The Economics of Biodiversity Loss

Stefano Giglio (Yale), Theresa Kuchler (NYU Stern),
Johannes Stroebel (NYU Stern), Olivier Wang (NYU Stern)

ECB Forum on Central Banking
Sintra, July 2024

Accelerating Loss in Biodiversity

- Recent species extinction rates 10-100x higher than prior (Ceballos et al, 2015, Science)
- Concern: This might affect economic activity and potentially financial stability
- Existing models of economy-nature interaction usually consider monolithic stock of natural capital

Accelerating Loss in Biodiversity

- Recent species extinction rates 10-100x higher than prior (Ceballos et al, 2015, Science)
- Concern: This might affect economic activity and potentially financial stability
- Existing models of economy-nature interaction usually consider monolithic stock of natural capital
- Goal: Framework to understand **economic implications** of biodiversity (species) loss
- Value biodiversity using a **human-centric** approach through its provision of **ecosystem services** that support economic activity:
    - **Provisioning services** (e.g., agricultural production of food, timber,…)
    - **Regulating and supporting services** (e.g., pollination, clean air, water, pest regulation, carbon sequestration, …)

This paper: Economics of Biodiversity Loss

1. **New model of the role of bio*diversity* in producing ecosystem services**
   - Based on key features documented in ecology literature
   - Key insight: Importance of complex interactions of species
   - Applications: Consider economic risks from species loss, …

2. **Two-way interactions: biodiversity ↔ economy**
   - Ecosystem services as input into production
   - Production reduces biodiversity (e.g., through land use)
   - Applications: Optimal conservation, …

3. **Empirically test model implications using asset prices**

Modeling Biodiversity

Modeling Biodiversity and Ecosystem Services

Aggregate Output $Y = F(X, E)$

E: Ecosystem Services
X: Other factors of production

Modeling Biodiversity and Ecosystem Services

Aggregate Output $Y = F(X, E)$

E: Ecosystem Services

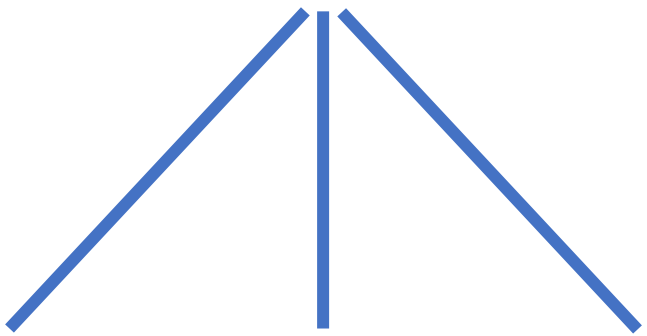
X: Other factors of production

X and E are complements

→ Decline in ecosystem services provision hard to offset by accumulation of physical capital or labor.

Modeling Biodiversity and Ecosystem Services

Aggregate Output $Y = F(X, E)$



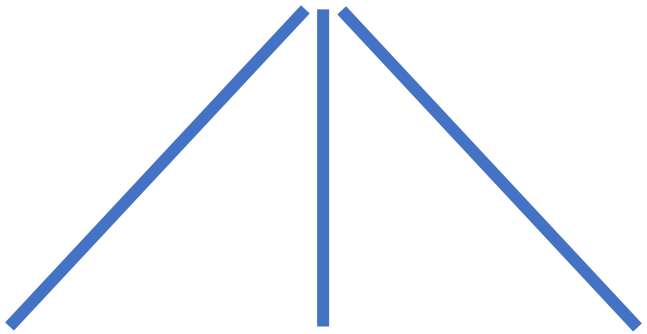
Ecosystem Functions E_1 .... E_g .... E_G

E: Ecosystem Services
X: Other factors of production
X and E are complements

Complementary ecosystem functions (e.g., pollination, nutrient recycling, …)

Modeling Biodiversity and Ecosystem Services

Aggregate Output $Y = F(X, E)$



Ecosystem Functions E_1 .... E_g .... E_G

E: Ecosystem Services

X: Other factors of production

X and E are complements

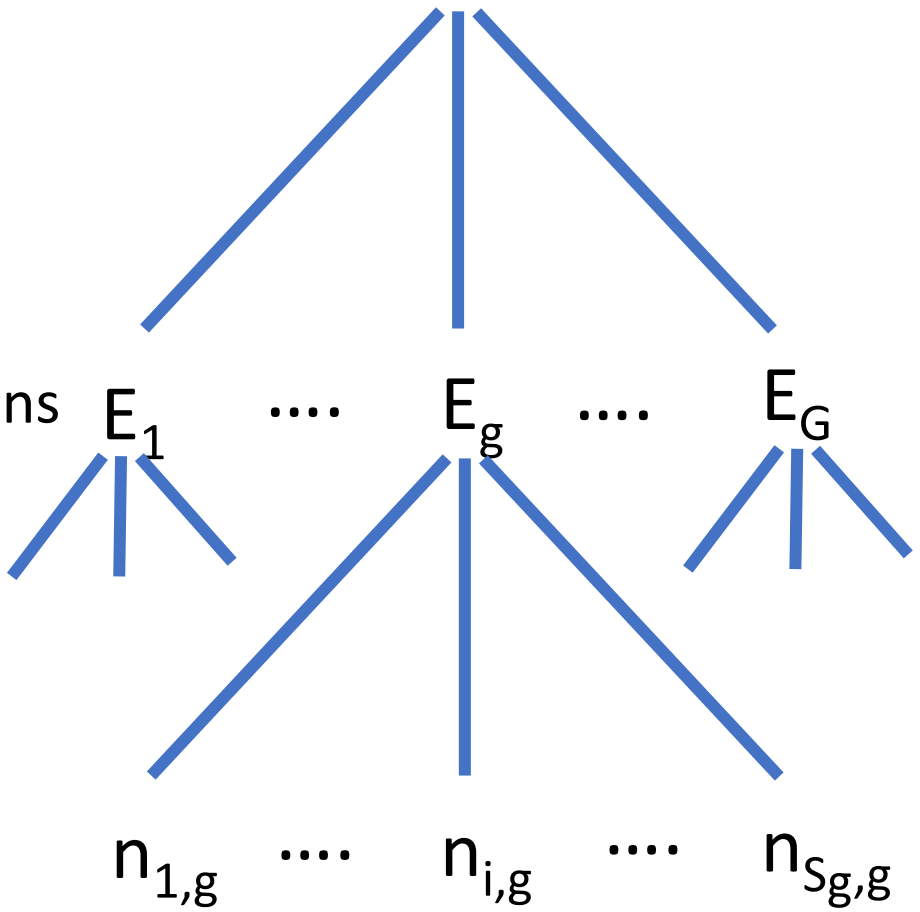
$$E = \left[\sum_{g=1}^{G} a_g E_g^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}$$

