Stochastic Detection Time Concept

and its Economic Implications

M. Makowski, T. Ermolieva, M. Jonas, Y. Ermoliev

Outline

1. Kyoto protocol and detection of emissions

2. Uncertainty (Variability) matters

3. Practical Example: Long time data series

4. Variability of emissions: "fast" and "slow" systems

5. Emission signal detectability: stochastic detection techniques

6. Emissions trading markets;
    b. insurance of carbon credits transactions

Kyoto protocol and detection of emissions

Kyoto –
binding commitments to limit or reduce the emissions of six GHGs
or groups of gases (CO2, CH4, N2O, HFCs, PFCs, and SF6).

Each Party of the protocol calculates how much of gases its country emits by adding together estimates/reported emissions from individual sources.

Often estimated/reported emissions are inaccurate:
M. Gillenwater & F. Sussman & J. Cohen: Practical Policy Applications of Uncertainty Analysis for National Greenhouse Gas Inventories.

In many countries, agreed emission changes are smaller than their underlying uncertainty.

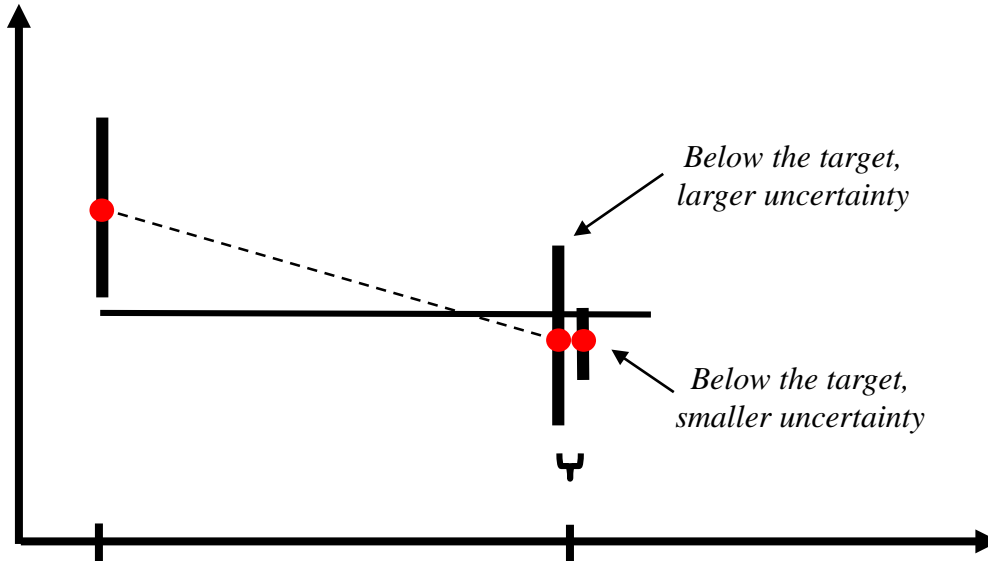In IPCC practice, emission/emission changes are reported, but without rigorous signal detection

The KP requires that net <u>emission changes</u> be "verified" on the spatial scale of countries by the time of commitment, relative to a specified base year.
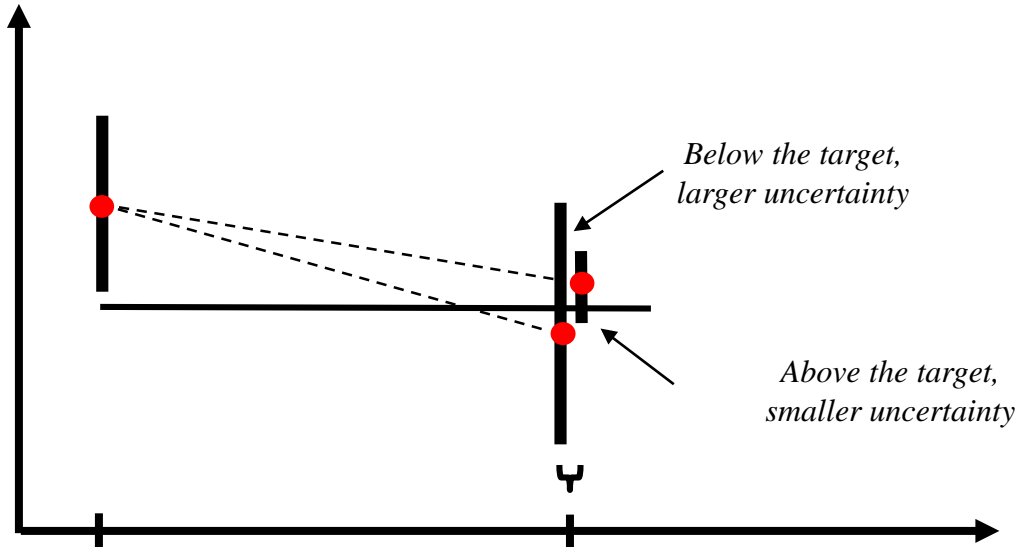
The key questions:

1. Whether reported emissions outstrip uncertainty and can be "verified/detected" ?

2. What percentage of all possible emissions can be detected within a given time ?
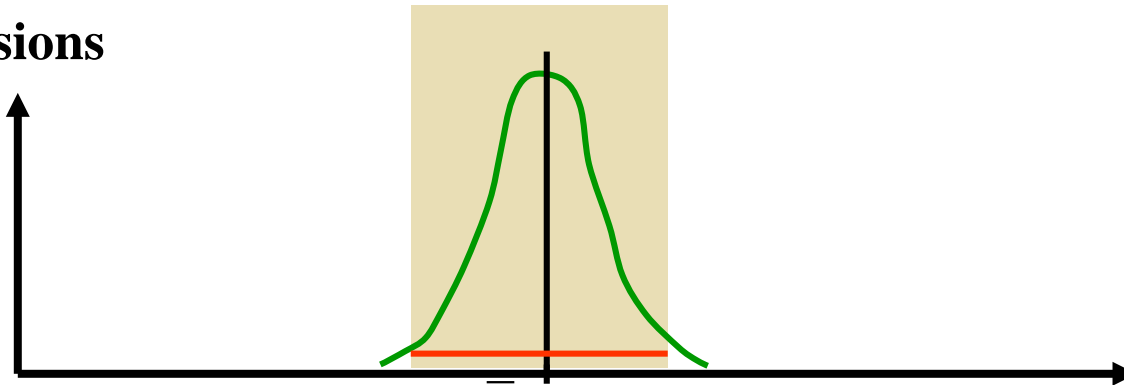
Uncertainty (variability) matters

