Sustainability of agricultural systems: Agricultural productivity measurements, issues and challenges

Upali Wickramasinghe
Regional Adviser on Poverty Reduction and Food Security
ESCAP-CAPSA

Objectives of the discussion

- Measuring agricultural productivity and natural assets
- Examine composite indicators for sustainable production and natural resource use
- The effects on the environment of achieving food security

Why do we want productivity measurements?

- Solow – gauge progress - Enhancing human welfare from relatively fixed resources (land, water, biodiversity)
- Griliches – Explain progress – how it is achieved is important for policy but don't use the result as a metric for progress
- Get a sense of whether the world can feed rising population
  - Compare rate of growth of demand (population growth + income growth) and rate of growth of supply of food (productivity growth)
- To identify if food systems are sustainable??

Approaches to measuring agricultural productivity

- Single factor: Output / Input
  - Land productivity: Output / No of acres
  - Labour productivity" Output / No of workers
- Total Factor Productivity= ratio of total output (Y) to total inputs (X), where Y and X are vectors.

$$TFP = Y/X$$

Changes over time are estimated by:

$$\frac{d\ln(TFP)}{dt} = \frac{d\ln(Y)}{dt} - \frac{d\ln(Y)}{dt}$$

- Rate of change of TFP is the difference between the rate of change in aggregate output and aggregate input

IF:

i. Production technology can be represented by Cobb-Douglas production function

ii. Farm producers maximize profits so output elasticity with respect to an input equals the cost share of that input

iii. Markets are in long-run equilibrium so that total revenue equals total cost

THEN,

$$\ln\left(\frac{TFP_t}{TFP_{t-1}}\right) = \sum_i R_i \ln\left(\frac{Y_{i,t}}{Y_{i,t-1}}\right) - \sum_j S_j \ln\left(\frac{X_{j,t}}{X_{j,t-1}}\right)$$

$R_{i\,=}$ Revenue share of the i^{th} output and S_j = cost share of the j^{th} input

- Total output growth = sum of growth rates for each commodity weighted by its revenue share.
- Total input growth = Sum of growth rate of each input, weighted by its cost share.
- TFP growth is the difference between the growth of total output and total input.

- Why do we use different growth accounting methods?
  - Depends on whether revenue and cost shares are fixed or vary over time
  - If fixed: Paasche and Laspeyer
  - If vary: Tornquist-Thiel and other chained indices (variable weights). They reduces potential "index number bias."
- Where does Index number bias arise?
  - When producers substitute among outputs and inputs depending on their relative profitability or cost (e.g., Labour wages rise relative to the cost of capital, producers are likely to substitute more capital for labour, thereby reducing the growth rate in labour and increasing it for capital)
  - Cost shares of agricultural capital and material inputs tend to rise in the process of economic development, while the cost share of labour tends to fall. Commodity revenue shares tend to show less change over time.
- USDA agricultural productivity estimates adjust input cost shares by decade (whenever such information is available)

Change in TFP:

$$\ln\left(\frac{TFP_t}{TFP_{t-1}}\right) = \sum_i R_i \ln\left(\frac{Y_{i,t}}{Y_{i,t-1}}\right) - \sum_j S_j \ln\left(\frac{X_{j,t}}{X_{j,t-1}}\right)$$

Input cost decomposition of output growth

$$\dot{Y} = T\dot{F}P + \sum_{j=1}^{J} S_j \dot{X}_j$$

Growth in cost From using more of the j[th] input

Consider, One input (Land, X_1):

$$\dot{Y} = \dot{X}_1 + \left(\frac{\dot{Y}}{X_1}\right)$$

Land expansion

Change in output per unit of land

Resource decomposition of growth

$$\dot{Y} = \dot{X}_1 + T\dot{F}P + \sum_{j=2}^{J} S_j \left(\frac{\dot{X}_j}{X_1}\right)$$