$$\sigma < 1$$

Complementarity between functions

Modeling Biodiversity and Ecosystem Services

Aggregate Output $Y = F(X, E)$



E: Ecosystem Services

X: Other factors of production

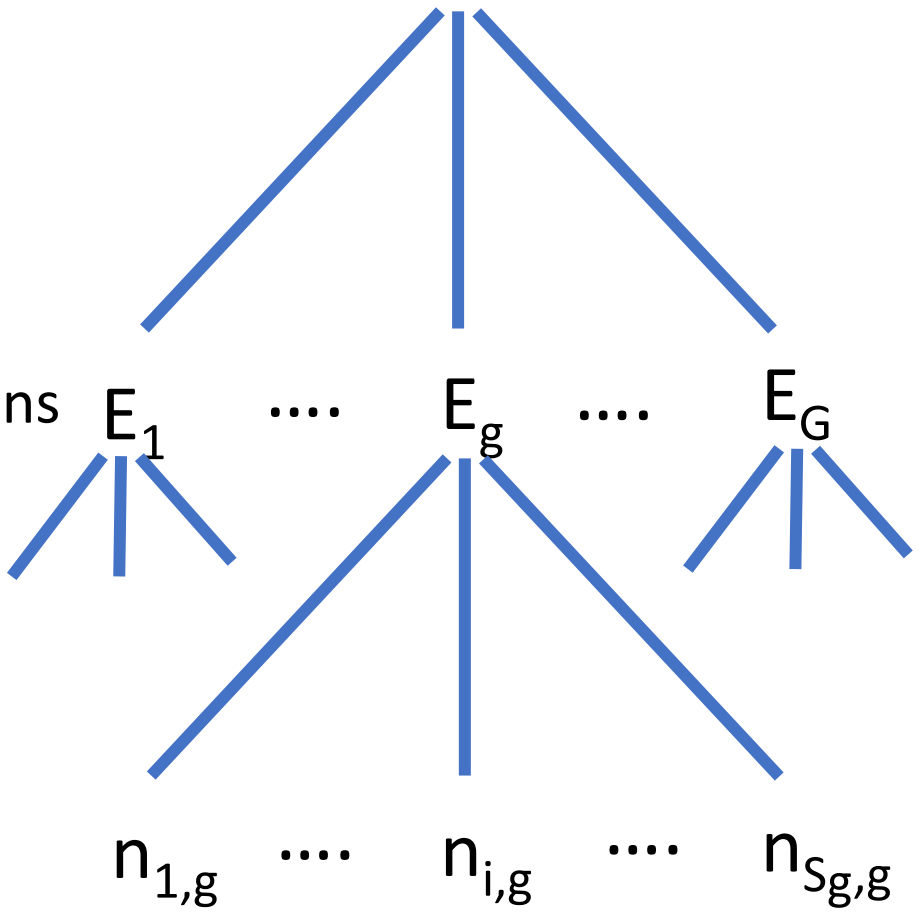
X and E are complements

$$E = \left[\sum_{g=1}^{G} a_g E_g^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$$