Net Emissions

*Below the target,
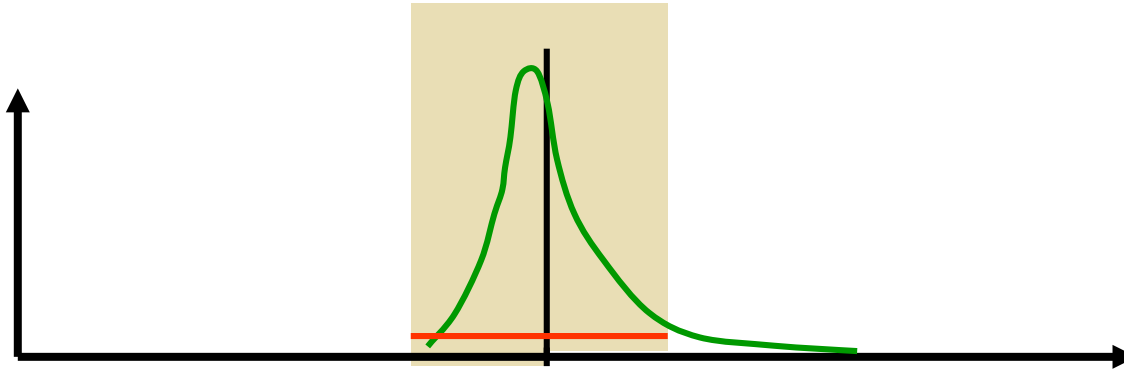larger uncertainty*

*Below the target,
smaller uncertainty*

Net Emissions

*Below the target,
larger uncertainty*

*Above the target,
smaller uncertainty*

Variability matters

Net Emissions

95ᵗʰ confidence = $\bar{a} \pm 2\delta$

Variability matters

Net Emissions

A

B

C

Base year

Commitment year/period

95th confidence

95th

B   C
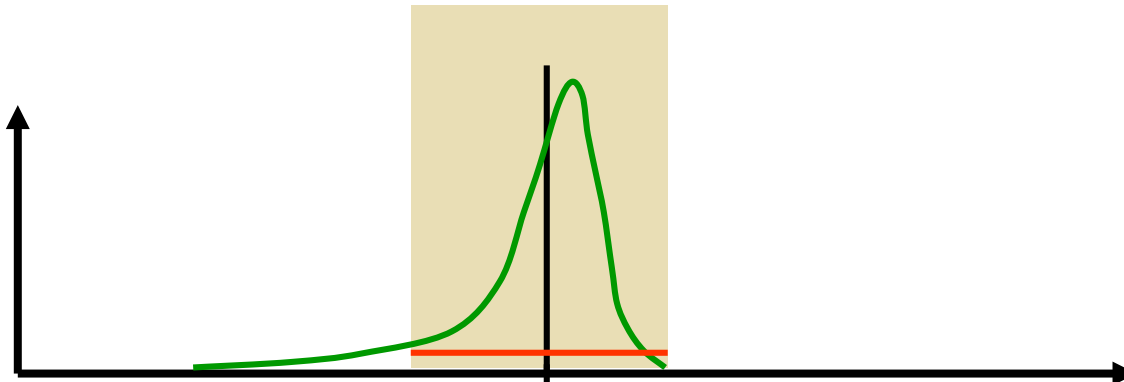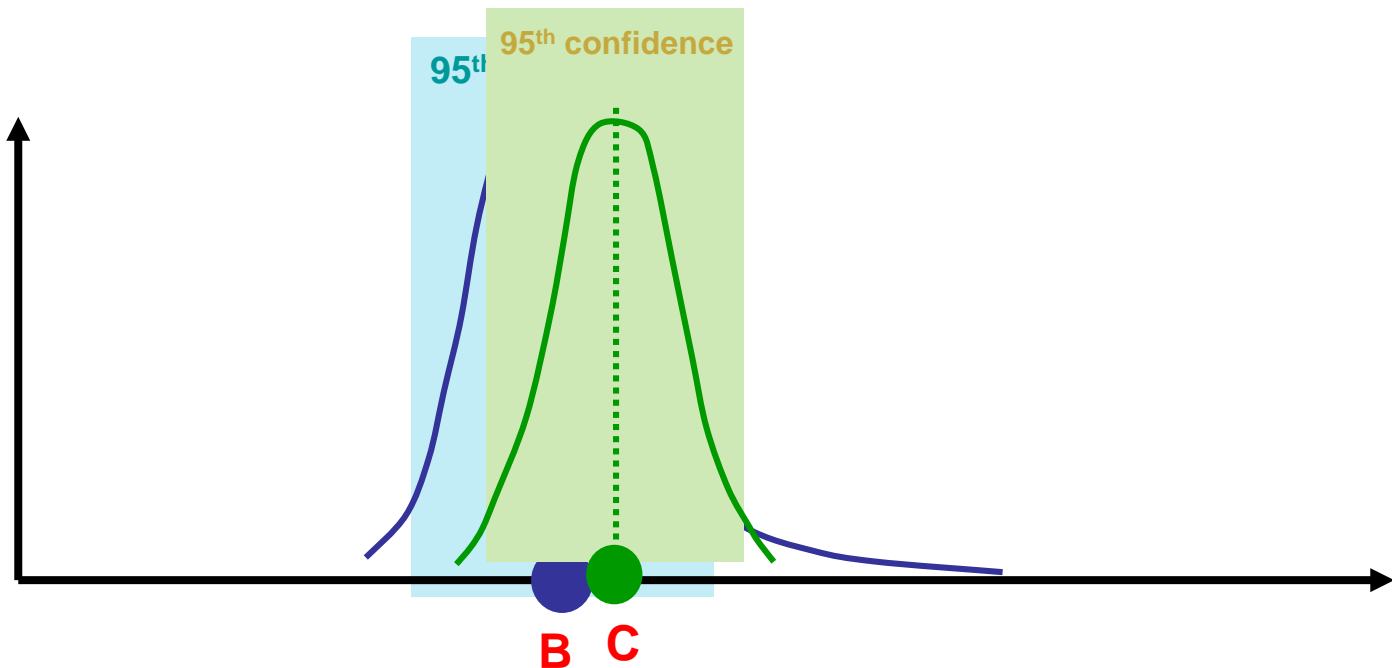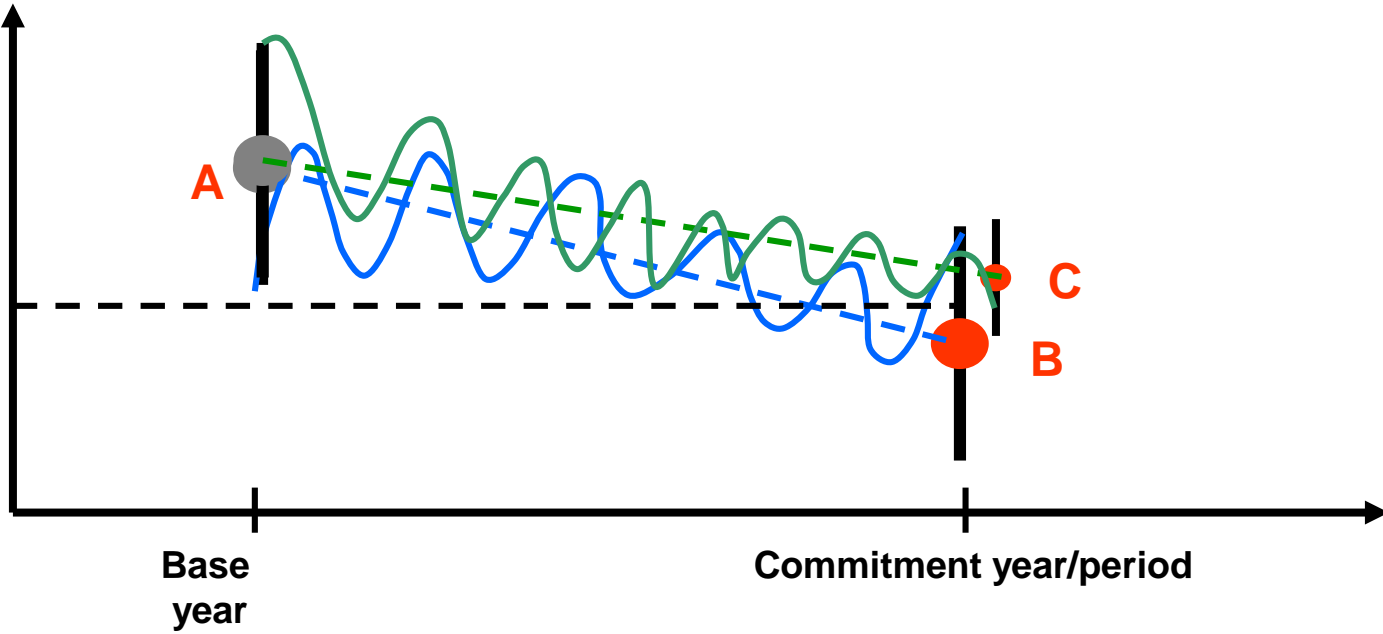
Practical examples

Longer data time series on **FF**, **LUC** and **OU** taken from global carbon budget:

http://lgmacweb.env.uea.ac.uk/lequere/co2/carbon_budget.htm

Fossil Fuel Emissions (FF) are estimated from data on the global consumption of coal, oil, and natural gas.