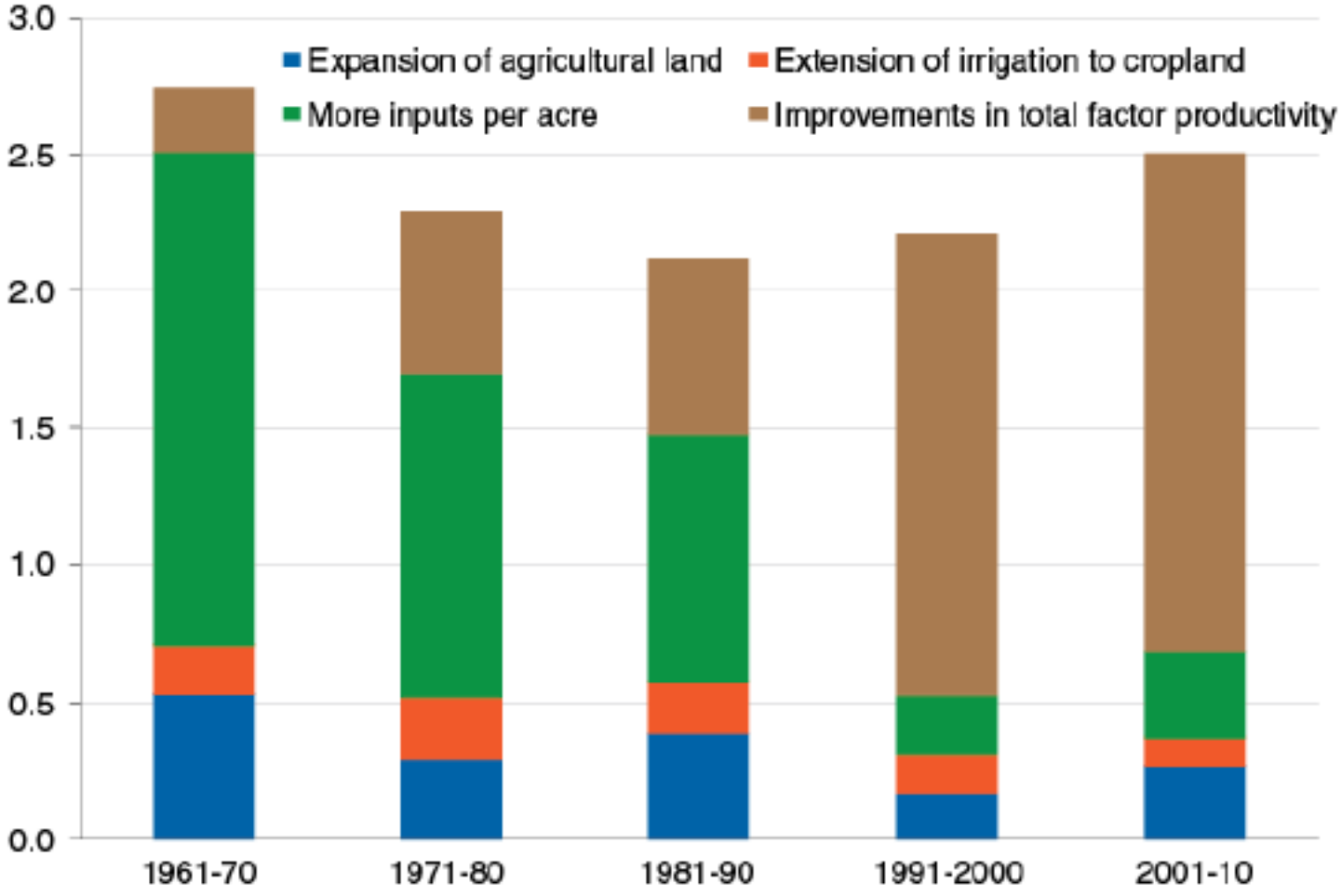
Total factor productivity

Share due to using other inputs more intensively

Global region	Agricultural output	Total factor productivity	All inputs	Land	Labor	Machinery capital	Livestock capital	Materials (fertilizers)
	Average annual growth over 2001-10, percent per year							
Developed countries	0.59	2.32	-1.73	-0.77	-3.34	-0.51	-0.28	-2.07
North America	1.33	2.10	-0.77	-0.78	-1.96	-0.54	0.07	-0.58
Europe	-0.13	2.07	-2.20	-0.47	-3.14	0.06	-0.60	-3.26
Transition economies	1.49	1.90	-0.41	-0.21	-2.33	-0.54	-0.15	2.80
Developing countries	3.39	2.20	1.20	0.93	-0.13	3.47	1.55	3.53
East and South Asia	3.40	2.69	0.71	0.63	-0.65	3.25	1.31	3.90
Latin America	3.37	2.67	0.70	1.89	-0.50	0.06	1.24	2.00
Sub-Saharan Africa	3.26	0.99	2.28	1.83	2.06	1.32	2.60	4.14
West Asia and North Africa	2.42	2.04	0.39	-0.11	0.12	1.19	1.62	-0.19
World	2.50	1.81	0.70	0.37	-0.23	1.23	1.16	1.99

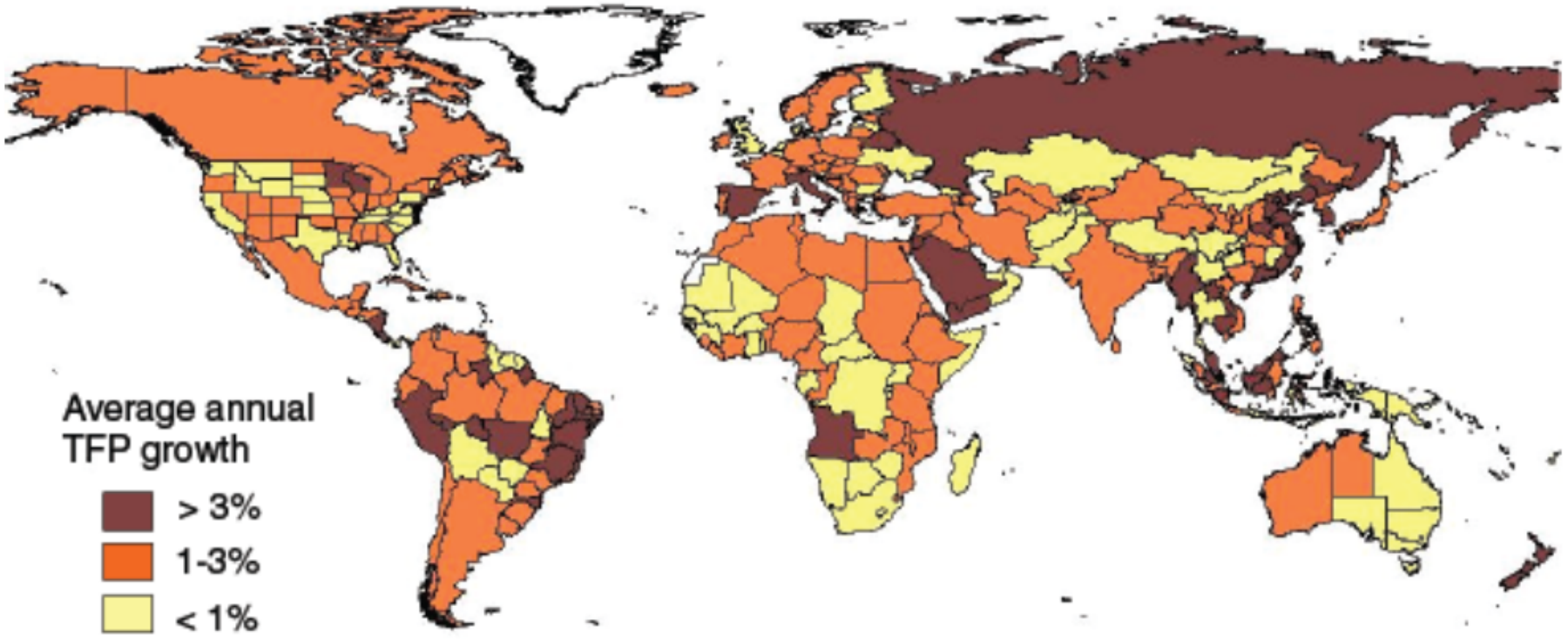
Source: USDA, Economic Research Service, derived from Food and Agriculture Organization of the United Nations and other agricultural data using methods described in Fuglie et al. (2012).