$$\sigma < 1$$

Modeling Biodiversity and Ecosystem Services

Aggregate Output $Y = F(X, E)$



E: Ecosystem Services
X: Other factors of production
X and E are complements

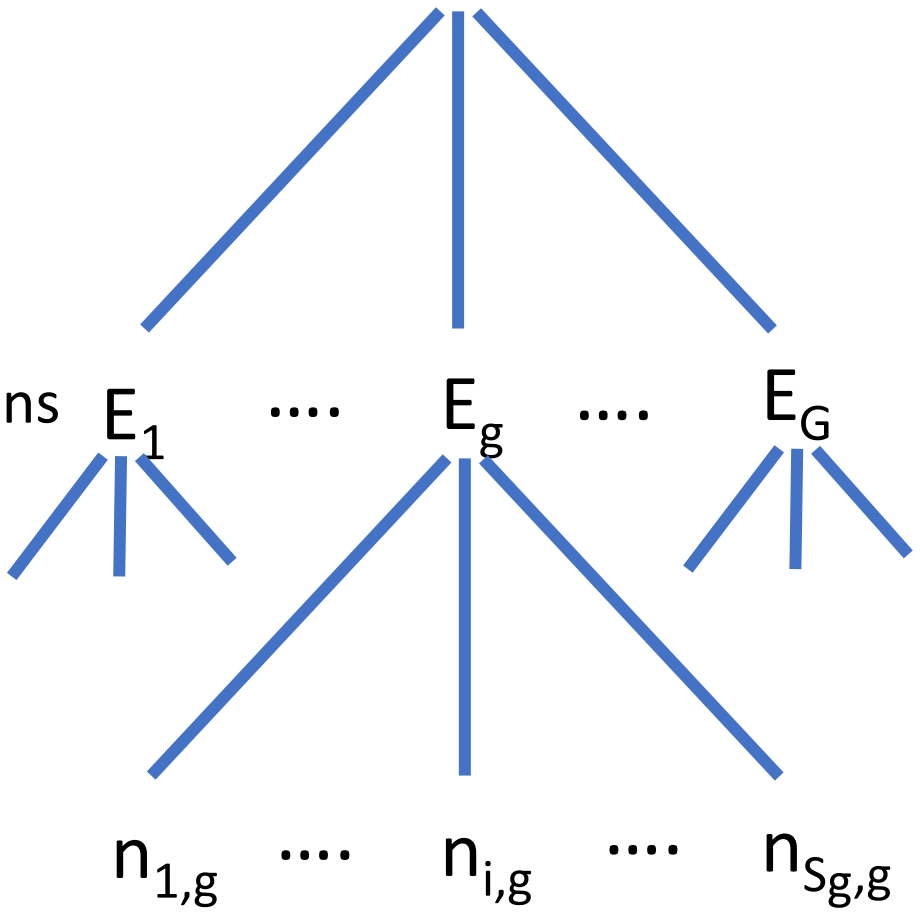
$$E = \left[\sum_{g=1}^{G} a_g E_g^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$$

$$\sigma < 1$$

Ecology literature:
Species substitutable (some redundancy) but imperfectly so (niche differentiation)

Modeling Biodiversity and Ecosystem Services

Aggregate Output $Y = F(X, E)$



E: Ecosystem Services
X: Other factors of production
X and E are complements

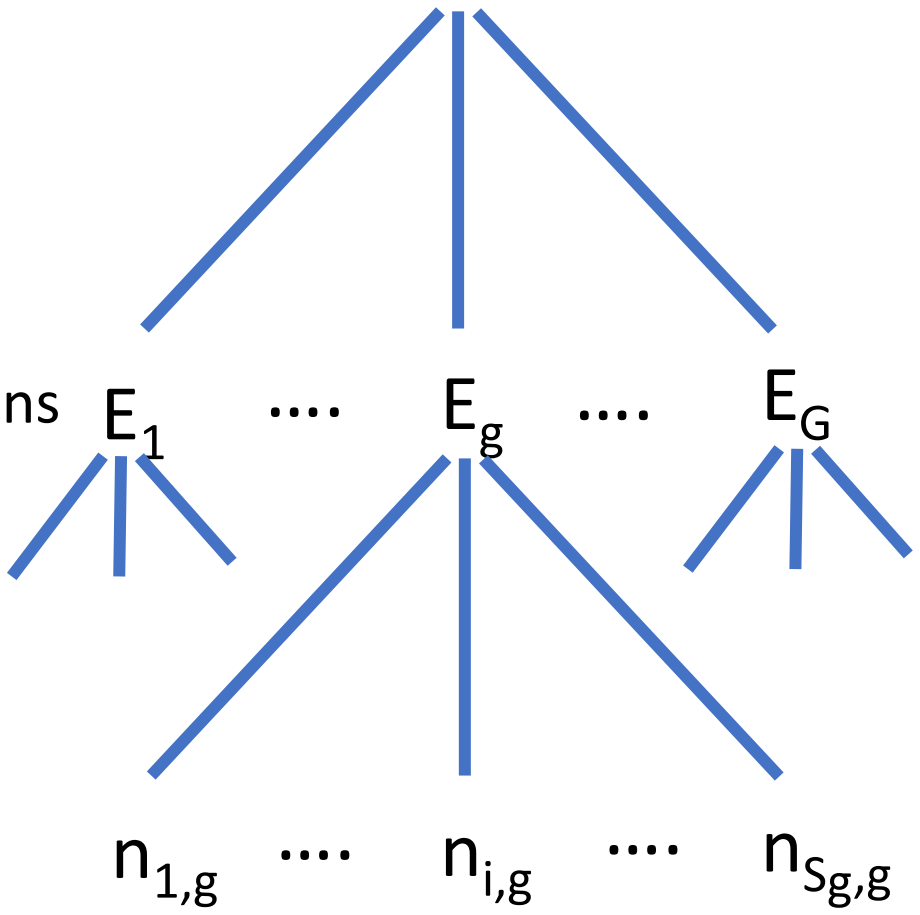
$$E = \left[\sum_{g=1}^{G} a_g E_g^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$$

$$\sigma < 1$$

Ecology literature:
Species substitutable (some redundancy) but imperfectly so (niche differentiation)
→Productivity is increasing & concave in biodiversity

Modeling Biodiversity and Ecosystem Services

Aggregate Output $Y = F(X, E)$



E: Ecosystem Services

X: Other factors of production

X and E are complements

$$E = \left[\sum_{g=1}^{G} a_g E_g^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$$

$$\sigma < 1$$

$$E_g = \left[\sum_{i=1}^{S_g} n_{i,g}^{\frac{\epsilon_g-1}{\epsilon_g}}\right]^{\frac{\epsilon_g}{\epsilon_g-1}}$$