The **Land Use Change (LUC)** are estimated using a bookkeeping model updated in August 2006 using revised data from the FAO of the United Nations.
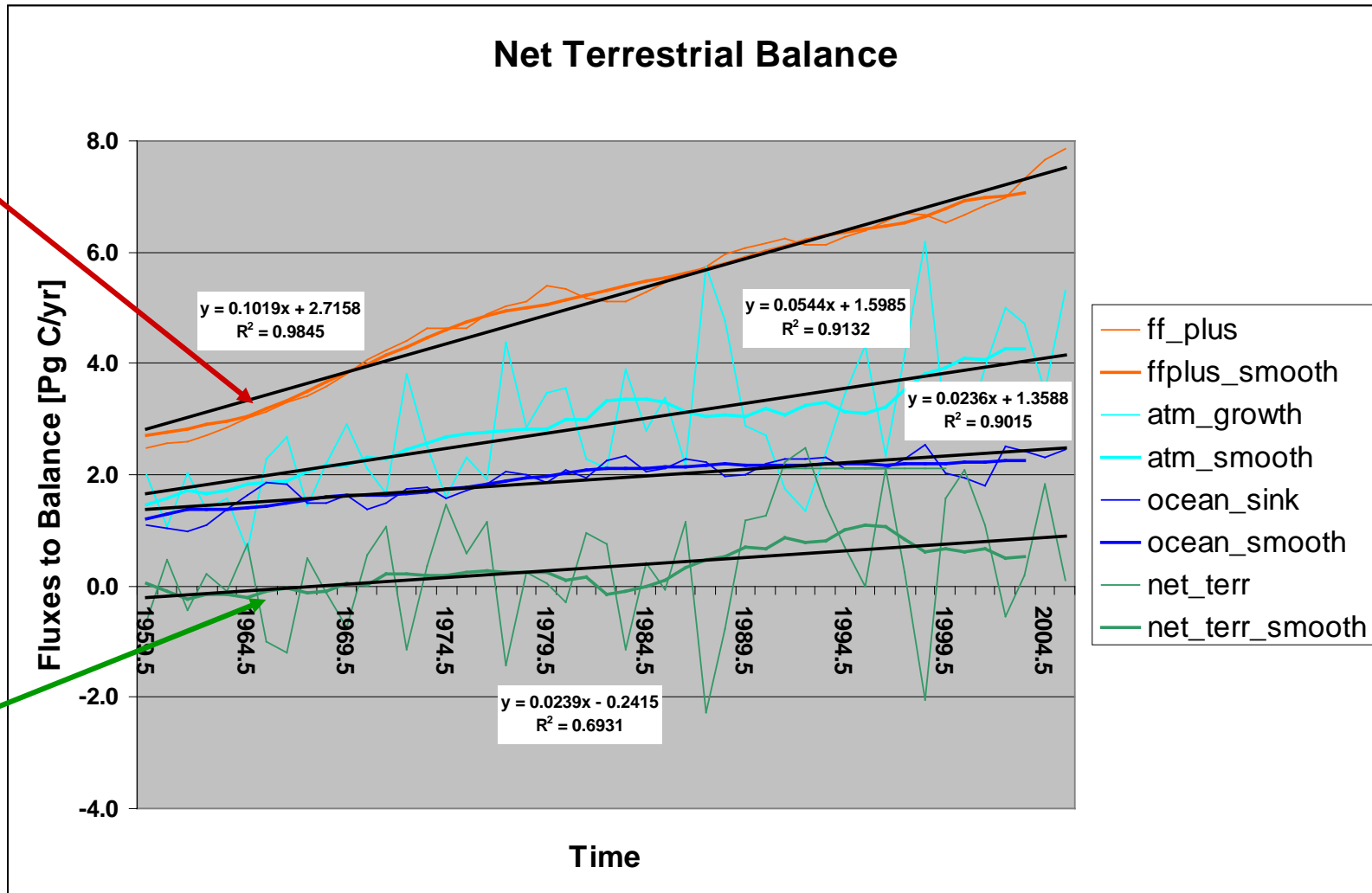
The mean **Ocean Uptake (OU)** for 1959-2005 is estimated using an ocean general model forced by observed atmospheric conditions of weather and CO2 concentration.

The **terrestrial uptake** is estimated as a residual of all the sources minus the ocean uptake and atmosphere increase
(Assessment Report 4, WG 1, Ch. 7, 2007, p. 519).

Variability of emissions:
"fast" and "slow" emissions dynamics

Net Terrestrial Balance

Fossil Fuels: strong dynamics, small variability

$y = 0.1019x + 2.7158$
$R^2 = 0.9845$

$y = 0.0544x + 1.5985$
$R^2 = 0.9132$

$y = 0.0236x + 1.3588$
$R^2 = 0.9015$

$y = 0.0239x - 0.2415$
$R^2 = 0.6931$

Fluxes to Balance [Pg C/yr]

Time

Net terrestrial: slow dynamics, large variability

- ff_plus
- ffplus_smooth
- atm_growth
- atm_smooth
- ocean_sink
- ocean_smooth
- net_terr
- net_terr_smooth

http://lgmacweb.env.uea.ac.uk/lequere/co2/carbon_budget.htm

Data series

Net Emissions
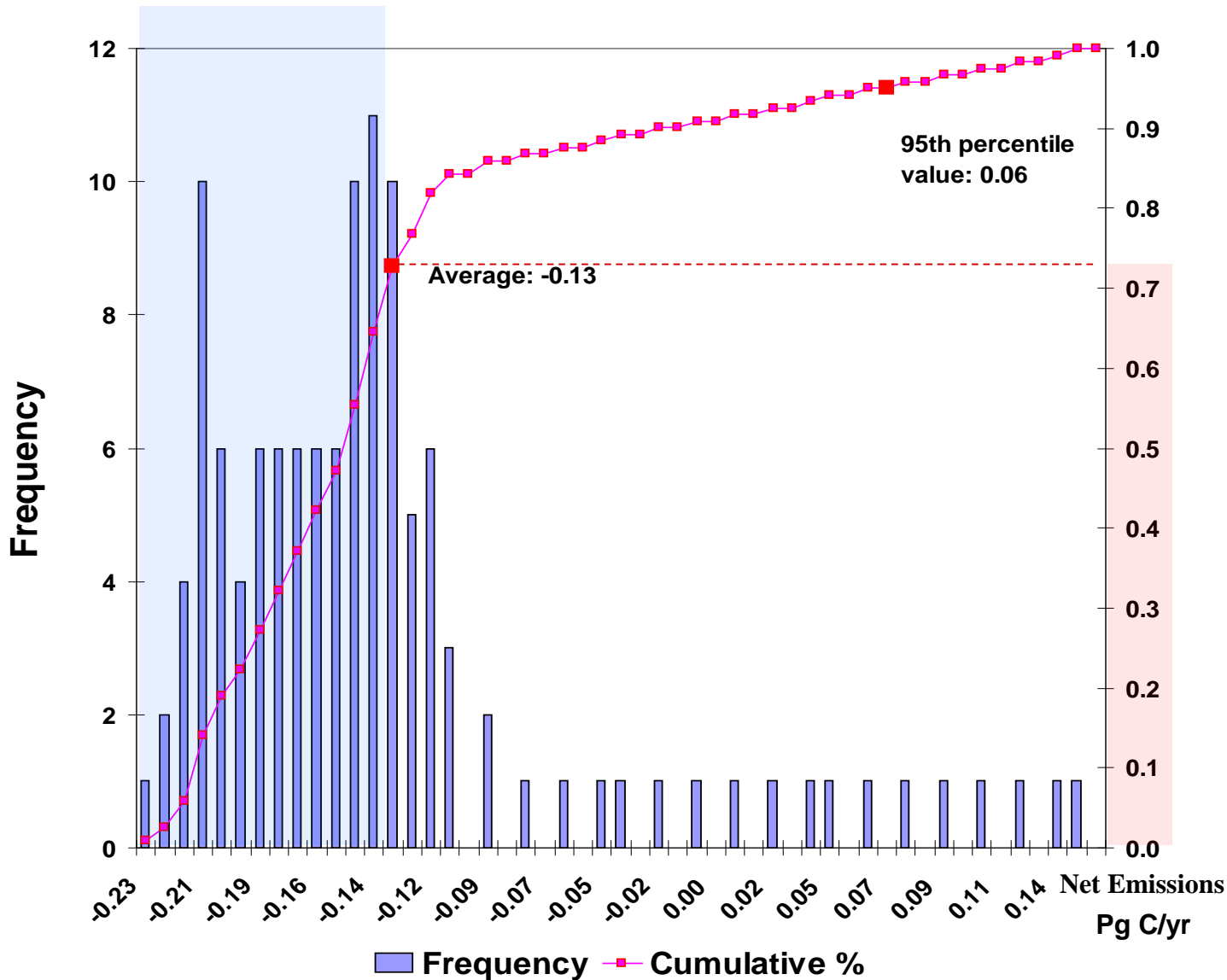
y = 0.0239x - 0.2415
R2 = 0.6931

Data — De-trended — Trend

Slow dynamics vs large variability:

Net terrestrial uptake, 1960-1970

95th percentile value: 0.06

Average: -0.13

Net Emissions
Pg C/yr

☐ **Frequency** ▪ **Cumulative %**

More emissions below average !

$$\bar{a} \pm 2\delta$$

Slow dynamics vs large variability:

Net terrestrial uptake, 1985-1995

95th percentile value: 0.79

Average: 0.6

Frequency (y-axis), Cumulative % (right y-axis)

