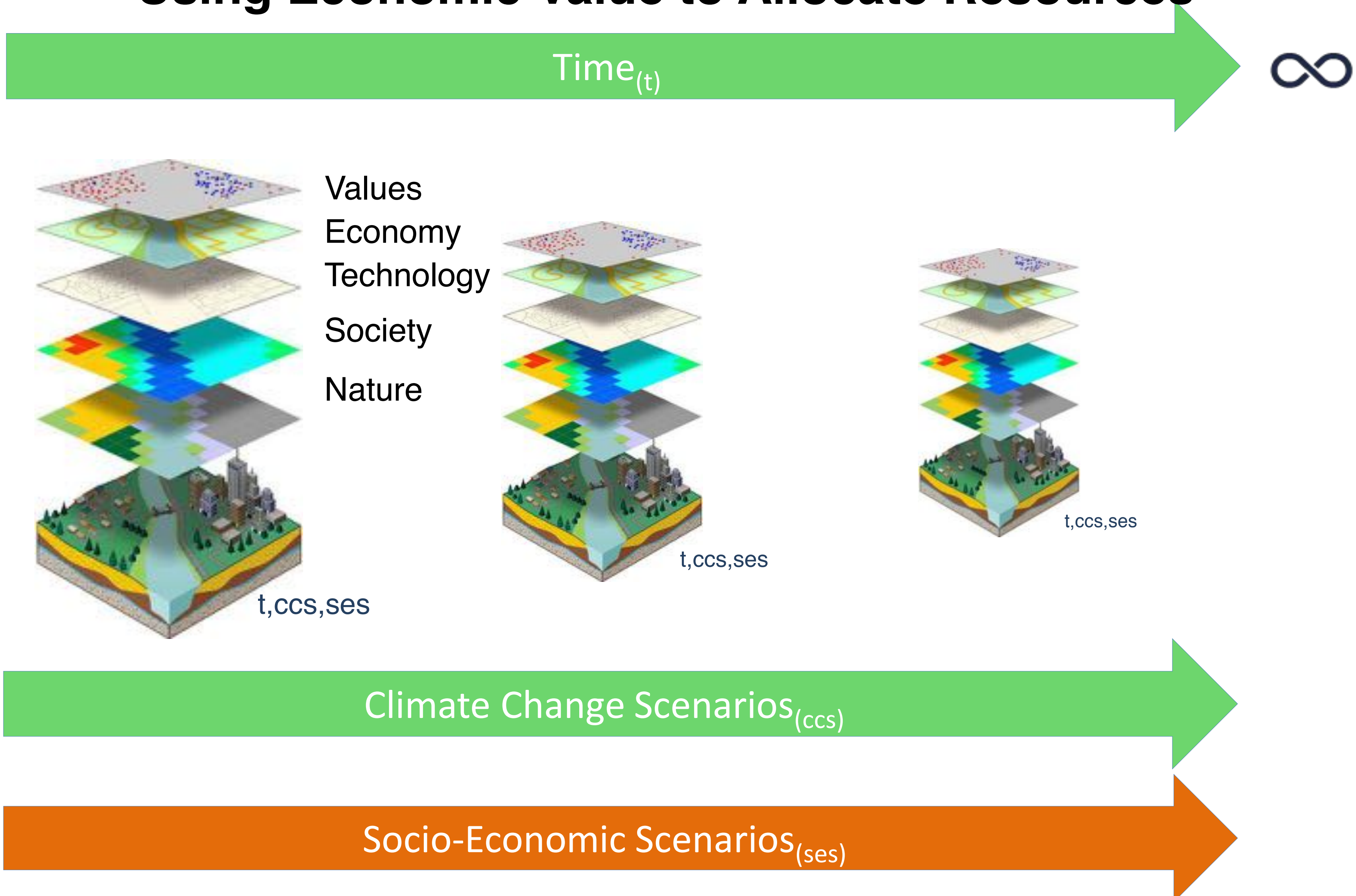
If You Can't Measure It, You Can't Improve It

(William Thomson, Lord Kelvin)



Variable			Unit	Value for each variable
B_t	Market benefit	GDP impact (OPEX aquaculture)	Million SNT	672
		GDP impact (OPEX aquaculture+leisure+energy)	Million SNT	1403
	Non-market benefit	Aquaculture	Million SNT	-996.62
		Aquaculture+leisure+energy	Million SNT	618.25
C_t		OPEX (aquaculture)	Million SNT	1565
		OPEX (aquaculture+leisure+energy)	Million SNT	3192
R	Interest rate			0.04
T	Project life span		Year	20
I	CAPEX	Aquaculture	Million SNT	2759
		Aquaculture+leisure+energy	Million SNT	7724
	GDP impact of CAPEX	Aquaculture	Million SNT	955
		Aquaculture+leisure+energy	Million SNT	2743

Deriving Sustainable Development Plans Using Economic Value to Allocate Resources