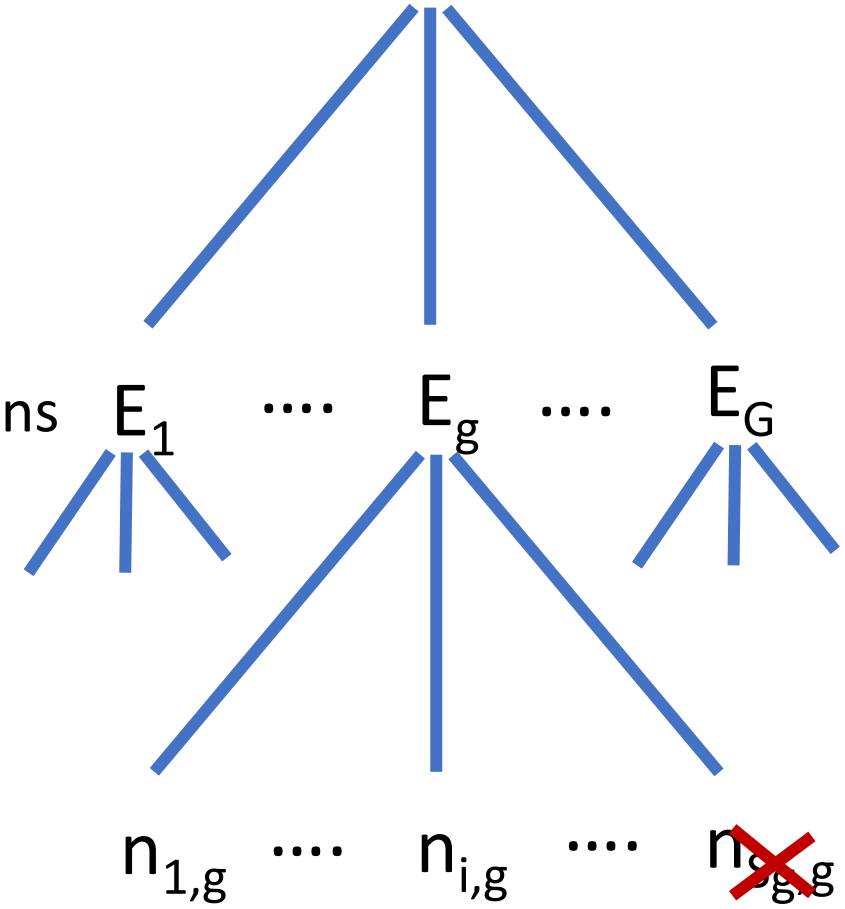
$$1 < \epsilon_g < \infty$$

Substitutability between species

Economic Effects of Biodiversity Loss

Economic Effects of Biodiversity Loss

Aggregate Output $Y = F(X, E)$

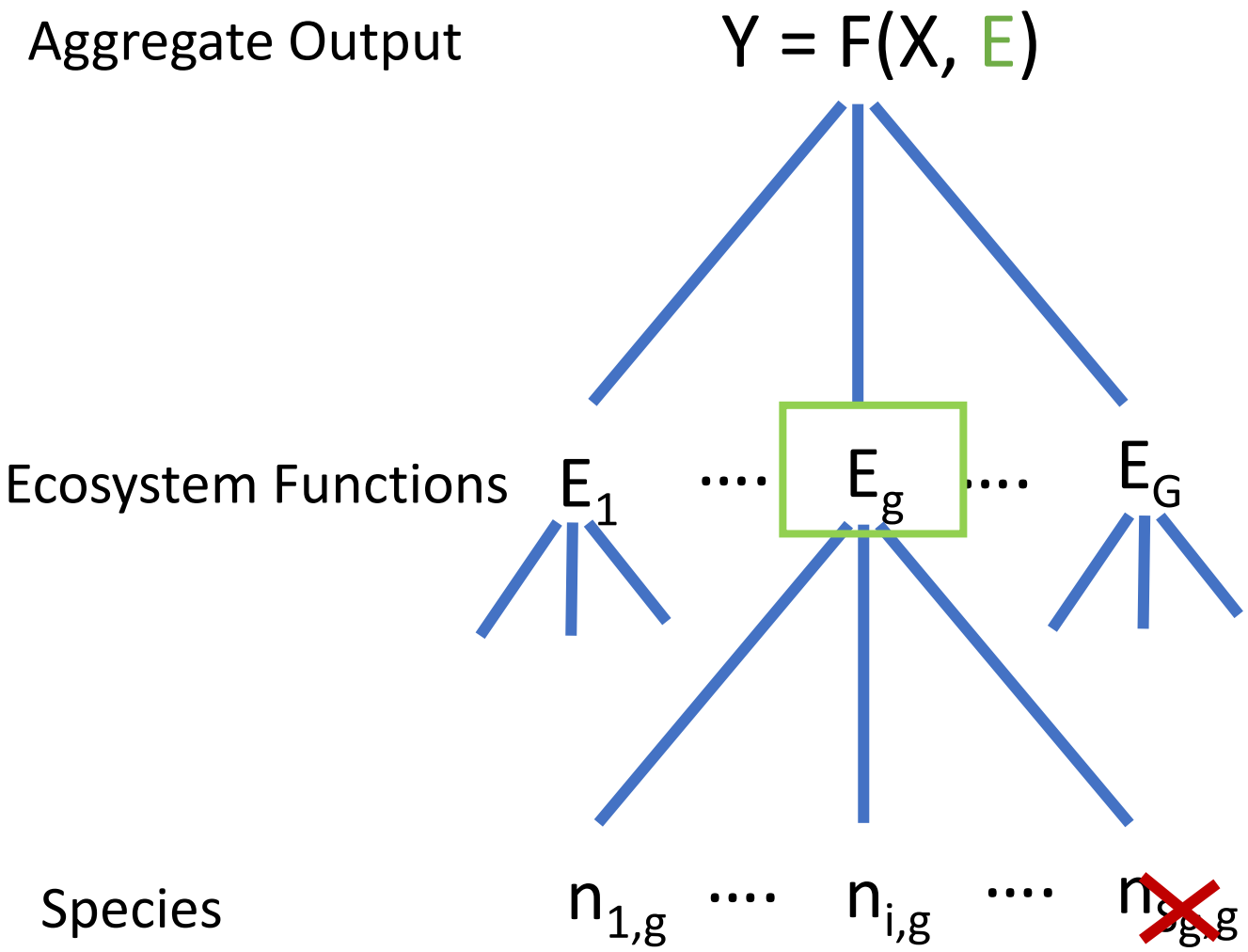