Net Emissions Pg C/yr

☐ **Frequency** ■ **Cumulative %**

$a \pm 2\delta$
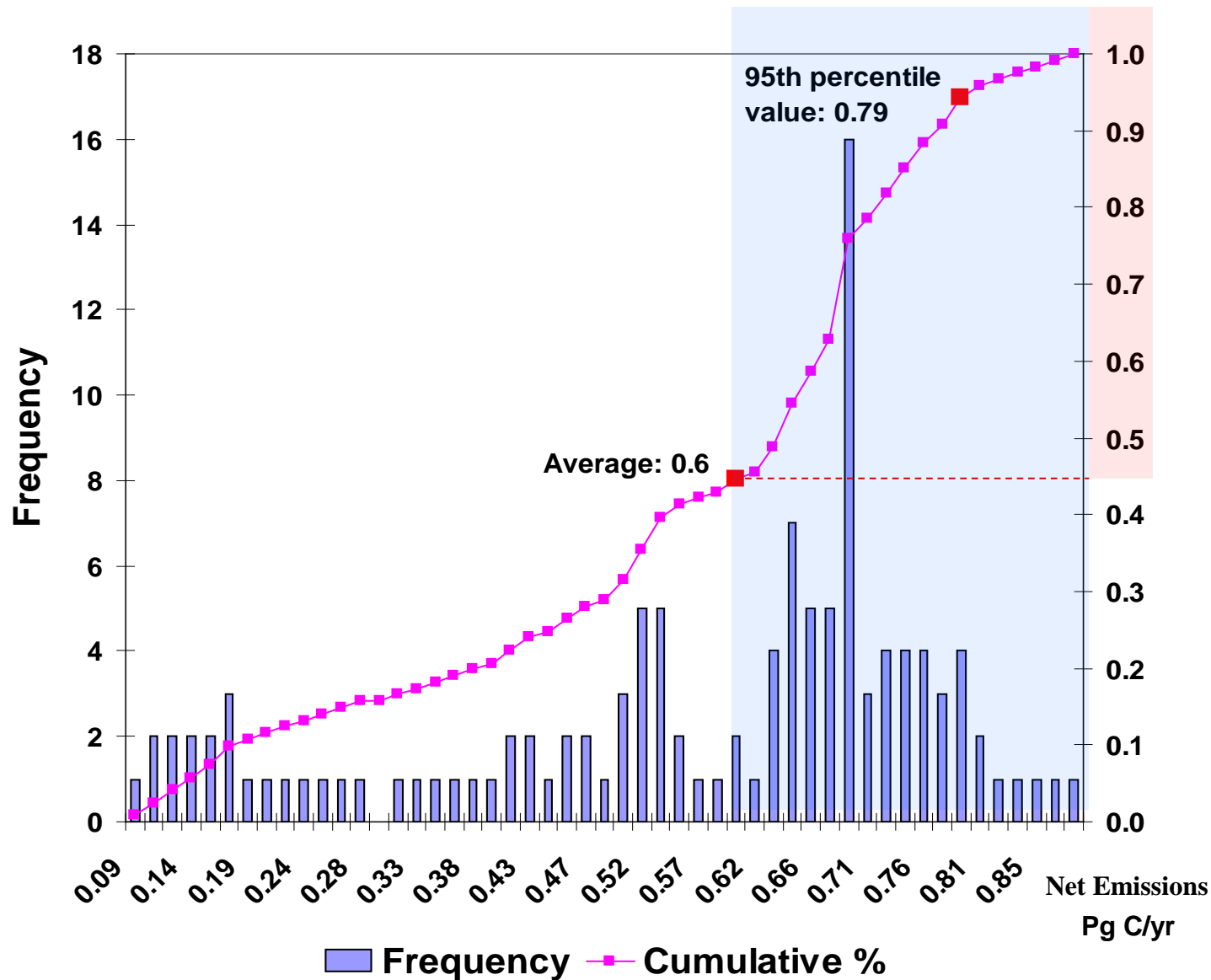
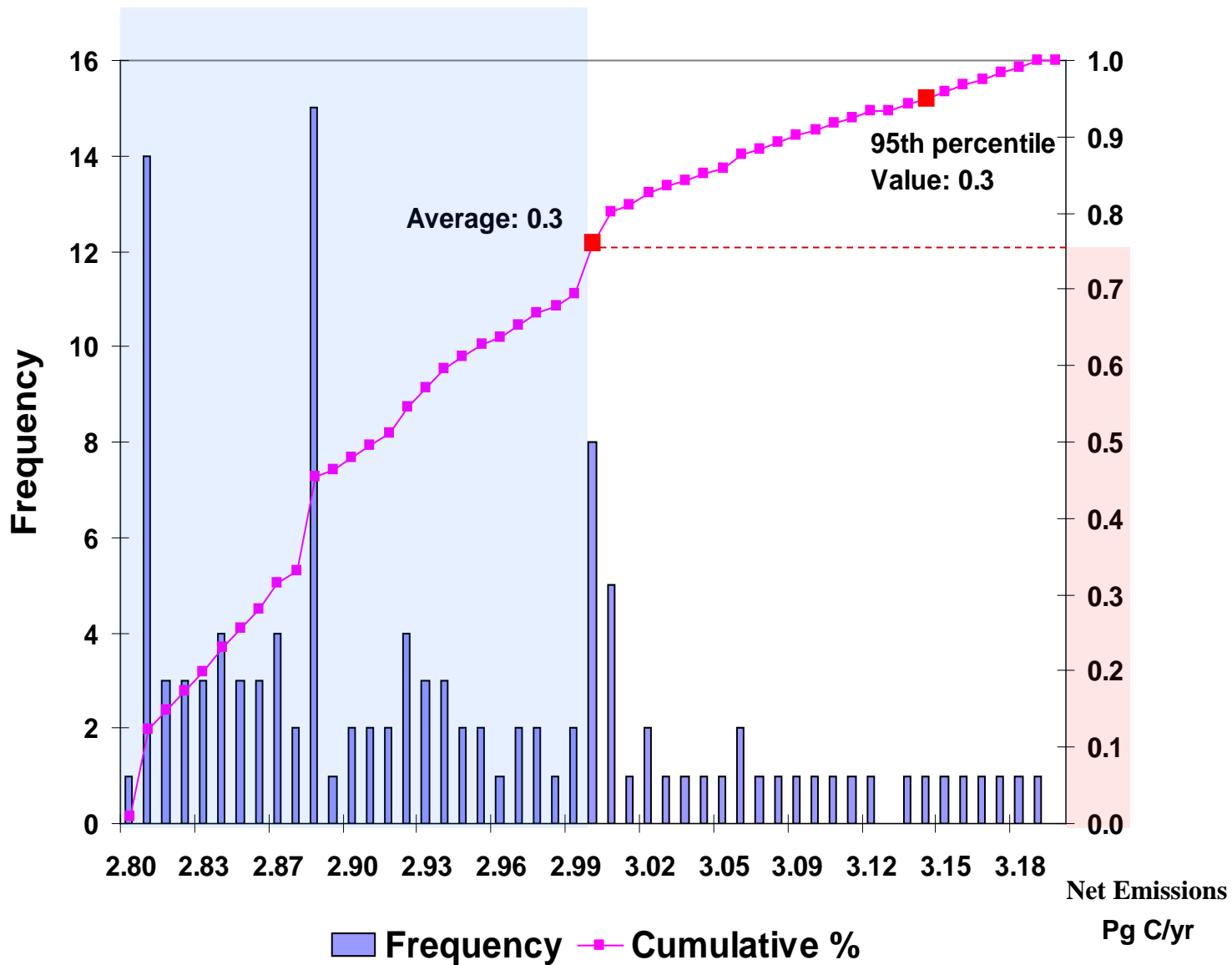**More emissions above average !**
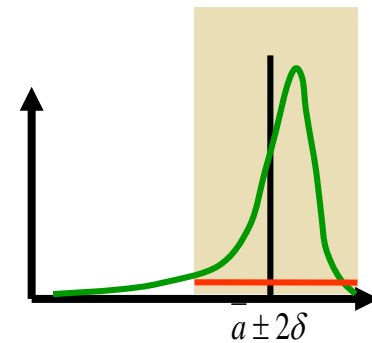
Fast dynamics vs small variability:

Fossil fuel emissions, 1960-1970

More emissions below average !
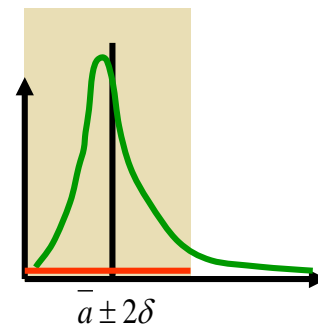
Fast dynamics vs small variability:

Fossil fuel emissions, 1985-1995

95th percentile Value: 6

Average: 5.8

Frequency axis (left): 0, 2, 4, 6, 8, 10, 12, 14, 16

Cumulative % axis (right): 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0

Net Emissions axis: 5.621, 5.650, 5.679, 5.708, 5.737, 5.766, 5.796, 5.825, 5.854, 5.883, 5.912, 5.942, 5.971

Net Emissions Pg C/yr

■ **Frequency** ■— **Cumulative %**

More emissions above average !