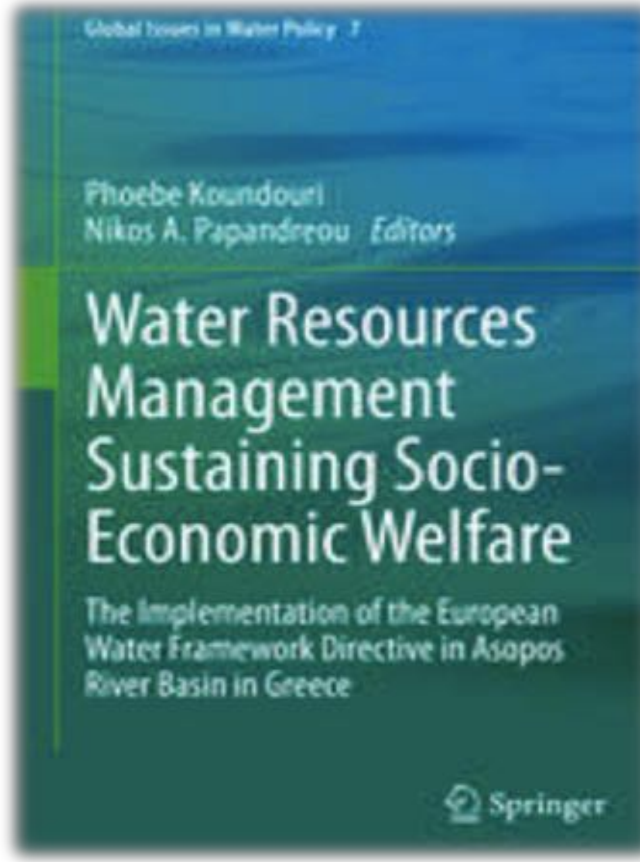
Choose Optimal Allocation of Resources

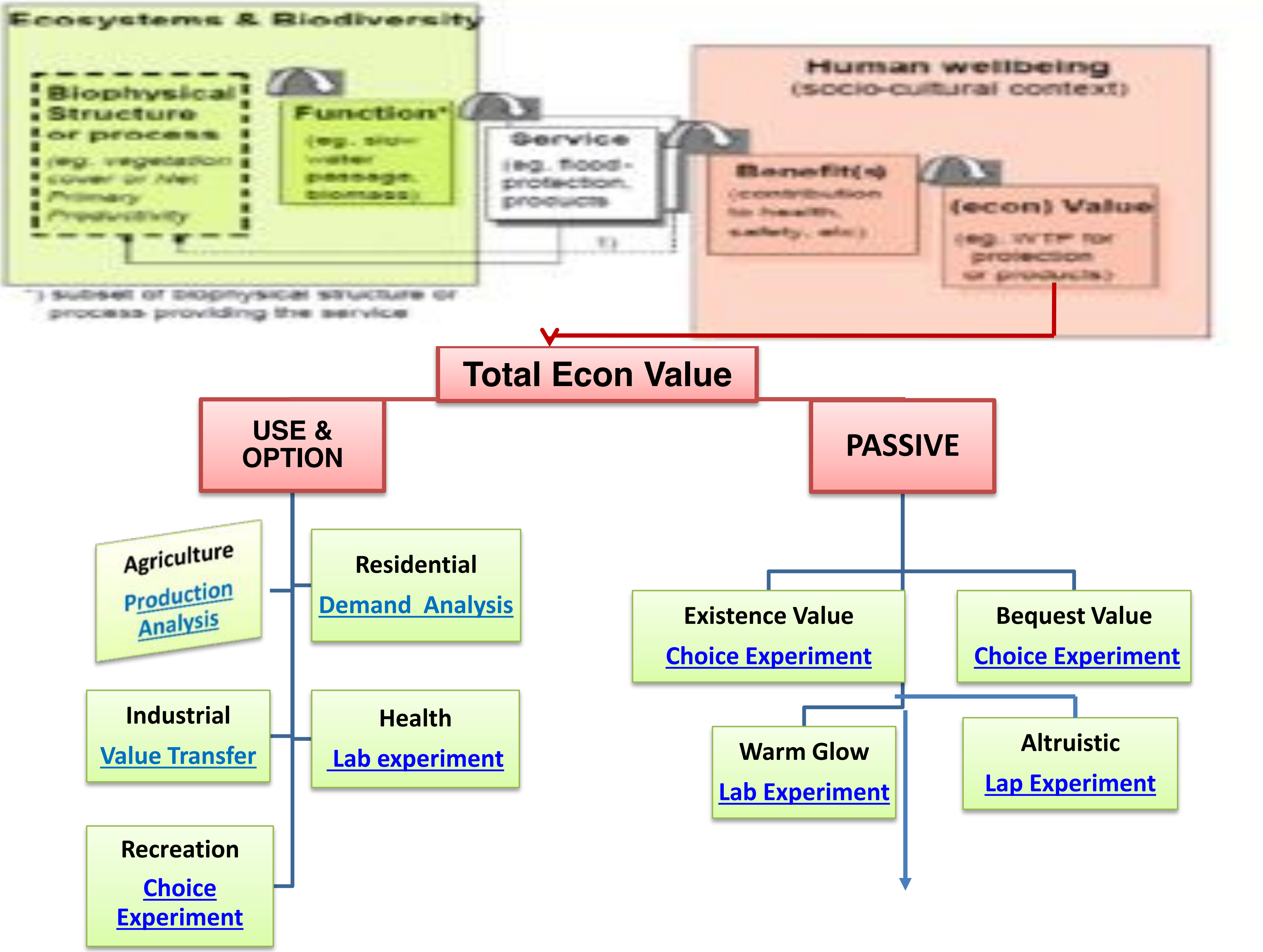
DERIVING & MANAGING VALUES IN A RIVER BASIN

Asopos River Basin

- *Area 724 km^2 , flows into Evoikos Gulf*
- *Habitat of 140 bird species: Natura 2000*
- *Coastal zone: recreational activities*
- *Largest industrial area & pollution*
- *Agricultural activity & pollution*
- *200,000 citizens (including second houses)*

We acknowledge the financial support of :
Integrated Management of Water Resources in Asopos River Basin
Project Website: http://www.aueb.gr/users/koundouri/resees/en/aswposprojen.html




Ecosystems & Biodiversity
Biophysical Structure or process
(eg. vegetation cover or Net Primary Productivity)
Function*
(eg. slow water passage, biomass)
Service
(eg. flood-protection, products)
Human wellbeing
(socio-cultural context)
Benefit(s)
(contribution to health, safety, etc.)
(econ) Value
(eg. WTP for protection or products)
*) subset of biophysical structure or process providing the service
Total Econ Value
USE & OPTION
PASSIVE
Agriculture
Production Analysis
Residential
Demand Analysis
Industrial
Value Transfer
Health
Lab experiment
Recreation
Choice Experiment
Existence Value
Choice Experiment
Bequest Value
Choice Experiment
Warm Glow
Lab Experiment
Altruistic
Lap Experiment

PROJECT DELIVERABLES & BOOK CHAPTERS

- A Bird's Eye View of the Greek Water Situation: The Potential for EU WFD
- The Economic Characterization of Asopos River Basin
- Simulating Residential Water Demand and Water Pricing Issues
- Irrigated Agriculture: Information Diffusion in Technology Adoption
- The Economic Value of the River Ecosystem: A Choice Experiment for Sustaining NATURA (2000) species and the Coastal Environment
- Value Transfer for the Economic Estimation of Industrial Pollution
- Laboratory Experiment for the Estimation of Health Risks
- An Economically Efficient, Environmentally Sustainable and Socially Equitable DSS for Asopos River Basin: A Manual of Measures
- Creating the Institutional Background to Support the Implementation of the Policy Manual

Is there a dominant driving force shaping Economic Values and Allocation of Resources?

Crucial Questions to be answered:

- Does relevant information exist?
- Who owns it?
- Who understands it?
- How is it diffused over time/over space?
- Is information uncertainty?
- Do we face parameter/model uncertainty?
- How people react to information uncertainty?
- How we deal with information uncertainty in the LR?

It is important to explicitly incorporate the level, quality & dynamics of information in the theoretical and empirical attempts to measure values.

Information is Interdisciplinary!

The Value of Water in Irrigated Agriculture

Information Transmission in Technology Diffusion:

Social Learning, Extension Services, Spatial Effects

CONTRIBUTION:

- First Model that combines:
  - Dynamic Adoption and Diffusion under Uncertainty
  - Different Learning Processes: social networks, extension, learning by doing
  - Peers Identification
  - Risk Preferences characterization & estimation
  - Socio-economic, Environmental and Spatial Characteristics

- Theoretical and Empirical Models are Generic

- Policy Recommendations:
  - incentivizing welfare increasing technology adoption & diffusion
  - water value, pricing and allocation

BACKGROUND LITERATURE

Empirical studies, developed & developing countries, ITAD patterns:
e.g. Dinar et al. AJAE 1992; Dridi & Khanna AJAE 2005; Koundouri et al. AJAE 2006, etc.:

Evidence that:
- economic factors: e.g. water , input prices, cost of irrigation equipment, crop prices
- farm organizational & demographic characteristics: e.g. size of farm operation, educational level, experience
- environmental conditions: e.g. soil quality, precipitation, temperature
- risk preferences with regards to production risk

…matter in explaining TAD.

TAD patterns are conditional on knowledge about new technology:
Besley & Case AER 1993; Foster & Rosenzweig JPE 1995; Conley & Udry AER 2010, etc.

Sources of Information/Knowledge:
-**Extension Services (private or public):** Rivera & Alex 2003; World Bank 2006; Birkhaeuser et al. 1991: ES target specific farmers who are recognized as peers.
-**Social Learning:** Rogers 1995: via peers (homophilic or heterophilic neighbors)….

PEERS: farmers exerting direct or indirect influence on the whole population of farmers

Homophilic

- Social ties
- Common professional & personal characteristics (education, age, religious beliefs, farming activities etc.)