Total factor productivity has replaced resource intensification as the primary source of growth in world agriculture



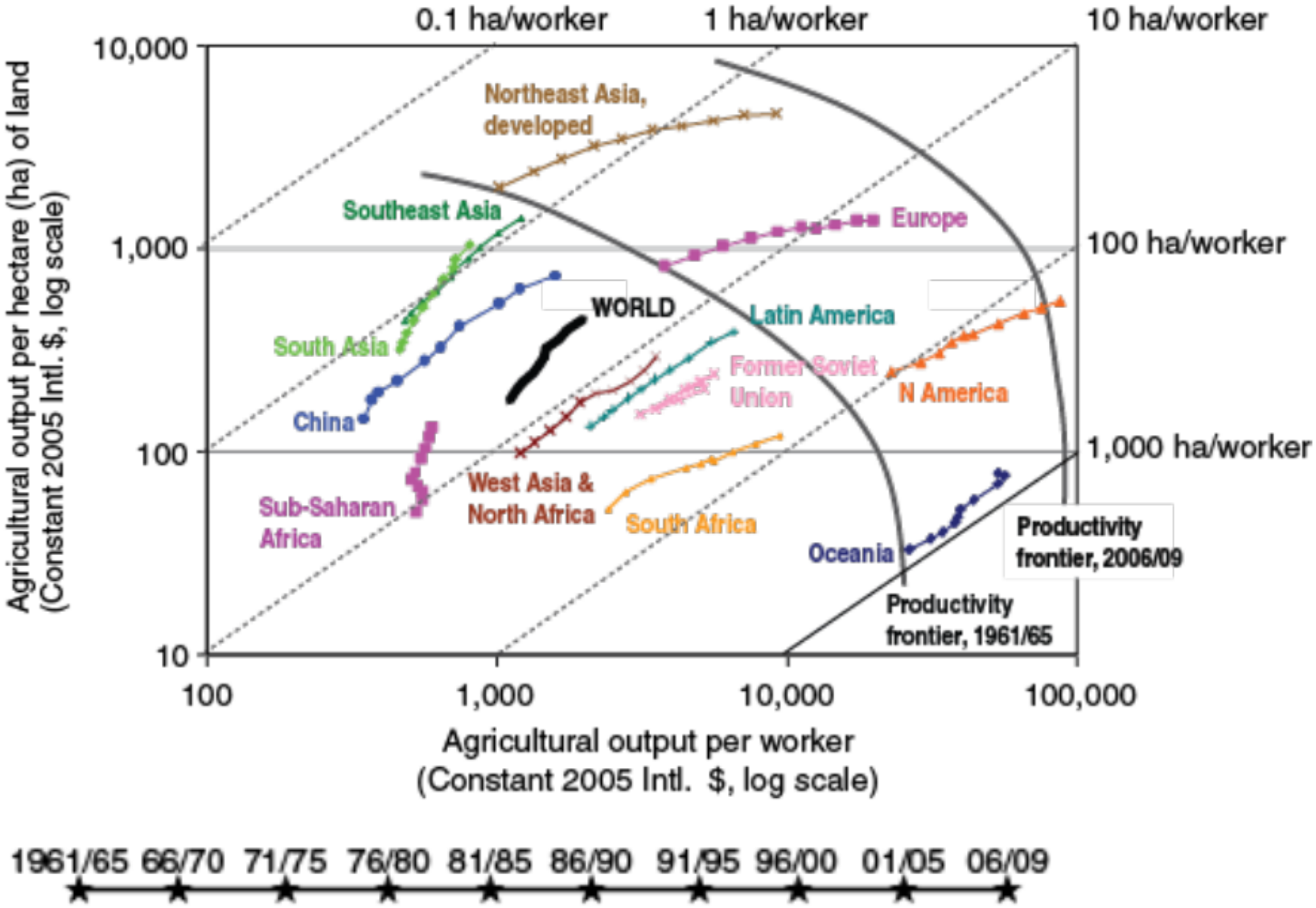
Source: USDA, Economic Research Service, derived from Food and Agriculture Organization of the United Nations and other agricultural data using methods described in Fuglie et al. (2012).

Improvement in agricultural total factor productivity (TFP) growth was highly variable among countries, 1991-2010



Source: USDA, Economic Research Service using Fuglie et al., 2012.