$a \pm 2\delta$
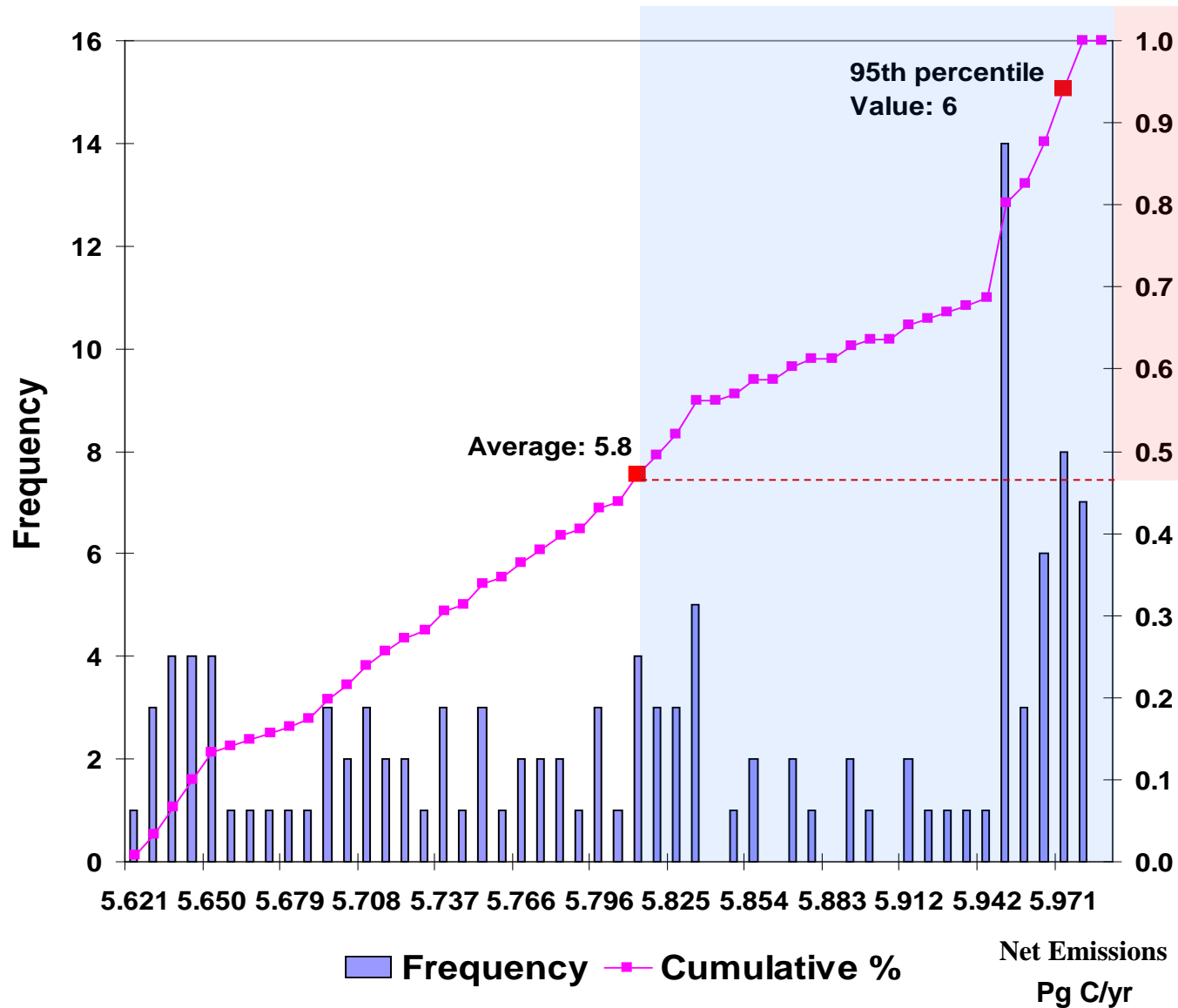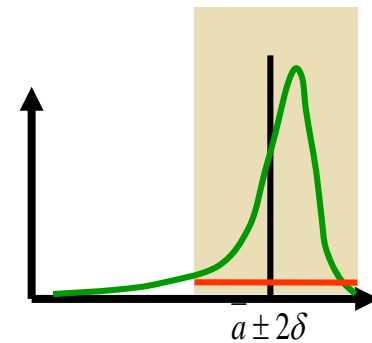
The need for "detection" of emission shapes

1. In 1960 to 1970, the terrestrial system was mostly a sink.

2. Average flow -0.13. Higher likelihood of flows larger than average.

3. More of probability mass below average

4. In 1985 to 1995, it turned to source. Average flow 0.6.

5. More of probability mass above average.

Emission signal: detectability

Detect time when emission outstrips the uncertainty represented by a symmetrical interval
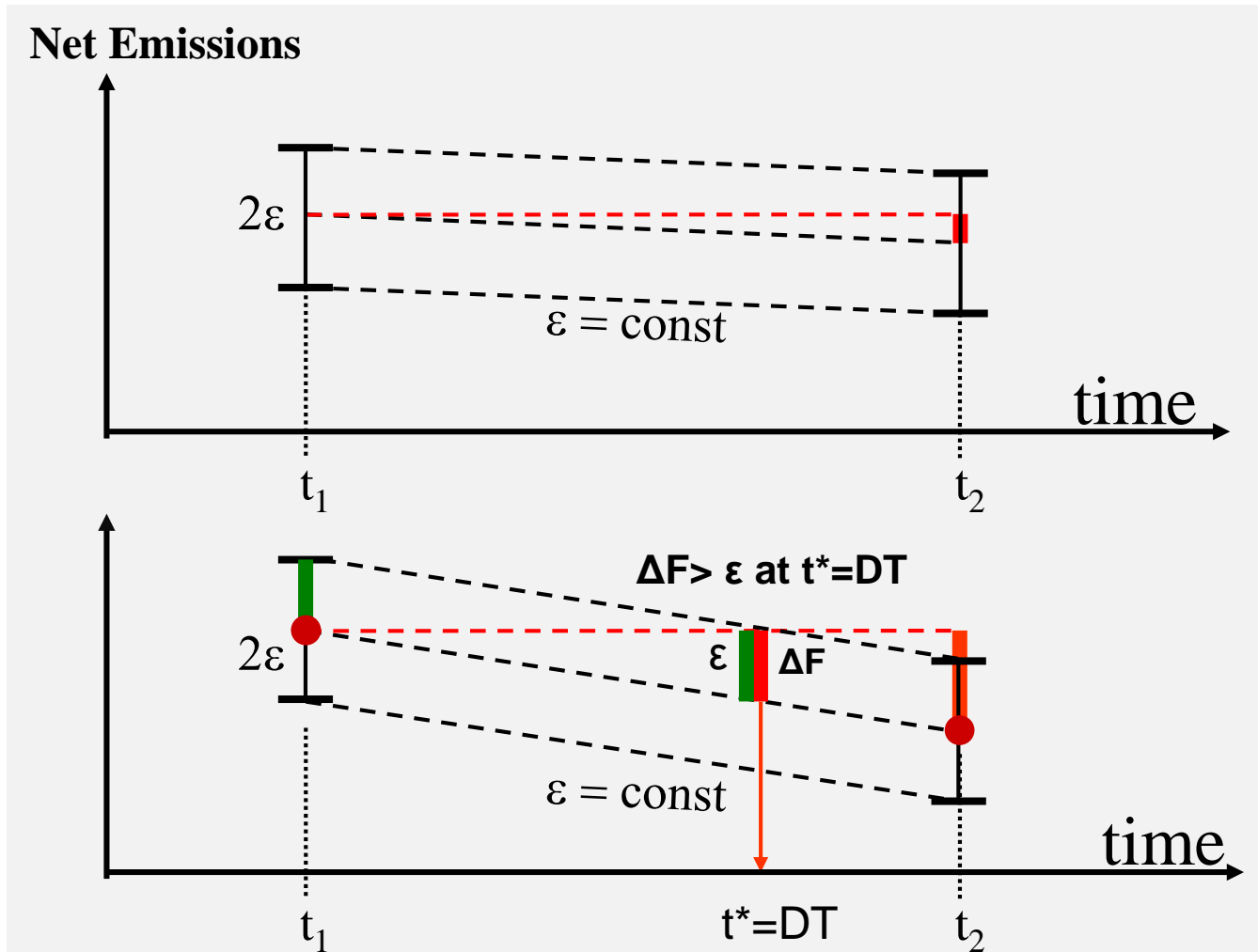
Emission signal: detectability