Heterophilic

- Perceived successful in their farming operation
- Share different characteristics

Measuring the extent of information transmission is challenging:

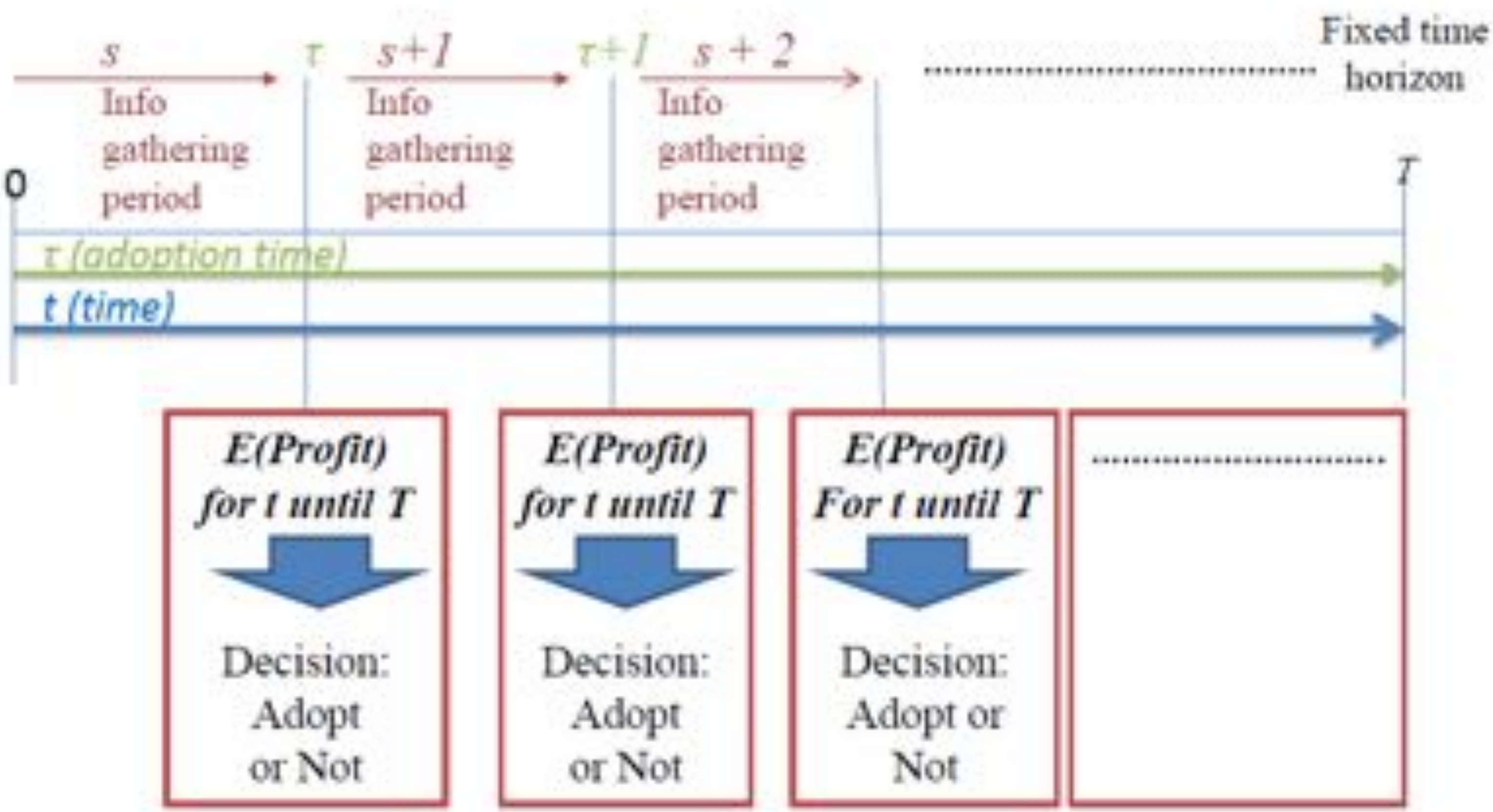
1. **Maertens & Barrett AJAE 2013:** Difficult to define set of Peers, beyond simplistic definition of physical neighbors.

2. **Manski RES 1993:** Difficult to distinguishing learning from other phenomena (interdependent preferences & technologies; related unobserved shocks) that result in similar observed outcomes.

THEORETICAL MODEL

Modeling the timing of Adoption

$s \in \{0,1,2,\ldots,T-1\}, \tau \in \{s+1,\ldots,T\}, t \in \{\tau,\tau+1,\tau+2,\ldots,T\}$



Farm's j technology, continuous twice-differentiable concave production function:

$$y_j = f(\mathbf{x}_j^v, x_j^w, A_j)$$

y_j: crop production
$\mathbf{x}_j^v$: vector of variable inputs (labor, pesticides, fertilizers, etc.)
x_j^w: irrigation water

$x_j^w < x_{min}^w$, risk of low (or negative) profit in case of water shortage.
Adoption allows hedging against the risk of drought and consequent profit loss.

A_j: technology index: irrigation effectiveness index:
(water used by crop)/(total water applied in field)

Expected Discounted Profit Functions:

- $p, w^w, \mathbf{w}^v$: expected discounted prices (assumed dynamically constant by farmer)

No Adoption

$$\pi_j(p, \mathbf{w}^v, w^w, A_j) = \max_{\mathbf{x}^v, x^w} \{p f(\mathbf{x}_j^v, x_j^w, A_j) - \mathbf{w}^v \mathbf{x}_j^v - w^w x_j^w\}$$

Already Adopted

$$\pi_{s,\tau,t}(p, \mathbf{w}^v, w^w, A_s(t, \tau)) = \max_{\mathbf{x}^v, x^w} \{p f(\mathbf{x}_{s,\tau,t}^v, x_{s,\tau,t}^w, A_s(t, \tau)) - \mathbf{w}^v \mathbf{x}_{s,\tau,t}^v - w^w x_{s,\tau,t}^w\}.$$

A_j^{o} with conventional technology

A_j^* with new technology farmer produces same y using same $\mathbf{x}^v$ and lower x^w

$A_j = A_j^*$: max irrigation effectiveness is reached

$A_j^* > A_j^{o}$: max irrigation effectiveness cannot be reached with A_j^{o}

May require time before the new technology is operated at A*.

$A_{j,s}(t,\tau)$: the expected, at time s, efficiency index for t, under the assumption the new technology is adopted at time τ.

c , $\partial c_{j,t}/\partial t < 0$: fixed cost of NIT known at period t.

Expected Discounted Equipment Cost:

- At any point in time, s, farmer j assumes a rate of decrease for the discounted equipment cost:

$$c_{s,s+k} = (1 + a_s e^{-\delta_{c,s}(k-1)})c_s^*$$

- $a_s, \delta_{c,s} > 0$

- $c_{s,s+k}$ is a decreasing value of k, and converges to c_s^* , the asymptotic discounted equipment cost for farmer j at time s, as $k \to \infty$.

Farmer max over τ her temporal aggregate discounted profit:

$$V_{s,\tau,T} \coloneqq \underbrace{\left[\sum_{t=s+1}^{\tau-1} \pi\right]}_{\text{Discounted profit before adoption}} + \underbrace{\left[\sum_{t=\tau}^{\{\tau+T_e-1\}\wedge T} \pi_s\right]}_{\text{Discounted profit after adoption (technology lifetime)}} - \underbrace{c_{s,\tau}}_{\text{Cost}} + \underbrace{\left[\sum_{t=1+(\{\tau+T_e-1\}\wedge T)}^{T} \pi\right]}_{\text{Discounted profit beyond technology lifetime}}$$

<u>Farmer's Trade-off:</u>

Benefit: Delaying investment by one year allows the farmer to purchase the modern irrigation technology at a reduced cost.