Agricultural land and labor productivity has steadily improved since 1960, but developing countries lag decades behind developed countries



USDA TFP (based on FAO data)

- Developed countries: total resources used in agriculture have been falling since about the 1980s. Rising TFP has offset declining resources use to keep the productivity still rising
- Developing countries:
  - TFP growth doubled from less than 1% per year in 1990-60 to over 2% in 1991-2009
  - Input growth slowed but is still expanding to keep output growing

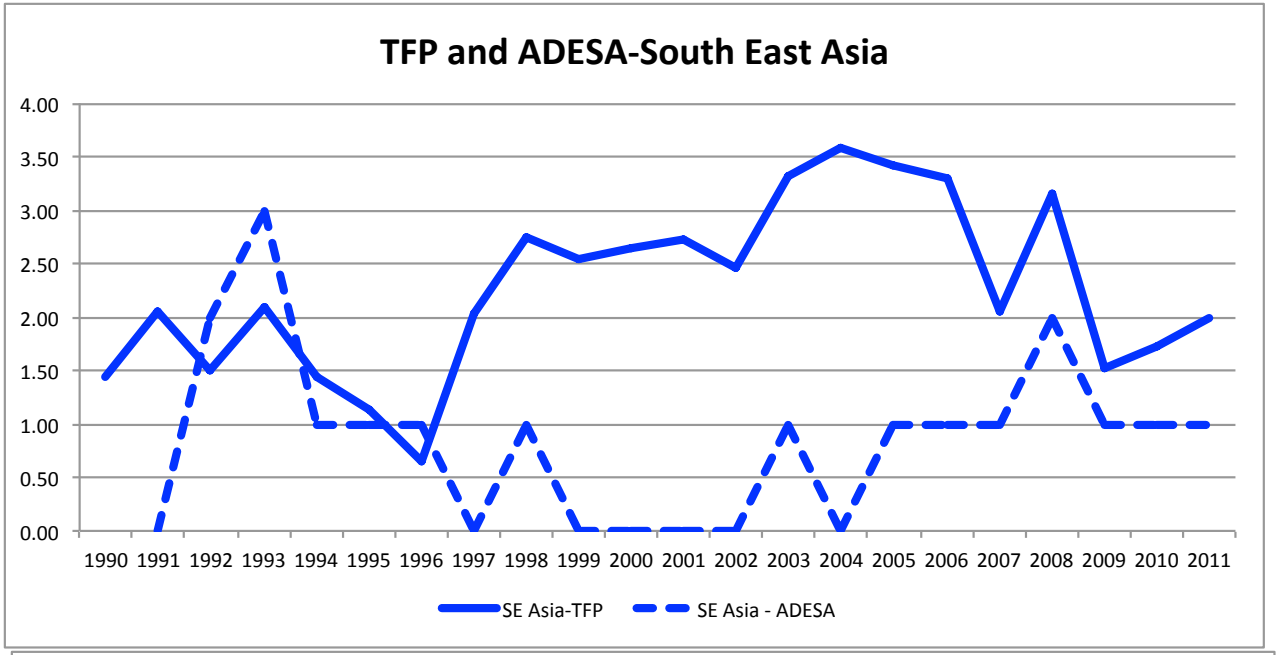
So, is what we know complete?

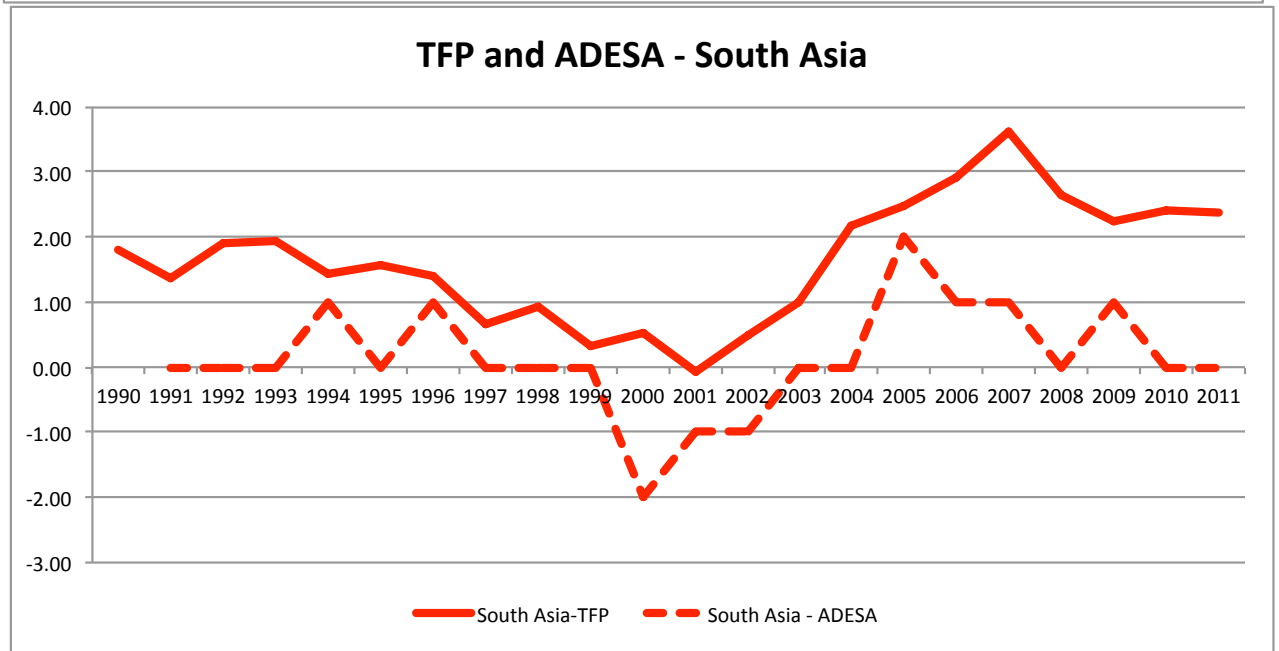
- TFP growth implies that a system is sustainable in view of the fact that output appears to increase at least as fast as inputs rise
- Can this be valid?
- There are other aspects that need to be considered besides production
  - Externalities generated by agricultural activity
  - The way natural resources are depleting
- TFP estimates are biased:
  - Because of unmeasured / unpriced inputs (e.g. water, climate, ecological support) → Research on missing inputs is needed (Perring and Pulginiti, 2011)
  - TFP + when negative externalities + (Ball et al , 2005)

So, is what we know complete?...