Biodiversity Loss

=

Decrease in number of species

Economic Effects of Biodiversity Loss

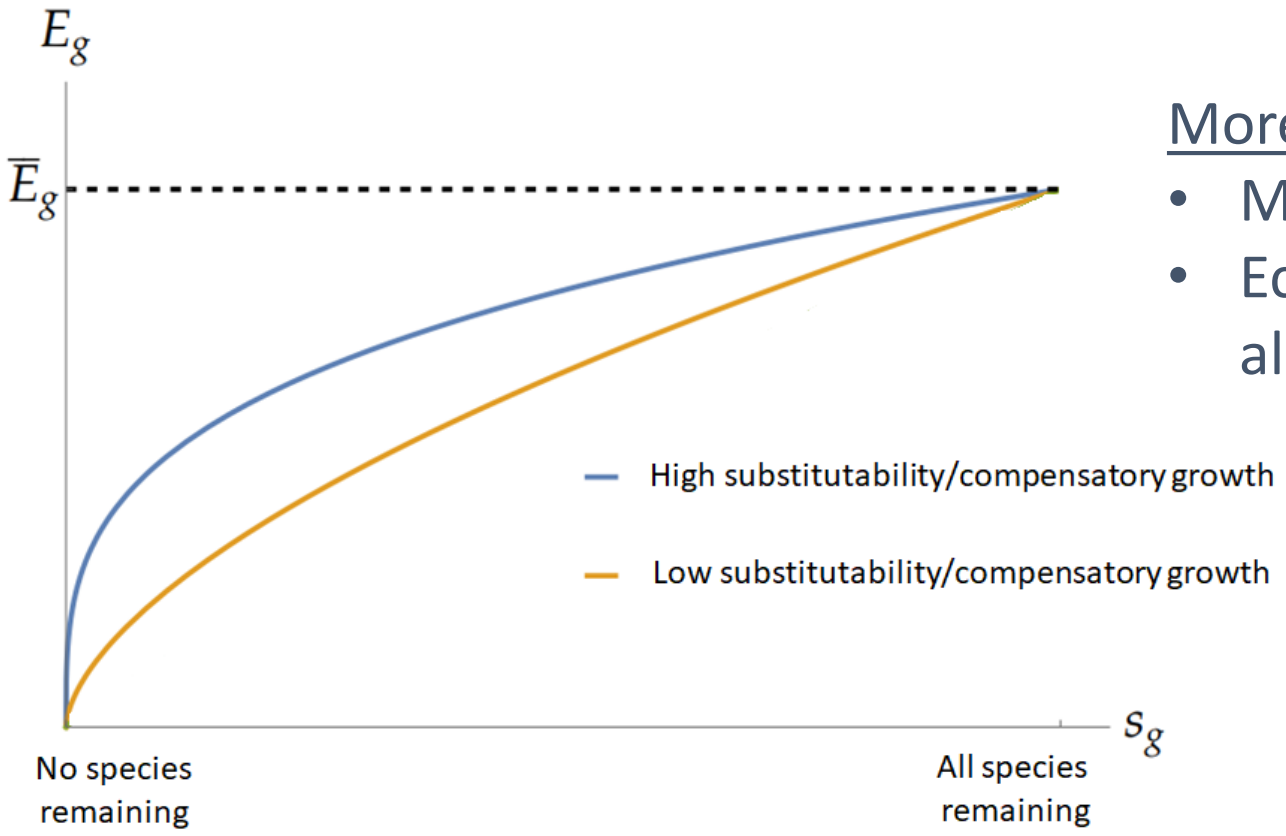


<u>Within Function</u>

Effect depends on

- Substitutability between species (ε)
- Extent of compensatory growth of other species