Cost: Delaying adoption by one year results in producing with the conventional less efficient technology and bearing a higher risk of water shortage (thus a loss in expected profit).

Adoption Equation: $\pi_s - \delta_{c,s}(c_{s,s+1} - c_s^*) \geq \pi.$

The quantity $c_{s,s+1} - c_s^*$ represents approximately the expected excess discounted cost, between choosing to adopt the new technology at time $s+1$, namely, as soon as possible, and postponing the adoption for a very long period, namely, for a period where the rate of decrease of the equipment cost is practically zero.

Heterogeneity in Adoption Decision Deriving from Heterogeneity in E(π) :

- **Info Channels for farm-specific:**
  Expected Cost for Technology
  Water Efficiency Index
  extension services before and after adoption
  social learning before and after adoption
  learning by doing after adoption

- **Farm-specific information accumulation depends on:**
  socioeconomic characteristics (age, education, experience)
  spatial location
  behavior of influential peers

- **Farm-specific characteristics:**
  input & output prices
  environmental conditions (defining min water crop requirements)
  risk preferences…

Empirical Measurement of Risk Attitudes
Integrating work from Koundouri et al. (AJAE 2006, 13)

Methodology:

- Technology adoption under production risk
  - Risk Averse Agents
- Flexible Method of Moments
- Estimate Risk Preference
- Discrete Choice Model of Adoption

Results:

- Risk preferences affect the prob. of adoption: evidence that farmers invest in new technologies to hedge against input related production risk.

- The **option value** (value of waiting to gather better information) of adoption, approximated by education, access to information & extension visits, affects the prob. of adoption.

Technology Choice Depends:

input & output prices
agent's characteristics
fixed cost of the new technology
utility function : $U(.)$
production function : $f(.)$
distribution of risk : $G(.)$

→ Deriving an analytical solution is problematic!

Antle (1983, 1987): max E[U(π)] is equivalent to max a function of moments of the distribution of ε (=exogenous production risk), those moments having X as arguments. Agent's program becomes:

$$\max_X E[U(\pi)] = F[\mu_1(X), \mu_2(X), \ldots, \mu_m(X)]$$

$$\text{where } \mu_j,\ j = 1, 2, \ldots, m \text{ is the } m^{th} \text{ moment of profit}$$

Taking a Taylor approximation of $E[U(\pi)]$, the FOC of the max problem:

$$\frac{\partial \mu_1(X)}{\partial X_k} = (-1/2!)\frac{\partial \mu_2(X)}{\partial X_k} \times \frac{\partial F(X)/\partial \mu_2(X)}{\partial F(X)/\partial \mu_1(X)} - (1/3!)\frac{\partial \mu_3(X)}{\partial X_k} \times \frac{\partial F(X)/\partial \mu_3(X)}{\partial F(X)/\partial \mu_1(X)} - \ldots - (-1/m!)\frac{\partial \mu_m(X)}{\partial X_k} \times \frac{\partial F(X)/\partial \mu_m(X)}{\partial F(X)/\partial \mu_1(X)}$$

$$k = 1, \ldots, K\ (inputs)$$

The following model is estimated for each k:

$$\frac{\partial \mu_1(X)}{\partial X_k} = \theta_{1k} + \theta_{2k}\frac{\partial \mu_2(X)}{\partial X_k} + \theta_{3k}\frac{\partial \mu_3(X)}{\partial X_k} + \ldots + \theta_{mk}\frac{\partial \mu_m(X)}{\partial X_k} + u_k$$

$$where\ :\ \theta_{2k} = -a_{2k} \times (1/2!), \theta_{3k} = -a_{3k} \times (1/3!), \ldots, \theta_{mk} = -a_{mk} \times (1/m!)$$

$$:\ a_{jk} = (\partial F(X)/\partial \mu_j(X))/(\partial F(X)/\partial \mu_1(X))$$

$\frac{\partial \mu_1(X)}{\partial X_k}$: marginal contribution of input k to expected profit

$\frac{\partial \mu_2(X)}{\partial X_k}$: marginal contribution of input k to varaince

$\frac{\partial \mu_3(X)}{\partial X_k}$: marginal contribution of input k to skewness

a_{mk} : weight attributed by farmer to the mth moment of profit

Estimation Procedure:

1) Estimate conditional expectation of profit using a quadratic functional form: total observed profit is regressed on all levels, squared and cross-products of input expenditures.

2) Use residuals to compute conditional higher moments, which are regressed on all levels, squared and cross-products of input expenditures.

3) Compute analytical expressions for derivatives of these moments with respect to each input.

4) Fit 2SLS of the estimated derivative of the expected profit on derivatives for higher moments.

Linking Estimated Parameters with Risk Theory:

1. Arrow-Pratt (AP) Absolute Risk Aversion:

+ve if risk averse agent (agent's welfare is negatively affected by higher variance of returns)

$$AP_k = -\frac{E(U''(\pi))}{E(U'(\pi))} \cong -\frac{\partial F(X)/\partial \mu_2(X)}{\partial F(X)/\partial \mu_1(X)} = 2\theta_{2k}$$

2. Down-side (DS) Risk Aversion:

+ve if agent is averse to DS risk (agent's welfare is negatively affected by situations, which offer the potential for substantial gains, but which also leave him slightly vulnerable to losses below some critical level)

$$DS_k = \frac{E(U'''(\pi))}{E(U'(\pi))} \cong \frac{\partial F(X)/\partial \mu_3(X)}{\partial F(X)/\partial \mu_1(X)} = -6\theta_{3k}$$

3. θ_{1k} captures systematic deviations from profit maximization or specification error.

4. k– specific Risk Premium (RP):

The larger amount of money the agent is willing to pay to replace the random vaiable π by its expected value $E(\pi)$, which is a monetary measure of the implicit cost of private risk bearing.

+ve if risk averse agent (concave utility function)

Generalizing Pratt (1964)

$$RP_k = \mu_2 \frac{AP_k}{2} - \mu_3 \frac{DS_k}{6}$$

: where μ_2, μ_3 are measures of 2nd & 3rd moments, respectively.

SURVEY DESIGN
DATA COLLECTION
DESCRIPTIVE STATISTICS

- Survey carried out: 2005-06 cropping period.
- Greek Agricultural Census used to select a random sample of 265 olive-growers in the four major districts of the RB.
- A pilot survey: none of the surveyed farmers had adopted before 1994.

- Farmers were asked to recall data for the years 1994-2004 :

  - time of adoption (drip or sprinklers)

  - variables related to their farming operation on the same year:

      production patterns

      gross revenues

      input use, water use and cost

      structural & demographic characteristics.

- All information was gathered using questionnaire-based interviews undertaken by the extension personnel from Regional Agricultural Directorate.