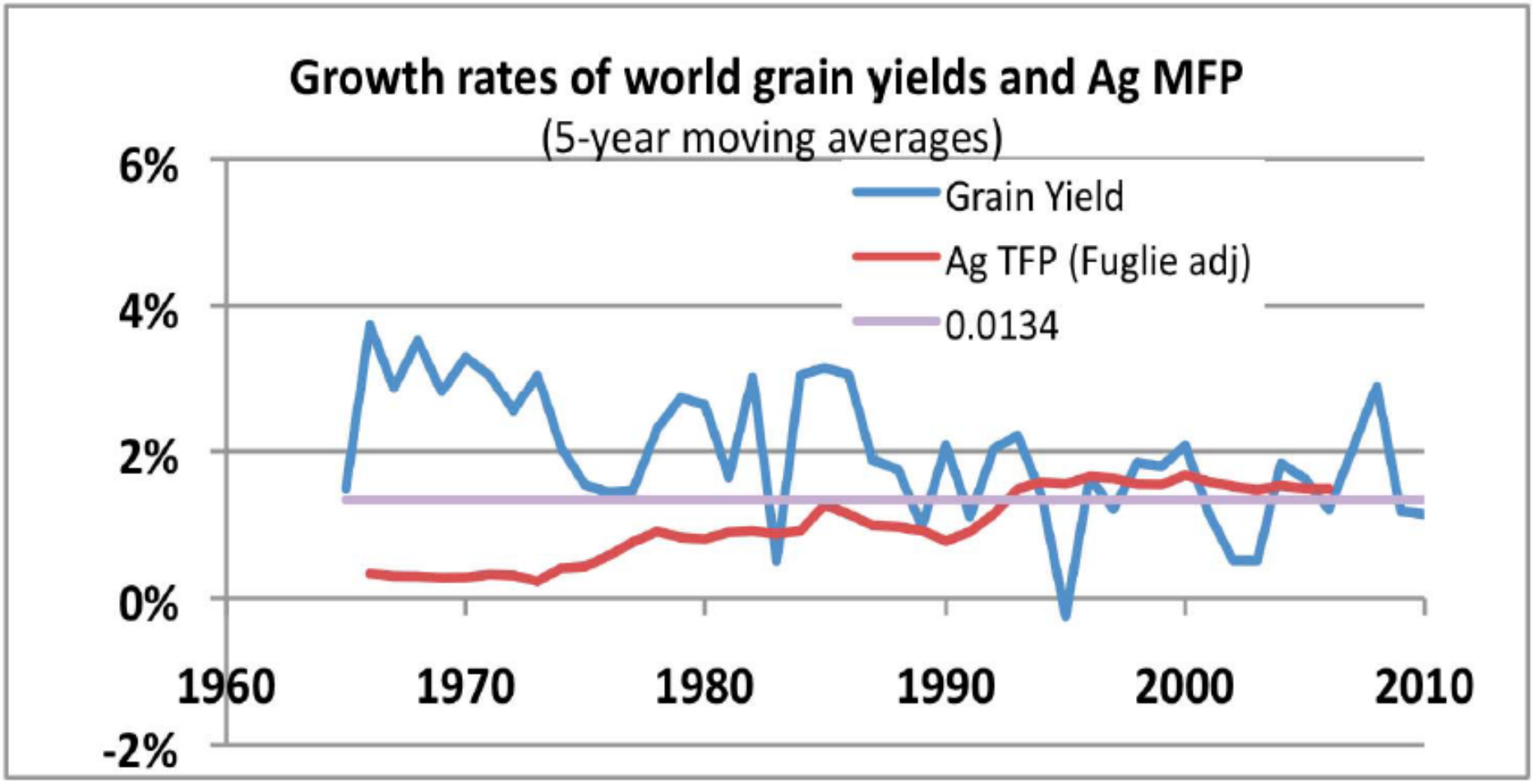
- Externalities
  - E.g., externalities: “good” or “bad”
  - Run off from the use of agrochemicals pollutes a lake → fisherman are negatively affected
  - Property owner takes action to improve his property → value of properties in the vicinity may increase