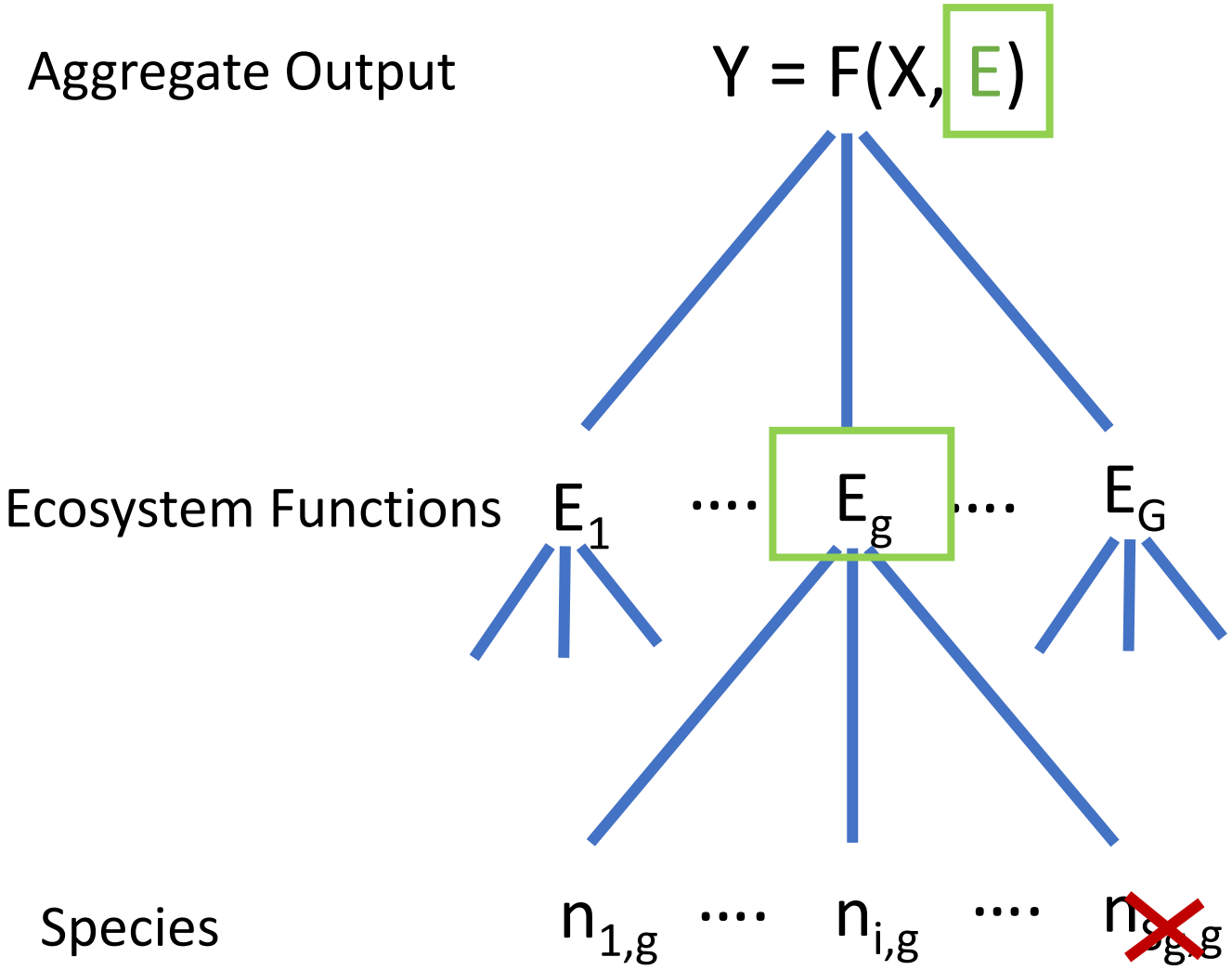
Biodiversity Loss: Effect on Functional-Level



<u>More substitutability & compensatory growth</u>

- More resilience to initial losses
- Ecosystem function productivity higher at all levels of biodiversity