Net Emissions

a)

ε_1

ε_2

t_1

DT < t_2

t_2

time

Net Emissions

b)

ε_1

ε_2

t_1

DT = t_2

t_2

time

Net Emissions

c)

ε_1

ε_2

t_1

DT > t_2

t_2

time
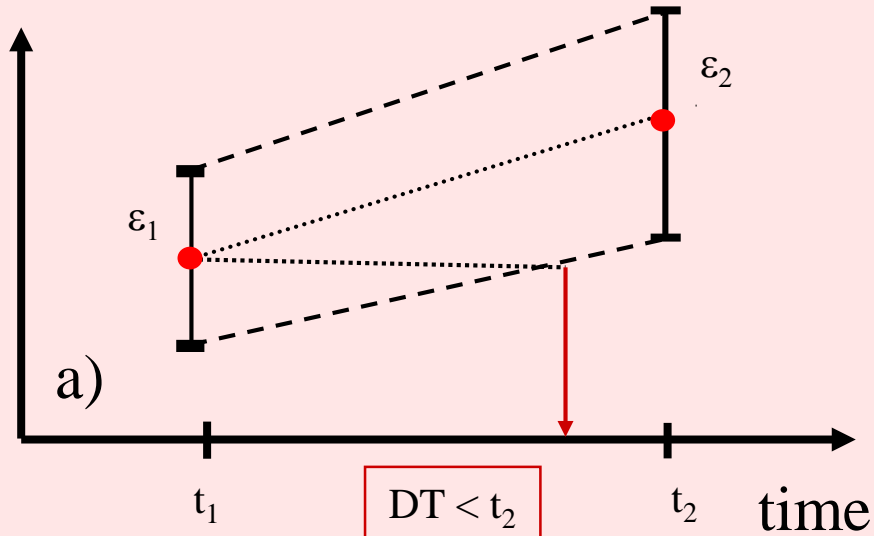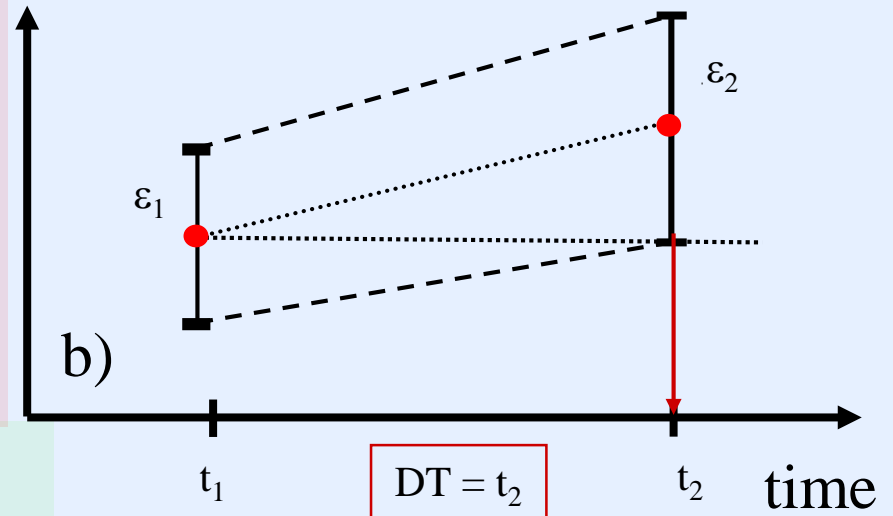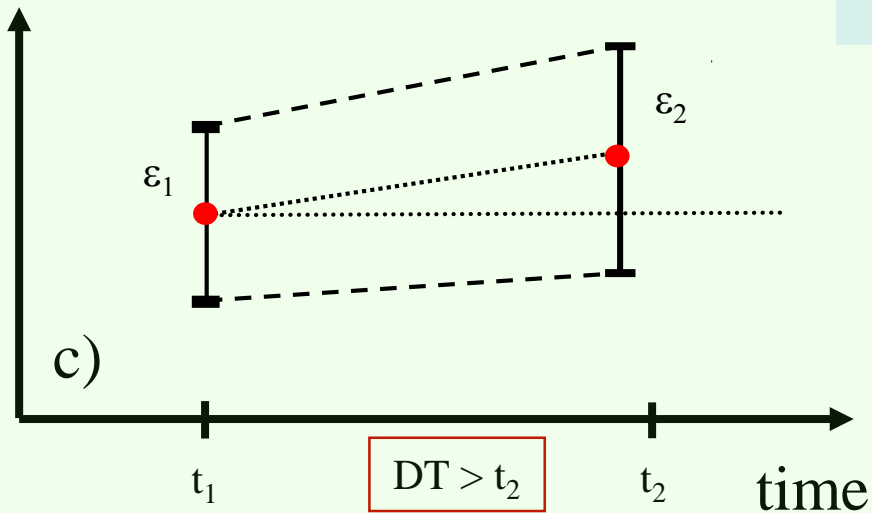
$$\Delta t > \frac{\varepsilon(t_1)}{2\left|\dfrac{dF_{net}}{dt}\right|_{t_1} - \left(\dfrac{d\varepsilon}{dt}\right)_{t_1}}$$

Stochastic detection of emission signal
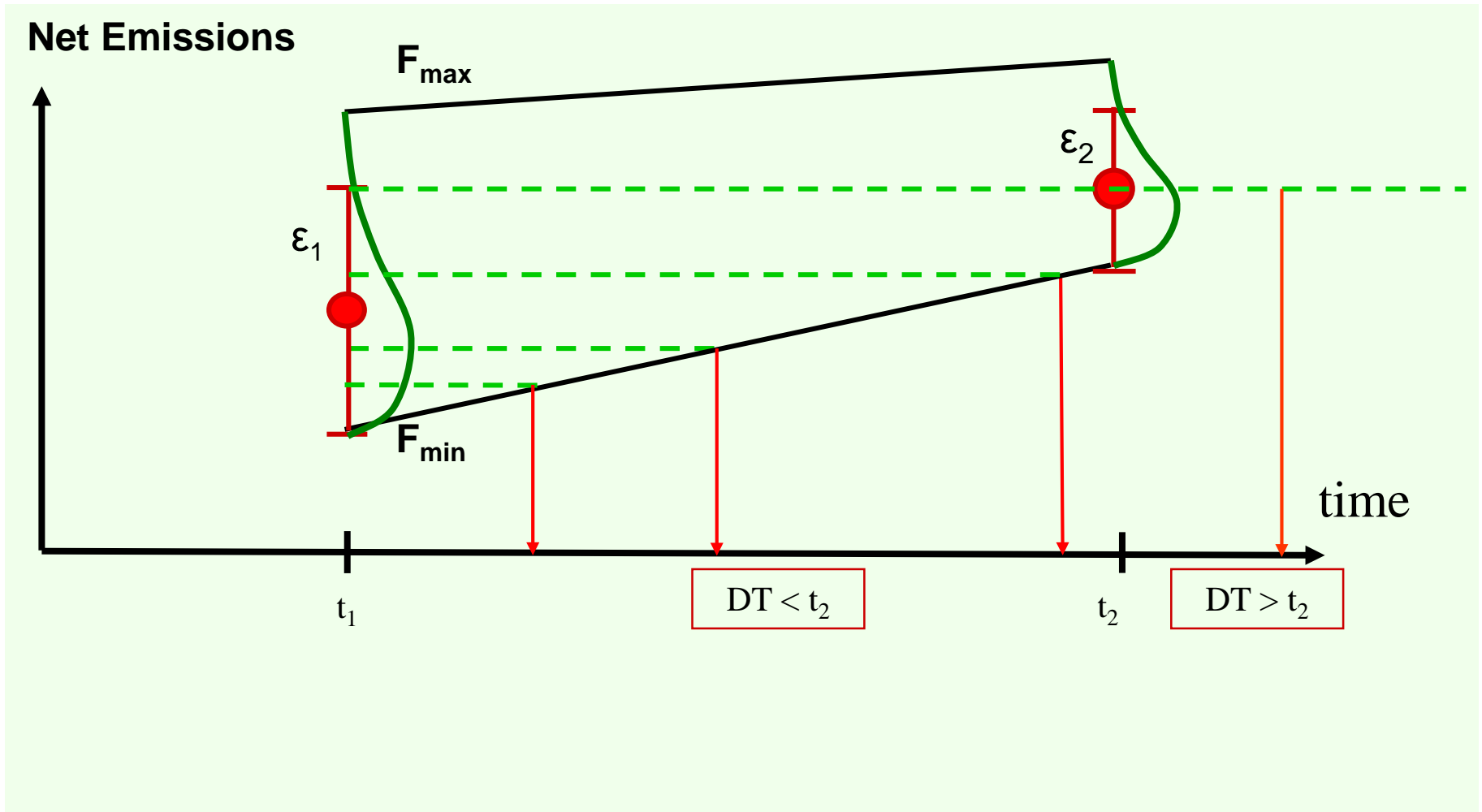
E-sided vs stochastic detection, slow dynamics and large variability:
Net terrestrial uptake, 1965 – 1985