TFP and food security





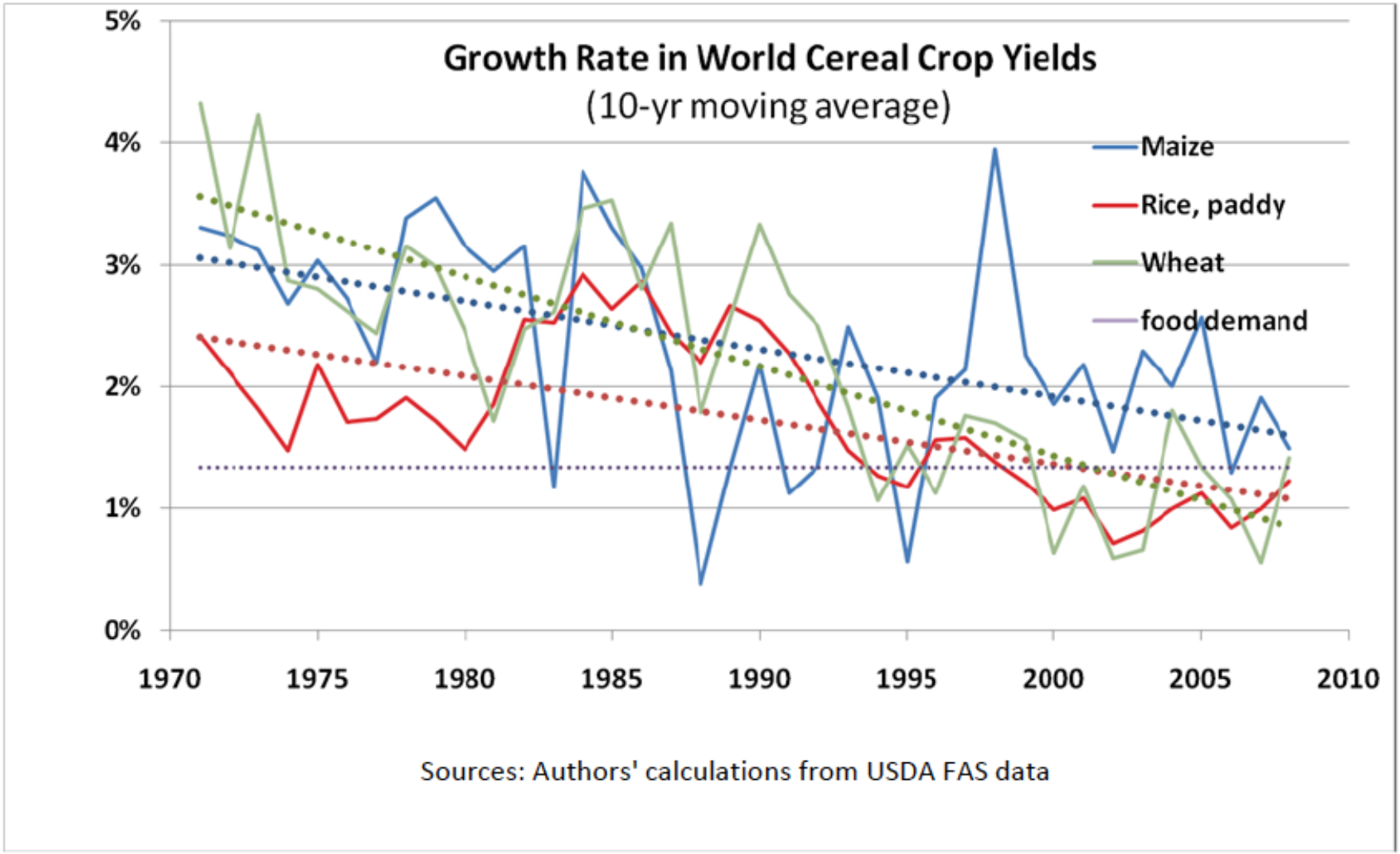
Crop Yields vs MFP - world



Sources: Authors' calculations from USDA FAS data, Fuglie (2008)

Source: Perrin and Pulginiti (2012)

Decline in growth rate of world grain yields



Source: Perrin and Pulginiti (2012)

Further issues of using TFP for sustainable food security

- Location of production is important for poverty alleviation and food security, but TFP estimates depend on national or regional data at best
- Spatial dynamics are missing
- Prevalence of pests and diseases are not part of the estimates

Data issues – FAO and World Bank data

- Land – count arable, permanently pastured and cropped area
- labour: - headcount of economically active population in agriculture
- Capital – count of tractors in use / on-farm irrigated % of acres
- Livestock – weighted headcount of buffalo, cattle, pig, sheep, and goat
- Materials – fertiliser (nitrogen, phosphate and potash and use in units of active ingredients)
- Much of data are estimated and quality of data provided by governments