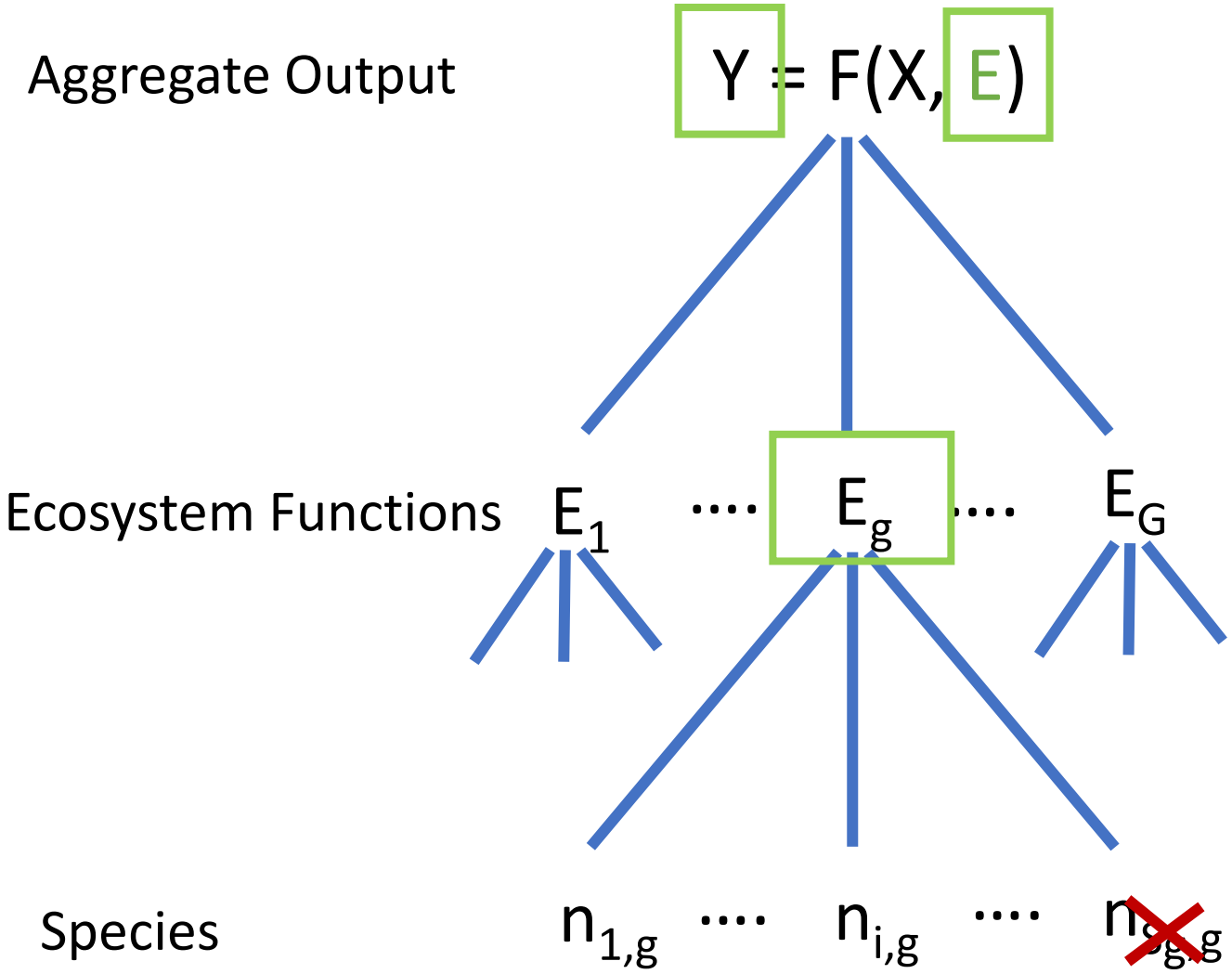
Economic Effects of Biodiversity Loss



Across Function

- Complementarity across functions amplifies within-function concavity
- Decline in functional output reduces overall ecosystem output only when function is binding

Economic Effects of Biodiversity Loss



Effect on output

- Depends on relative abundance of factors of production.
- Economic effects smaller in countries where output is currently constrained by lack of other factors.

Implications

- Initial losses of biodiversity might have only small effects on output, but each loss reduces the economy's **resilience** to future losses.
  - Small losses from past biodiversity loss do not imply small losses from future species extinction ('tipping points')
- Effects of biodiversity loss are **context-dependent**
  - Losses concentrated in a few functions or in those with little redundancy are particularly damaging
  - As species go extinct, the remaining species are more likely to become **keystone species** that don't have a functional replacement.
  - The **marginal economic value of species** differs substantially across functions, countries, and ecosystems.
    - Important for optimal targeting of conservation efforts

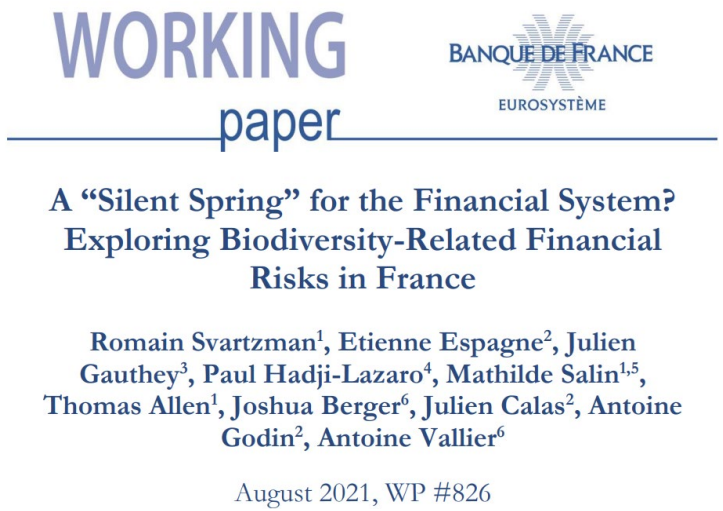
Biodiversity Risk Assessment

Risk = f(Hazard, Exposure, Vulnerability)

Biodiversity Risk Assessment

Risk = f(Hazard, Exposure, Vulnerability)

- Substantial prior progress measuring exposure (and to some extent vulnerability): *"We find that 42% of the value of securities held by French financial institutions comes from issuers that are highly or very highly dependent on one or more ecosystem services. "*


WORKING paper

BANQUE DE FRANCE
EUROSYSTÈME

A "Silent Spring" for the Financial System? Exploring Biodiversity-Related Financial Risks in France

Romain Svartzman[1], Etienne Espagne[2], Julien Gauthey[3], Paul Hadji-Lazaro[4], Mathilde Salin[1,5], Thomas Allen[1], Joshua Berger[6], Julien Calas[2], Antoine Godin[2], Antoine Vallier[6]

August 2021, WP #826


Indebted to nature

Exploring biodiversity risks for the Dutch financial sector

June 2020

DeNederlandscheBank
EUROSYSTEEM

Planbureau voor de Leefomgeving

Biodiversity Risk Assessment

Risk = f(Hazard, Exposure, Vulnerability)

Q: Likelihood of losing ecosystem service provision due to biodiversity loss?

Paper proposes a formal definition of “ecosystem fragility”

Biodiversity Risk Assessment

Risk = f(Hazard, Exposure, Vulnerability)

Q: Likelihood of losing ecosystem service provision due to biodiversity loss?

Paper proposes a formal definition of "ecosystem fragility"

$$d \log E = \underbrace{\sum_{g=1}^{G} \omega_g \frac{\alpha_g}{s_g} ds_g}_{\Delta \text{ Community abundance}} + \underbrace{\sum_{g=1}^{G} \omega_g \frac{v_g}{s_g} ds_g}_{\Delta \text{ Niche differentiation}} + \underbrace{\text{Cov}\left[\gamma_g, \frac{\phi_g}{s_g} ds_g\right]}_{\Delta \text{ Across-function imbalances}}$$

Biodiversity Risk Assessment

Risk = f(Hazard, Exposure, Vulnerability)

Q: Likelihood of losing ecosystem service provision due to biodiversity loss?

Paper proposes a formal definition of "ecosystem fragility"

$$d \log E = \underbrace{\sum_{g=1}^{G} \omega_g \frac{\alpha_g}{s_g} ds_g}_{\Delta \text{ Community abundance}} + \underbrace{\sum_{g=1}^{G} \omega_g \frac{v_g}{s_g} ds_g}_{\Delta \text{ Niche differentiation}} + \underbrace{\text{Cov}\left[\gamma_g, \frac{\phi_g}{s_g} ds_g\right]}_{\Delta \text{ Across-function imbalances}}$$

Direct loss of community abundance (e.g., biomass)

Biodiversity Risk Assessment

Risk = f(Hazard, Exposure, Vulnerability)

Q: Likelihood of losing ecosystem service provision due to biodiversity loss?