95th percentile
Value: 54.7

Average: 17.7

Median: 15

E-sided approach: 7.9

Years
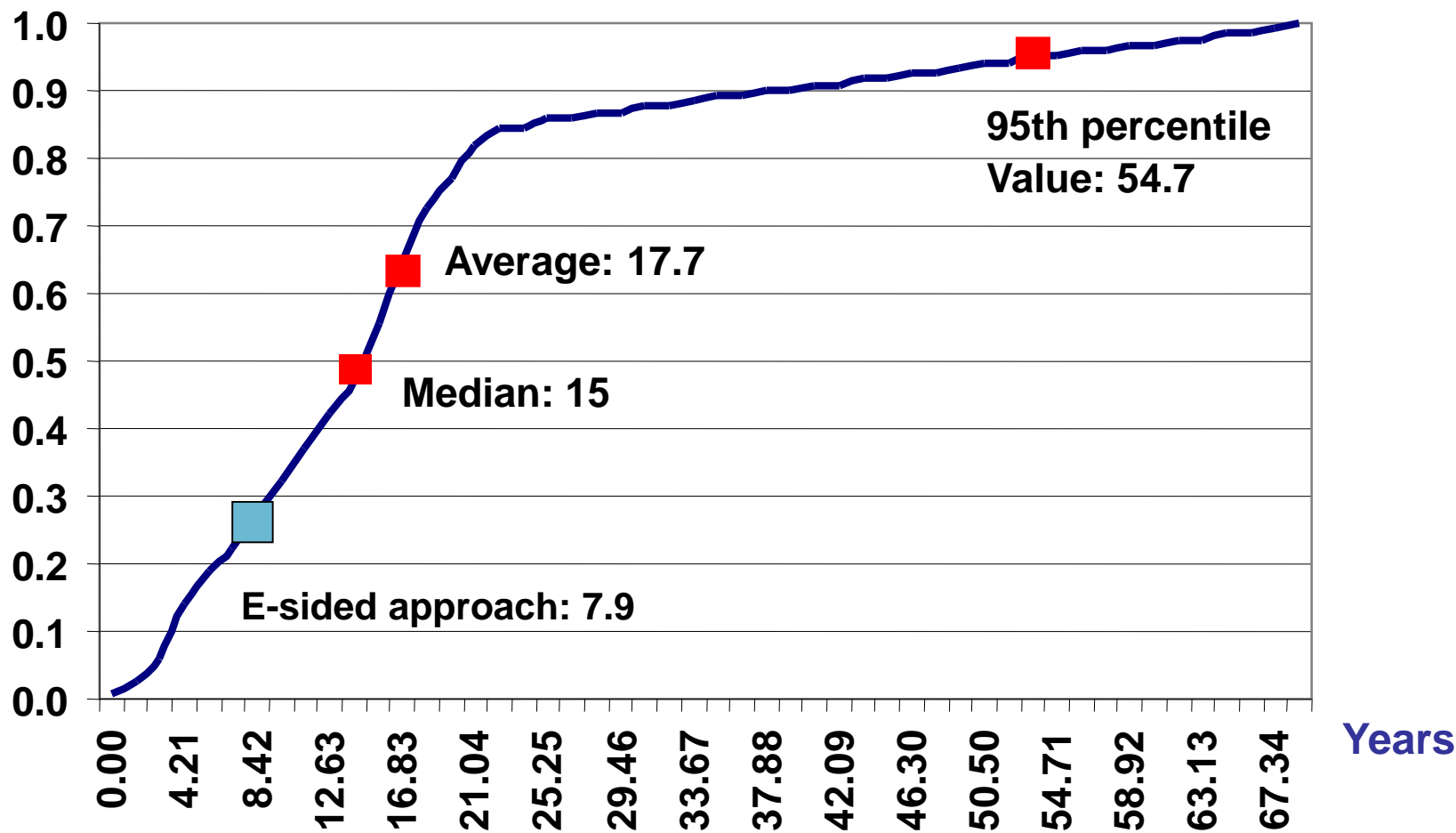
E-sided vs stochastic detection, slow dynamics and large variability:
Net terrestrial uptake, 1965 – 1985

Example 1.	1965–1985	
$F(t_1)$	-0.13	Pg C yr-1
$F(t_2)$	0.18	Pg C yr-1
$\varepsilon(t_1)$	0.16	Pg C yr-1
$\varepsilon(t_2)$	0.39	Pg C yr-1
dt	20	Pg C yr-1
$d\varepsilon=\varepsilon(t_2)-\varepsilon(t_1)$	0.23	Pg C yr-1
$|dF_{net}|=|F(t_2)-F(t_1)|$	0.32	Pg C yr-1
VT	7.9	yr

E-sided vs stochastic detection, fast dynamics vs small variability:

Fossil fuel emissions, 1965 – 1985
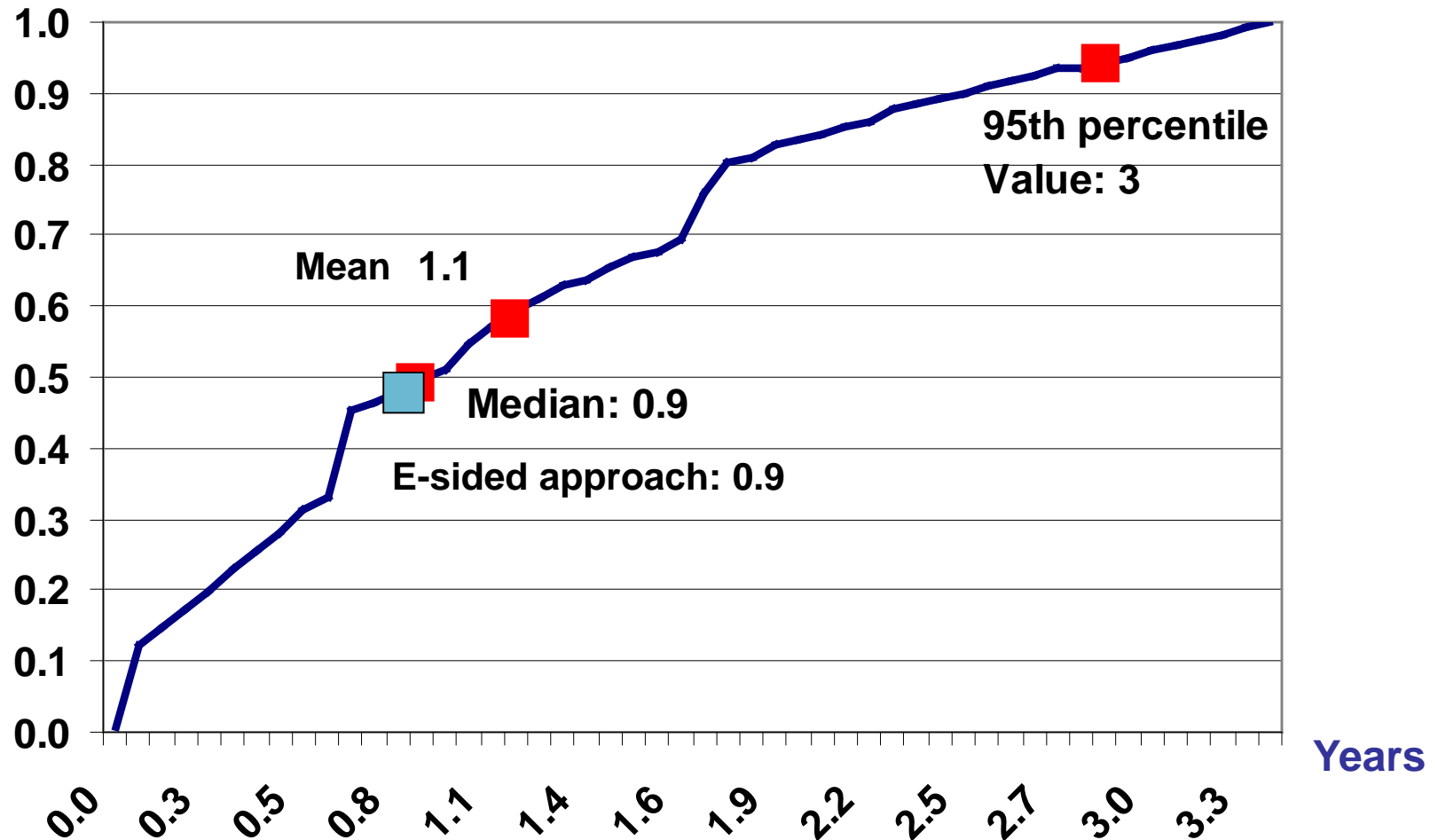
Economic implications of emissions uncertainties: stochastic detection techniques