Figure: Diffusion of Drip Irrigation Technology
Mean adoption time: 4.68 years

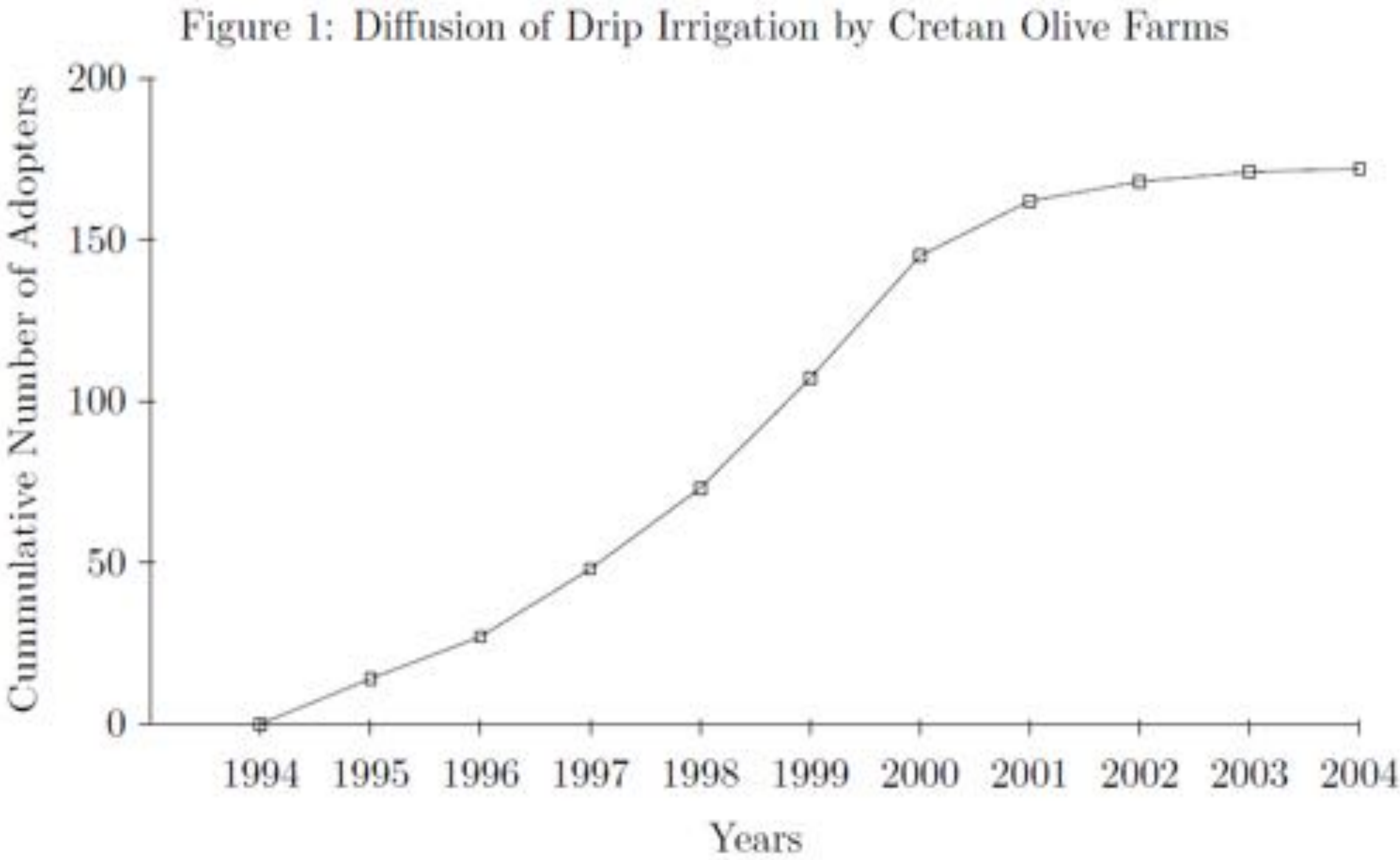


Table 1: Definitions and Summary of the Variables

Variable	All Farms	Adopters	Non Adopters
Number of Farms	265	172	93
Duration length (in years)	–	4.68	–
<u>Farm Characteristics</u>			
Farmer's age (in years)	53.9	49.9	61.3
Farmer's education (in years of schooling)	6.3	8.1	2.9
Farm size (in stremmas)	21.8	22.6	20.2
Tree density (in trees per stremma)	13.6	14.7	11.5
Installation cost (in euros per stremma)	129.3	125.8	135.8
Irrigation water price (in cents per m^3)	20.6	25.7	11.2
Olive-oil price (in euros per kg)	2.80	2.38	3.56
Profit moments:			
1st moment	1.132	1.422	0.596
2nd moment	0.569	0.702	0.323
3rd moment	0.582	0.738	0.293
4th moment	3.566	4.073	2.629
Aridity index	0.982	1.152	0.668
Altitude (in meters)	341.8	167.6	664.1

Table 1: Definitions and Summary of the Variables (cont.)

Soil type (in % of farm land):			
Sandy and Limestone	56.6	62.8	55.2
Marls and Dolomites	43.4	37.2	54.8
Information Variables			
Stock of adopters	31.3	35.4	23.6
Stock of *homophilic* adopters	12.6	15.0	8.1
Stock of farmers' indicated *homophilic* adopters	4.6	5.4	3.2
Distance from the adopters	49.4	44.3	58.7
Distance from *homophilic* adopters	17.4	15.2	21.6
Distance from farmers' indicated *homophilic* adopters	10.1	8.9	12.5
No of extension visits in the area	6.4	8.7	2.2
No of extension visits in *homophilic* farms	3.3	4.8	0.6
No of visits in farmers' indicated *homophilic* farms	2.0	2.9	0.2
Distance of extension outlets:			
from farms in the area	111.2	87.6	154.9
from *homophilic* farms	52.3	34.9	84.3
from farmers' indicated *homophilic* farms	23.6	17.0	35.6

All data refer to the year of adoption as those have been recalled by individual farmers. Monetary values have been deflated prior to econometric estimations.

Measurement of Information Transmission

Table 2: Correlation Matrix of the Twelve Information Indicators

Variable	*Stock*	*HStock*	*RStock*	*Dista*	*HDista*	*RDista*	*Ext*	*HExt*	*RExt*	*Distx*	*HDistx*	*RDistx*
Stock	1.000											
HStock	**0.673**	1.000										
RStock	**0.579**	**0.772**	1.000									
Dista	-0.439	-0.526	-0.572	1.000								
HDista	-0.326	-0.450	-0.478	**0.732**	1.000							
RDista	-0.254	-0.410	-0.429	**0.692**	**0.919**	1.000						
Ext	0.521	0.624	0.767	-0.585	-0.521	-0.453	1.000					
HExt	0.519	0.599	0.735	-0.573	-0.510	-0.445	**0.918**	1.000				
RExt	0.520	0.595	0.719	-0.600	-0.503	-0.451	**0.882**	**0.934**	1.000			
Distx	-0.453	-0.539	-0.534	0.521	0.472	0.428	-0.556	-0.570	-0.565	1.000		
HDistx	-0.529	-0.535	-0.489	0.448	0.447	0.373	-0.496	-0.534	-0.507	**0.791**	1.000	
RDistx	-0.459	-0.455	-0.416	0.422	0.428	0.386	-0.424	-0.430	-0.417	**0.648**	**0.842**	1.000

where *Stock* is the stock of adopters, *HStock* is the stock of *homophilic* adopters, *RStock* is the stock of farmers' indicated *homophilic* adopters, *Dista* is the distance from the stock of adopters, *HDista* is the distance from the stock of *homophilic* adopters, *RDista* is the distance from the

SOCIAL NETWORK CHANNEL I:
Total no. of adopters in farmer's reference group

- **Stock:** stock of adopters on the year the farmer adopted
- **HStock:** stock of homophilic adopters (same age -6 year range- and education -2 year range-)
- **RStock:** stock of farmer-perceived homophilic adopters

SOCIAL NETWORK CHANNEL II:
Distance of farmer to adopters in her reference group

- **Dista :** average distance to adopters
- **HDista:** average distance to homophilic adopters
- **RDista :** average distance to farmer-perceived homophilic adopters

EXTENSION SERVICES CHANNEL I:
Overall exposure of farmer to Extension Services

- **Ext :** no. on-farm extension visits until the year of adoption
- **Hext:** no. on-farm extension visits to homophilic farmers
- **RExt :** no. on-farm extension visits to farmer-perceived homophilic adopters

EXTENSION SERVICES CHANNEL II:
Distance of farmer to Extension Agencies

- **Distx :** distance of the respondent to the nearest EA
- **HDistx :** average distance of homophilic farmers to the nearest EA
- **RDistx :** average distance of farmer-perceived homophilic adopters to the nearest EA

Factor Analysis: Information Transmission Paths & Peers

- To describe variability among observed (correlated) variables, in terms of lower number of unobserved variables (factors).
- The observed variables modeled as linear combinations of unobserved factors, plus error terms.