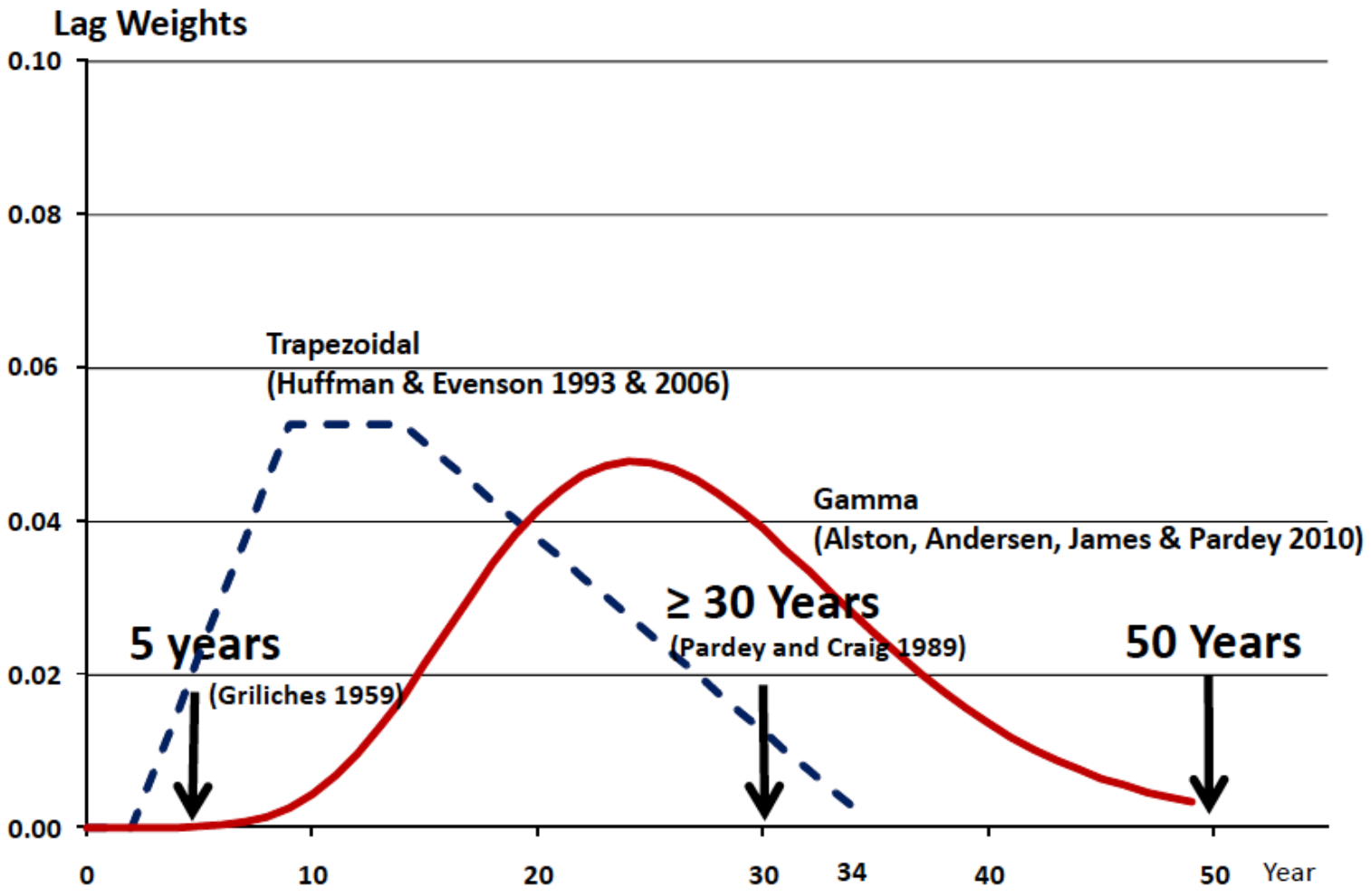
New Ideas

- Key to understanding the nexus between productivity and environmental endowments and flows
  - Weather (rainfall, sunlight, day length, wind)
  - Terrain (slope, elevation)
  - Soil (type, depth, organic and nutrient content)
  - Pests and diseases (Pardey, 2011)