1. Emissions are tradable commodities.

2. Variability of emissions is a key element for pricing commodities:

   2.a. Inclusion of various systems (forestry and land use CDMs) in emission trading markets: *Carbon Market Europe, 21, 2006. (Available on request)*

   2.b. Slow dynamic systems (forestry, land use) long response times.
   (The "must" for an appropriate emission detection technique - affects prices.)

   2.c. Emissions banking: temporal discounting of emissions

   2.d. Emissions borrowing

   2.e. Initial allowance allocation:
   grandfathering,
   equal emissions per capita,
   equal emissions per unit GDP;
   spatio-temporal discounting of emissions uncertainties, fairness.

   Stochastic detection: what percentile of possible emissions is detectable within a given time interval. This allows to compare and rank the parties in terms of their compliance potential (risks of not compliance).

Emissions banking and borrowing

Alternative emission trading schemes:

      (1) reduction credit trading,
      (2) emission rate averaging, and
      (3) cap-and-trade programs,

Emissions banking: complements emission trading programs

Banking provides flexibility to deal with many uncertainties associated with emissions trading market

Allows inter-temporal trading of emissions

Reliability of emissions estimates plays essential role in Inter-temporal discounting and trading of emissions

Effective banking improves environmental performance and reduces cumulative compliance costs

http://www.pewclimate.org/docUploads/emissions_trading.pdf

Applications of emission detection and verification techniques for emission control policies

- Ermoliev, Y., G. Klaassen and A. Nentjes (1996): The design of cost effective ambient charges under incomplete information and risk. In: E.C. van Ierland and K. Gorka (eds.) *Economics of Atmospheric Pollution*, NATO ASI Series, Partnership Sub-Series, 2. Environment, **V. 14**, 123–151, Springer, Berlin, Germany.

A deterministic and a stochastic technique is proposed to find the cost-effective vector of emissions through adaptation of emission charges in successive steps.

- Ermoliev, Y., M. Michalevich and A. Nentjes (2000): Markets for tradable emission and ambient permits: A dynamic approach. Environ. Res. Econ., 15, 39–56.

Sequential trading schemes in pollution permit markets are discussed in stochastic settings. The paper emphasized the need for an appropriate treatment of uncertainties and risks associated with emissions by designing specific risk-adjusted goal functions. Was shown that in order to reach the least-cost solution, the parties must reduce their emissions uncertainties.

- Godal O., Y. Ermoliev, G. Klassen and M. Obersteiner (2003): Carbon trading with imperfectly observable emissions. *Environmental and Resource Economics*, **25**, 151–169.

Sequential bilateral trading of emissions

- Scheme of sequential bilateral trade (in cap-and-trade scheme) takes into account safety constraints, i.e., risks of underestimating and overestimating real emissions.

- Global least cost solution for all parties.

- Cooperation through the bilateral trading reduces not only the aggregate cost, but this is achieved in a mutually beneficial way reducing individual costs.

- All participating parties create the stable coalition.

- In sequential trading, a stochastic detection technique (SDT) provides information as to what percentile of emissions and variability of a party is detectable in a certain time.

- The (SDT) "informs" the economic model of sequential bilateral trading as to how much and what is the likelihood of "free" emissions that a party can trade.

Summary

Stochastic detection technique:

Percentage of possible emissions detectable within a given time

Contrary to e-sided, captures variability of emissions

Applicable for/to evaluation of carbon related financial instruments

(emission trading, investments, Kyoto related mechanisms)

On-going research:

Development of specific risk-adjusted pricing procedures for emissions-related products

Clean Development Mechanisms (CDM), Joint Implementation (JI) projects.

CDM (including emission trading) insurance: emissions uncertainties are prices.

Insurance of "skewed" risks of emissions trading is similar to Catastrophic risks insurance.

Emission trading and endogenous discounting: credibility of parties is translated into discounting of emissions permits

Principles for allocation of emissions allowances: pros and cons of grandfathering, fairness, temporal discounting of emission reduction technologies

References

Jonas, M., S. Nilsson, R. Bun, V. Dachuk, M. Gusti, J. Horabik, W. Jęda and Z. Nahorski, 2004: Preparatory Signal Detection for Annex I Countries under the Kyoto Protocol—A Lesson for the Post-Kyoto Policy Process. Interim Report IR-04-024, International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 91. Available at: http://www.iiasa.ac.at/Publications/Documents/IR-04-024.pdf.

Jonas, M. and S. Nilsson, 2007: Prior to an economic treatment of emissions and their uncertainties under the Kyoto Protocol: Scientific uncertainties that must be kept in mind. *Water, Air & Soil Pollution: Focus*. Available at: http://dx.doi.org/10.1007/s11267-006-9113-7.

Nahorski, Z., J. Horabik and M. Jonas, 2007: Compliance and emissions trading under the Kyoto Protocol: Rules for uncertain inventories. *Water, Air & Soil Pollution: Focus*. Available at: http://dx.doi.org/10.1007/s11267-006-9112-8.

Nilsson, S., M. Jonas, V. Stolbovoi, A. Shvidenko, M. Obersteiner and I. McCallum, 2003: The missing "missing sink". *The Forestry Chronicle*, **79**(6), 1071−1074.

Pearce, F., 2006: Kyoto promises are nothing but hot air. *New Scientist*, 22 June. Available at: http://environment.newscientist.com/channel/earth/mg19025574.000-kyoto-promises-are-nothing-but-hot-air.html.

Rödenbeck, C., S. Houweling, M. Gloor and M. Heimann, 2003: CO_2 flux history 1982–2001 inferred from atmospheric data using a global inversion of atmospheric transport. *Atmos. Chem. Phys.*, **3**, 1919–1964.

References

Ermoliev, Y., Klaassen, G., Nentjes, A. The design of cost effective ambient charges under incomplete information and risk. NATO ASI Series, Partnership Sub-Series, 2. Environment, V. 14: Economics of Atmospheric Pollution. Edited by Ekko C. van Ierland and Kazimierz Gorka, Springer Verlag, Berlin-Heidelberg, 1996.

Ermoliev, Y., M. Michalevich and A. Nentjes, 2000: Markets for tradable emission and ambient permits: A dynamic approach. *Environmental and Resource Economics* 15, 39–56.

Gillenwater, M., F. Sussman and J. Cohen, 2007: Practical policy applications of uncertainty analysis for national greenhouse gas inventories. *Water, Air & Soil Pollution: Focus*. Available at: http://dx.doi.org/10.1007/s11267-006-9118-2.

Godal, O., 2000: Simulating the carbon permit market with imperfect observations of emissions: Approaching equilibrium through sequential bilateral trade. IIASA Interim Report IR-00-060, International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 25. Available at: http://www.iiasa.ac.at/Publications/Documents/IR-00-060.pdf.

House, J.I., I.C. Prentice, N. Ramankutty, R.A. Houghton and M. Heiman, 2003: Reducing apparent uncertainties in estimates of terrestrial CO2 sources and sinks. *Tellus* **55B**, 345–363.

Hudz, H., 2003: Verification Times Underlying the Kyoto Protocol: Consideration of Risk. Interim Report IR-02-066, International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 34. Available on the Internet: http://www.iiasa.ac.at/Publications/Documents/IR-02-066.pdf.

Jonas, M., S. Nilsson, M. Obersteiner, M. Gluck and Y. Ermoliev, 1999: Verification Times Underlying the Kyoto Protocol: Global Benchmark Calculations. Interim Report IR-99-062, International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 43. Available on the Internet: http://www.iiasa.ac.at/Publications/Documents/IR-99-062.pdf.