- All pair-wise correlations, 12 observed Info-Var, significant (0.01 level)
- All 12 Inf-Var are used in order to predict 4 latent variables
- Assuming multivariate normality of observable indicators, we estimate factors scores ξmi, $m=1,\ldots,4$, for the *ith* farmer (s = 12 InfVar), **x** : the vector of 12 observable indicators:

Factor analytic model estimated using principal components method with varimax rotation.

$$E(\xi_{mi}|x_{is})$$

Table 3: Estimation Results of the Factor Analytic Model for Informational Variables

Variable	Stock of Adopters (ξ_1)	Distance between Adopters (ξ_2)	Exposure to Extension (ξ_3)	Distance from Extension Outlets (ξ_4)
Stock	0.8188	-0.0873	0.2280	-0.2955
HStock	0.7729	-0.2465	0.3509	-0.2454
RStock	0.6801	-0.2574	0.6080	-0.1772
Dista	-0.2850	0.7143	-0.3478	0.2061
HDista	-0.1290	0.9022	-0.2288	0.2234
RDista	-0.0858	0.9270	-0.1767	0.1758
Ext	0.2762	-0.2554	0.8562	-0.2160
HExt	0.2311	-0.2324	0.8818	-0.2537
RExt	0.2359	-0.2489	0.8667	-0.2343
Distx	-0.1854	0.2420	-0.3565	0.7465
HDistx	-0.2519	0.1683	-0.2311	0.8847
RDistx	-0.2032	0.2051	-0.1216	0.8687

EMPIRICAL MODEL:

DURATION ANALYSIS
FACTOR ANALYSIS
FLEXIBLE METHOD OF MOMENTS

Empirical Hazard Function

$h(t)$: hazard function (rate), rate at which individuals will adopt the technology in period t, conditional on not having adopted before t:

$$h(t) = \lim_{\Delta \to 0}\left(\frac{F(t+\Delta) - F(t)}{\Delta S(t)} \right) = \frac{f(t)}{S(t)}$$

empirical counterpart of adoption equation from theoretical model.

- Assume T follows a Weibull distribution the hazard function is:

$$h(t, z_{it}, \alpha, \beta) = \alpha t^{\alpha-1} (\lambda_{it})^{\alpha}$$

- α : scale parameter
- α > 1: hazard rate increases monotonically with time
- α < 1: hazard rate decreases monotonically with time
- α = 1: hazard rare is constant
- $\lambda_{it} = \exp(-z_{it}\beta)$
- vector z_{it} : variables that determine farmers' optimal choice

  Some vary only across farmers (e.g. soil quality and altitude) other vary across farms and time (e.g. cost of acquiring the new technology)
- β : corresponding unknown parameters

Before estimating the HF we need to estimate the <u>risk attitudes</u> & <u>information variables</u>, in order to include them in the empirical HF.

Production Risk & Moments of Profit Distribution

- Koundouri et al. (AJAE, 2006) utilizing moments of the profit distribution as determinants of adoption.

- Using recall data on:
  - olive-oil revenues
  - variable inputs (labor, fertilizers, irrigation water, pesticides)
  - fixed (land) input

- Estimated profit function:

$$\pi_i = \underset{(0.423)}{2.341} + \underset{(0.104)}{0.657}\, p_{Oi} - \underset{(0.098)}{0.321}\, w_{Li} - \underset{(0.054)}{0.107}\, w_{Fi} - \underset{(0.032)}{0.076}\, w_{Wi} - \underset{(0.021)}{0.034}\, w_{Pi} + \underset{(0.125)}{0.431}\, x_{Ai} + u_i$$

The residuals have been used to estimate the *kth* central moments *(k=1,…,4)* of farm profit conditional on variable and fixed input use.

Estimation of Hazard Model

$$\lambda_{it} = \exp\Big(-\beta_0 - \beta_1 Age_{it} - \beta_2 Age_{it}^2 - \beta_3 Educ_{it} - \beta_4 Educ_{it}^2 - \beta_5 Cost_{it} - \beta_6 Fsize_{it} - \beta_7 Dens_{it}$$

$$(22) \qquad -\beta_8 w_{Wit} - \beta_9 p_{Oit} - \beta_{10} Ard_{it} - \beta_{11} Alt_i - \beta_{12} Soil_{sl,i} - \sum_{k=1}^{4} \delta_k M_{kit} \sum_{m=1}^{4} \zeta_m \hat{\xi}_{mit} - \zeta_5 \hat{\xi}_{1it} \hat{\xi}_{3it}\Big)$$

Using regression calibration we approximate :

$$E\Big[\exp\Big(-\textstyle\sum_j \beta_j z_j^o - \sum_k \delta_k M_k - \sum_m \zeta_m \xi_m - \zeta_5 \xi_1 \xi_3\Big)\Big]$$

By: $$\exp\Big(-\sum_j \beta_j z_j^o - \sum_k \delta_k M_k - \sum_m \zeta_m E\big[\xi_m | z_j^o, M_k, x_s\big] - \zeta_5 E\big[\xi_1 \xi_3 | z_j^o, M_k, x_s\big]\Big)$$

Assume the 4 latent variables, conditional on 12 InfoVar are uncorrelated with the explanatory variables, $E[\xi_m | z_j^o, M_k, x_s] = E[\xi_m | x_s]$, the estimated factor scores can be used in the hazard function.

EMPIRICAL RESULTS & POLICY IMPLICATIONS

A Reminder of the Empirical Method

- Sample of 265 randomly selected olive-growing farms in Crete, Greece.
- Estimate higher moments of profit (FMM).
- Estimate factor scores (PCA & varimax rotation).
- Merge profit moments & factor scores in hazard function and estimate a duration model (right censored ML)
- Consistent standard errors via stationary bootstrapping (Politis & Romano 1994)

Estimation Robustness Checks:

- Estimation of hazard function including & excluding 4 latent variables.
- All key explanatory variables in both models are found statistically significant.
- Signs of estimated parameters remarkably stable between models.
- Akaike and the Bayesian information criteria: full model is more adequate
- Predicted mean adoption times are not statistically different: 5.76 and 5.74 in the full and reduced model, respectively.