Links between R&D and productivity growth

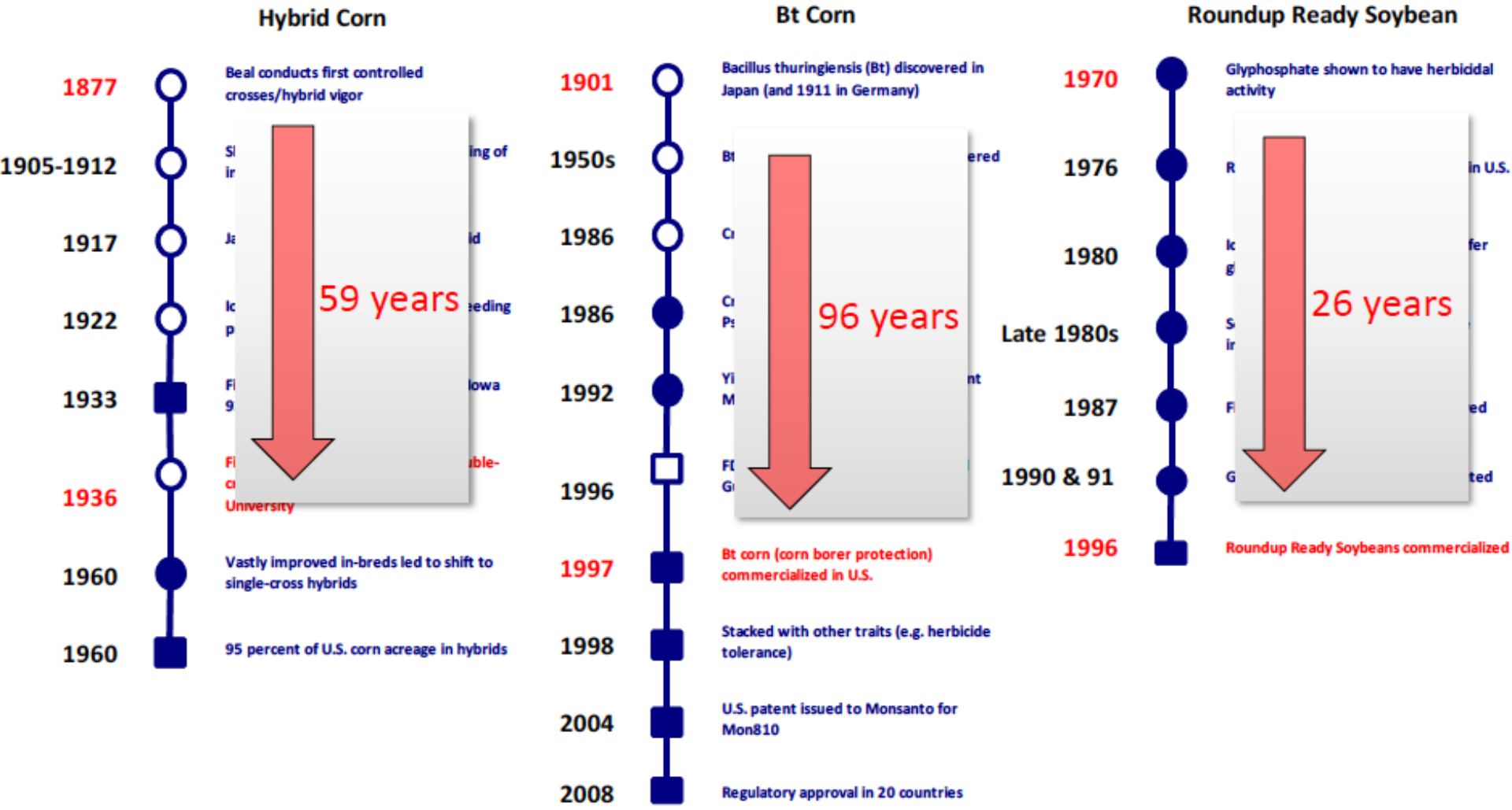
Need to introduce lag weights

Aggregate R&D Spending -Productivity Lag



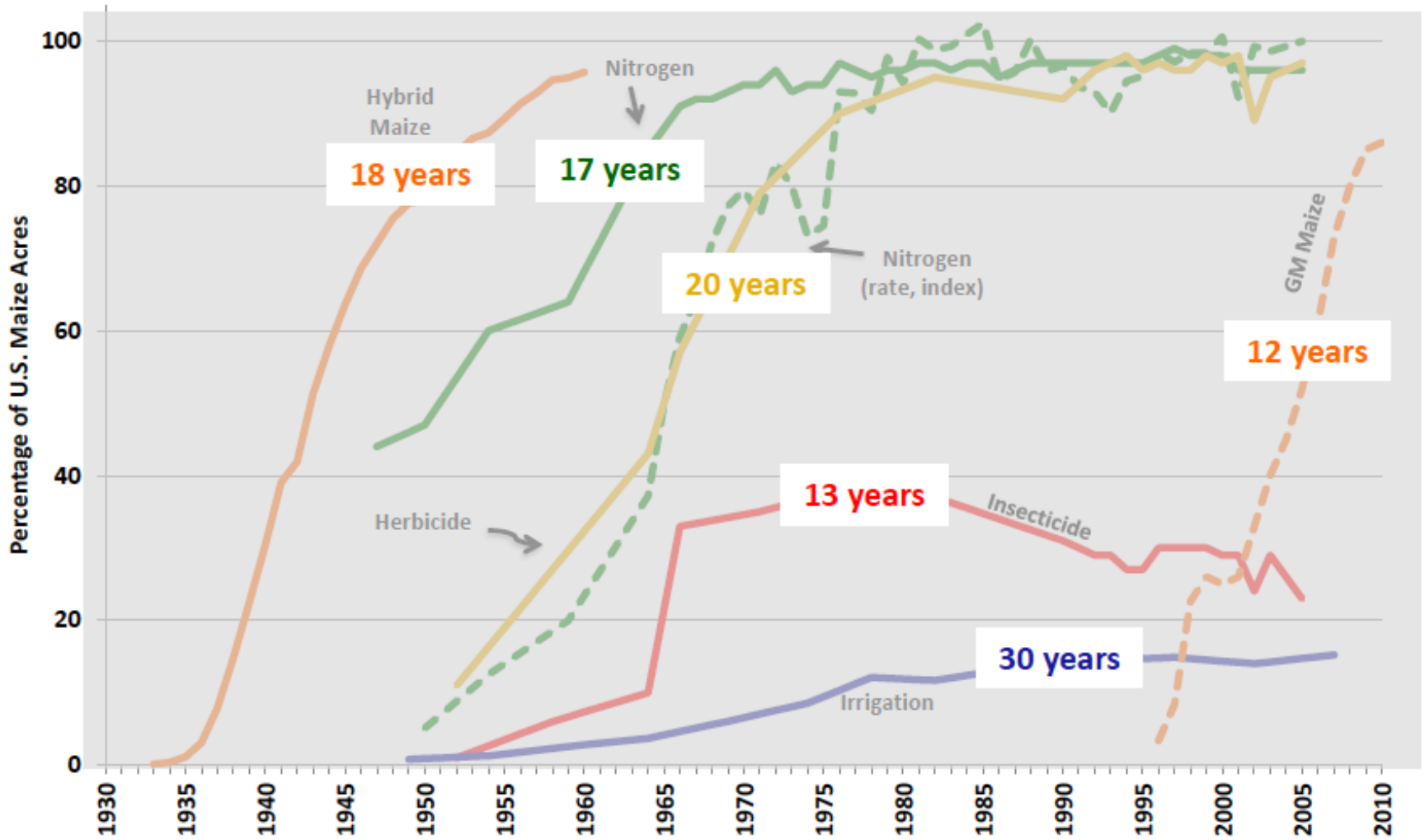
Source: Alston, Pardey and Ruttan (2008) and Alston et al. (2010)

Illustrative Technology Development Lags



Source: Alston, Pardey and Ruttan (2008) and Alston et al. (2010)

U.S. Maize Technology Adoption Lags



Source: Pardey, 2011

Incorporating externalities to TFP

- Difficulty with valuing externalities
  - Externalities are not associated with one activity, hence they are collective responsibility
- One suggestion: incorporate externalities through adding non-marketable inputs-outputs
  - Total Resource Productivity
  - Social Total factor Productivity (Gollop and Swinand, 1998; Barnes, 2002)
  - UK example of Barnes (2002): Social TFP which incorporates two "bads " pesticide and nitrogen pollution → regular TFP and environmentally adjusted TFP diverge over time.

Assessing resources stock value

- Consider resource stocks and flows (both inter-temporal and spatial changes) (Ehui and Spencer (1993)
- Assessing agricultural sustainability as a composite of agricultural nutrient balance, crop yield, soil quality, agricultural management, agri-environmental quality, agricultural bio-diversity, agricultural net energy balance. Nambiar et al. 2001 applied to China
- Assessing comprehensive wealth by incorporating everything related to cwealth (natural capital, reproducible capital, human capital etc.): Arrow, Dasgupta, Goulder, Mumford and Oleson (2010) NBER paper # 16599
- Incorporating resource quality + resource productivity measures (Byerlee and Murgai, 2001)
- Agricultural TFP using nutrients balance approach (Viet_Ngu Hoang and Tim Coelli, 2011)
- Big questions remain:
  - What weights to be used
  - Data quality

Thank you