Table 4: Maximum Likelihood Parameter Estimates of Alternative Specifications of the Hazard Function for the Adoption of Drip Irrigation Technology by Cretan Olive Farms

Variable	Model A.1		Model A.2	
	Estimate	t-ratio	Estimate	t-ratio
Constant	1.5617	1.8077	1.4303	1.5633
Farmer's age	-0.0168	-2.4766	-0.0106	-1.3404
Farmer's age-squared	0.0001	2.1568	0.0001	1.1931
Farmer's education	0.0182	1.1456	0.0347	2.2150
Farmer's education-squared	-0.0010	-1.5354	-0.0021	-3.0807
Installation cost	0.0089	1.0786	0.0099	1.1629
Farm size	-0.0048	-0.3848	-0.0117	-0.8617
Tree density	-0.0127	-3.7991	-0.0109	-2.9231
Water price	-0.0164	-10.892	-0.0205	-13.694
Crop price	0.0596	1.8796	0.0658	1.8465
1^{st} profit moment	-0.0943	-2.5987	-0.1132	-2.7071
2^{nd} profit moment	-0.1752	-2.4884	-0.1611	-1.8807
3^{rd} profit moment	0.0292	0.9414	0.0770	1.6685
4^{th} profit moment	-0.0024	-0.3167	-0.0125	-1.0554
Aridity index	-0.0389	-1.1718	-0.0412	-1.3601
Farm altitude	0.0006	3.3071	0.0005	2.9544
Sandy and limestone soils	-0.0002	-0.0075	0.0265	0.7475
Stock of adopters	-0.0509	-1.9745	-	-
Distance between adopters	0.0299	1.6498	-	-
Exposure to extension	-0.0531	-2.7988	-	-
Distance from extension outlets	-0.0238	-1.6691	-	-
(Stock of adopters)X(Exposure to extension)	-0.0554	-3.5119	-	-
Scale parameter (σ)	9.1085	15.075	8.0932	16.420
Log-Likelihood	107.709		86.834	
Akaike Information Criterion	-0.639		-0.520	
Bayesian Information Criterion	-0.329		-0.276	
Mean Adoption Time	5.76		5.74	

-ve coefficient implies faster adoption

Table 5: Marginal Effects of the Explanatory Variables on the Hazard Rate and Mean Adoption Time of Drip Irrigation Technology Adoption

Variable	Model A.1		Model A.2	
	Hazard Rate	Adoption Time	Hazard Rate	Adoption Time
Farmer's age	0.015	-0.010	0.007	-0.006
Farmer's education	-0.047	0.031	-0.058	0.047
Installation Cost	-0.079	0.051	-0.070	0.057
Farm size	0.043	-0.028	0.082	-0.067
Tree Density	0.112	-0.073	0.077	-0.063
Water Price	0.145	-0.095	0.145	-0.118
Crop Price	-0.525	0.343	-0.464	0.378
1^{st} profit moment	0.831	-0.543	0.798	-0.650
2^{nd} profit moment	1.544	-1.009	1.136	-0.925
3^{rd} profit moment	-0.258	0.168	-0.543	0.442
4^{th} profit moment	0.021	-0.014	0.088	-0.072
Aridity Index	0.343	-0.224	0.291	-0.237
Altitude	-0.005	0.003	-0.004	0.003
Sandy-Limestone soils	0.002	-0.001	-0.190	0.152
Stock of adopters	0.449	-0.293	–	–
Distance between adopters	-0.264	0.172	–	–
Extension services	0.468	-0.306	–	–
Distance from extension outlets	0.210	-0.137	–	–

Marginal effects are computed at the means values of explanatory variables. For the case of dummy variables, they are computed as the difference between the quantity of interest when the dummy takes the value 1 and when it takes a 0 value.

Discussion of Results I : Epidemic Effects

Scale parameter (Weibull hazard function) significant α >1:

Endogenous learning due to reductions in uncertainty resulting from extensive use of the new technology: **learning-by-doing effects.**

Empirical Result II: Complementarity of Information Channels

- Interaction term between the two channels of information transmission is significant and -ve: complementarity.
- The passage of information is improved when utilizing BOTH:
  - rules of thumb (manuals and blueprints): extension personnel
  - strong social networks between olive-growers

Empirical Results III: Extension & Social Learning

EXTENSION SERVICES

- Exposure to extension services induces faster adoption (-0.306)
- The bigger the distance from extension outlets the shorter the time before adoption (- 0.0531) Extension agents primarily targeting farmers in remote areas

SOCIAL LEARNING

- Larger stock of adopters in the farmer's reference group induces faster adoption (-0.293).
- Greater distance between adopters increases time before adoption (0.172).

The impact of social learning is comparable to the impact of information provision by extension personnel, mean marginal effects on adoption times:

- 0.293 for the stock of adopters
- 0.306 for exposure to extension services

Policy Recommendations from I, II, III

PR1: ES more effective in areas where there is already a **critical mass of adopters**.

PR2: Spatial dispersion of extension outlets should be designed away from market centers in a way that allows minimization of the average **distance between outlets and peer farms** in remote areas.

PR3: Nature of extension provision should be designed taking into account its **complementarity** with farmers' social networks.

Empirical Result IV: Human Capital Variables
Significant Impact of AGE & EDUCATION

- Marginal Effect Farmer's Age on adoption time: -0.010 years
  - up to 60: time before adoption decreases (experience effect)
  - after 60: follows an increasing trend (planning horizon effect)

- Marginal Effect of Education:
  - E < 9 years (elementary schooling): time until adoption increases
  - E > 9 years: faster adoption rates

Empirical Result V: Risk Attitudes Important Determinants of Adoption Behavior

- Higher expected profit & higher variance of profit induce faster adoption: Risk adversely affected by a high variability in returns.
- Adoption reduce production risk in periods of water shortage (confirms Koundouri et al. 2006 & Groom et al. 2008).
- 3rd & 4th moments of profit insignificant: farmers are not taking downside yield uncertainty into account when deciding whether to adopt.

Empirical Result VI: Environmental Variables, Input & Output Prices, Important Determinants of Adoption Behavior

- Adverse weather conditions induce faster irrigation technology adoption (magnitude of the effect is small).
- Olive farms with high tree density adopt faster.
- Marginal value of irrigation water in agr. production: 0.50 euro
- Water Price significant effect speeding up diffusion (0.145 and -0.95, respectively): Efficient water pricing important
- Higher crop price delays adoption rates (marginal effect is 0.343 years) : reduced incentives to change irrigation practices.

Policy Recommendations from IV, V, VI

PR4: Efficient pricing of agricultural inputs and outputs should become an explicit target of the reformed agricultural policy as it crucial affect adoption.

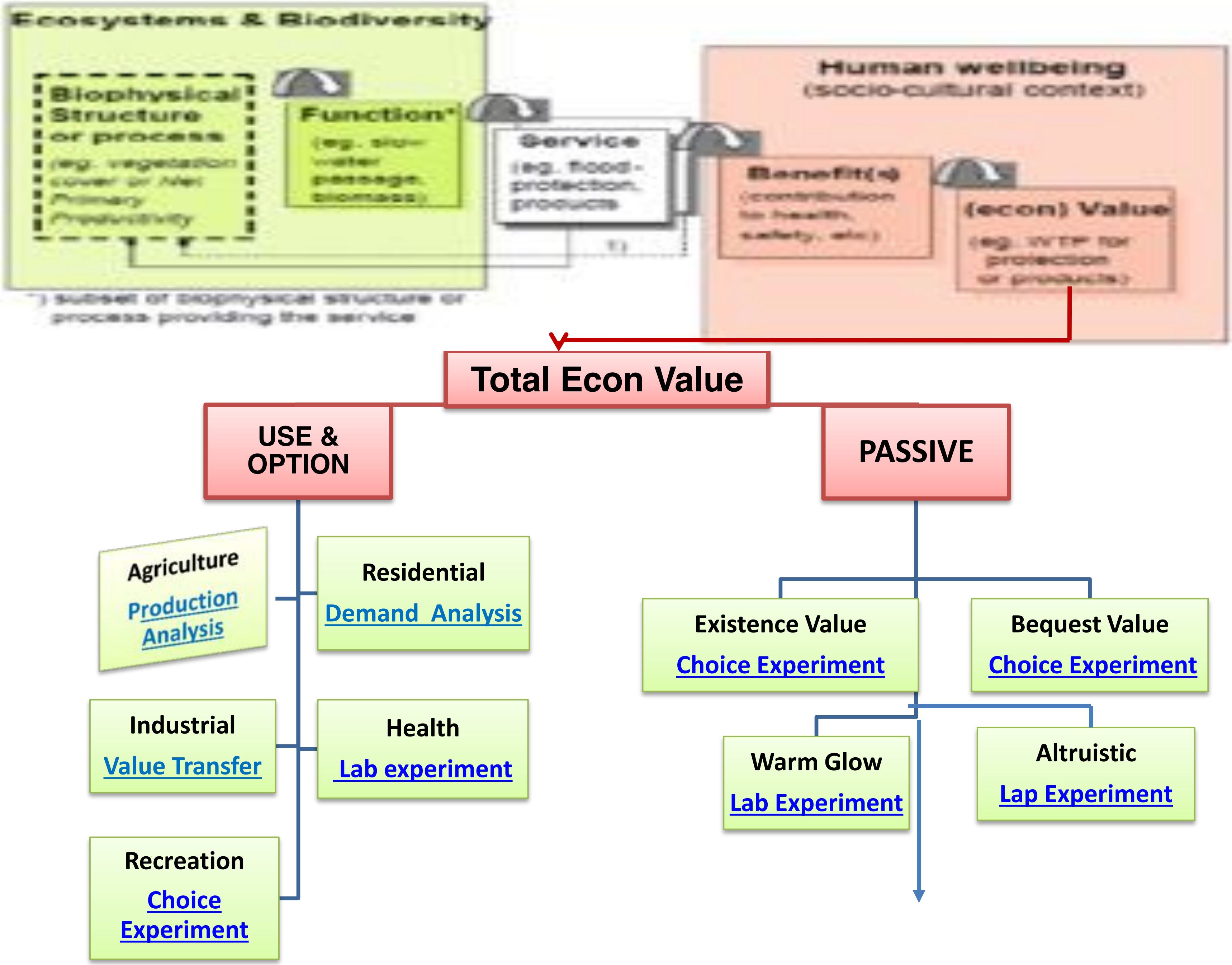
PR5: Farmer's characteristics (education, age) and **environmental variables** (aridity, altitude) are important drivers and should be integrated in relevant policies.

PR6: Policy makers should take into account the level of **farmers' risk-aversion**, in order to correctly predict the technology adoption and diffusion effects, as well as the magnitude and direction of input responses.

Relevant Existing Policies: UN SDGs, EU CAP reform;

EU Environmental Directives (WFD, MSFD, EIA, et.)

Europe 2020 vision: Stimulating Sustainable (eco & env) Inclusive Growth.


Ecosystems & Biodiversity
Biophysical Structure or process
(eg. vegetation cover or Net Primary Productivity)
Function*
(eg. slow water passage, biomass)
Service
(eg. flood-protection, products)
Human wellbeing
(socio-cultural context)
Benefit(s)
(contribution to health, safety, etc.)
(econ) Value
(eg. WTP for protection or products)
*) subset of biophysical structure or process providing the service
Total Econ Value
USE & OPTION
PASSIVE
Agriculture
Production Analysis
Residential
Demand Analysis
Industrial
Value Transfer
Health
Lab experiment
Recreation
Choice Experiment
Existence Value
Choice Experiment
Bequest Value
Choice Experiment
Warm Glow
Lab Experiment
Altruistic
Lap Experiment

The General Public Values Scientific Information

GENESIS Project

JEEM, 2012


Science for Environment Policy

The public value of including scientific information in groundwater protection policies

The Value of Distant Benefits:
The socially efficient discount rate

Humanity has the ability to make development sustainable: to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. WCED, 1987.

There is something awkward about discounting benefits that arise a century hence. For even at a modest discount rate, no investment will look worthwhile. The Economist, 1991.

The Value of Distant Benefits
Discount Rate for CBA, Ramsey Formula extended for Risk & Uncertainty
[series of papers with C. Gollier; EP, 2008]

In an Uncertain Environment:

- Persistent shocks on the growth rate of consumption
- Persistent shocks on short-term interest rates
- Persistent shocks on growth expectations, translate into persistent shocks on interest rates

→ Determine the shape of the term structure of the socially efficient discount rate & imply DDR.

Estimate Theory Consistent DDR trajectory

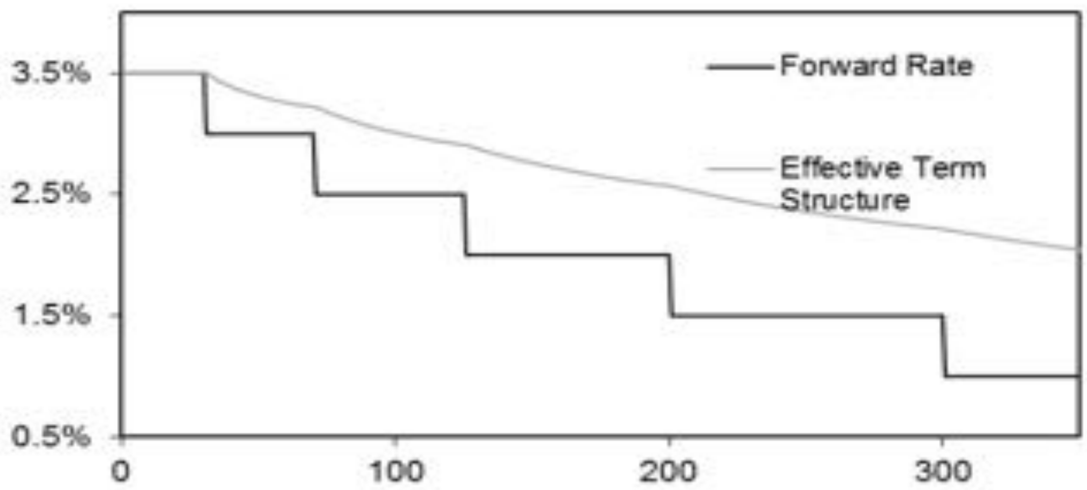
- *Using Historical Data*
- *Without Structural Model*
- *Using univariate time series regime switching models:*
  - *describe stochastic dynamics of the real IR*
  - *future properties of the IR are determined by its own past behaviour*

Information accumulation may transmit patterns of preferences towards Risk & Uncertainty: Influence time preferences & attitudes towards the environment.

As environment becomes more important and current generations care more about the future: DDR for PV of LR effects!

Recommended Schedule for Discount Rates

Period of years	0–30	31–75	76–125	126–200	201–300	301+
Discount rate	3.5%	3.0%	2.5%	2.0%	1.5%	1.0%



Adopted in:
UK, USA,
France, Norway,
Etc.

Marine and Coastal Management
Inland Water Management
Renewable Energy
Climate Change and Discount Rate
Biodiversity
Forest Management
Waste Management
Nuclear Energy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