Paper proposes a formal definition of "ecosystem fragility"

$$d \log E = \underbrace{\sum_{g=1}^{G} \omega_g \frac{\alpha_g}{s_g} ds_g}_{\Delta \text{ Community abundance}} + \underbrace{\sum_{g=1}^{G} \omega_g \frac{v_g}{s_g} ds_g}_{\Delta \text{ Niche differentiation}} + \underbrace{\text{Cov}\left[\gamma_g, \frac{\phi_g}{s_g} ds_g\right]}_{\Delta \text{ Across-function imbalances}}$$

Lower functional diversity
→ Less efficient use of resources

Biodiversity Risk Assessment

Risk = f(Hazard, Exposure, Vulnerability)

Q: Likelihood of losing ecosystem service provision due to biodiversity loss?

Paper proposes a formal definition of "ecosystem fragility"

$$d \log E = \underbrace{\sum_{g=1}^{G} \omega_g \frac{\alpha_g}{s_g} ds_g}_{\Delta \text{ Community abundance}} + \underbrace{\sum_{g=1}^{G} \omega_g \frac{v_g}{s_g} ds_g}_{\Delta \text{ Niche differentiation}} + \underbrace{\text{Cov}\left[\gamma_g, \frac{\phi_g}{s_g} ds_g\right]}_{\Delta \text{ Across-function imbalances}}$$

Species loss concentrated in few functions particularly damaging

Biodiversity Risk Assessment

Risk = f(Hazard, Exposure, Vulnerability)

Q: Likelihood of losing ecosystem service provision due to biodiversity loss?

Paper proposes a formal definition of "ecosystem fragility"

Framework to guide translation of ecological findings into economic effects

Is biodiversity loss reflected in asset prices?

Asset prices reflect effects of biodiversity loss

- Model prediction: Biodiversity loss → Current & future economic output
- Empirical challenge
  - Aggregate output and changes in biodiversity are slow moving, many confounds
  - Substantial effects from lower resilience to future shocks
- Asset prices
  - Reflect market expectations about future output
  - Incorporate news upon arrival
  - Here: CDS spreads as a high frequency measure of expected economic tail risk for countries.

Asset prices reflect effects of biodiversity loss

- Do CDS spreads move upon “bad news” about biodiversity loss?
  - Giglio et al. (2023): Textual analysis of news about biodiversity loss in NYT
- How does this vary across countries with
  i. Existing level of biodiversity degradation (measured by Yale’s EPI)?
  ii. Extent to which low levels of biodiversity are constraining economic output (share of renewable natural capital in total capital in World Bank data)?

Asset prices reflect effects of biodiversity loss

- CDS spreads increase following negative biodiversity news
  - 1std increase in bad news associated with 0.157 percent increase in CDS spreads

	% Change in CDS Spread (weekly)	
Biodiversity News	0.157***	omitted
	(0.026)	
Biodiversity News * State of Biodiversity Score	-0.079***	-0.076***
	(0.025)	(0.023)
Biodiversity News * Natural Capital Share of Wealth	-0.077**	-0.072**
	(0.030)	(0.028)
Year * Tenor	x	
Week * Tenor		x
Country * Tenor * Year	x	x
N	403,047	403,047
N excluding singleton observations	402,993	402,977
Unique countries	89	
Sample period	2001-2022	

Asset prices reflect effects of biodiversity loss

- CDS spreads increase following negative biodiversity news
  - 1std increase in bad news associated with 0.157 percent increase in CDS spreads
- Consistent with model, CDS spreads are less sensitive when
  - Biodiversity less degraded
  - Higher share of natural capital (physical capital the constraining factor of production)

	% Change in CDS Spread (weekly)	
Biodiversity News	0.157***	omitted
	(0.026)	
Biodiversity News * State of Biodiversity Score	-0.079***	-0.076***
	(0.025)	(0.023)
Biodiversity News * Natural Capital Share of Wealth	-0.077**	-0.072**
	(0.030)	(0.028)
Year * Tenor	x	
Week * Tenor		x
Country * Tenor * Year	x	x
N	403,047	403,047
N excluding singleton observations	402,993	402,977
Unique countries	89	
Sample period	2001-2022	

Asset prices reflect effects of biodiversity loss

- CDS spreads increase following negative biodiversity news
  - 1std increase in bad news associated with 0.157 percent increase in CDS spreads
- Consistent with model, CDS spreads are less sensitive when
  - Biodiversity less degraded
  - Higher share of natural capital (physical capital the constraining factor of production)

→Financial markets appear to care about biodiversity risks

→Consistent with our earlier work indicating that these risks are priced in the cross-section of US equities (Giglio et al, 2023; www.biodiversityrisk.org)

Two-way interactions between biodiversity and the economy

Biodiversity and the Economy

- So far: Biodiversity → ecosystem service provision and economic output
- Paper also discusses the other direction
  - Land use increases production but degrades future biodiversity
  - Policy Choice: Optimal level of land use vs. conservation?
  - Generalizes classic analysis of optimal extraction of exhaustible resource

Biodiversity and the Economy

- So far: Biodiversity → ecosystem service provision and economic output
- Paper also discusses the other direction
  - Land use increases production but degrades future biodiversity
  - Policy Choice: Optimal level of land use vs. conservation?
  - Generalizes classic analysis of optimal extraction of exhaustible resource

- Biodiversity losses today makes ecosystems more fragile in future
  - Incentive for early conservation
- Dynamics can be complex (non-linear, state- and context-dependent)
  - Non-trivial to implement optimal conservation
  - Substantial uncertainties introduce precautionary motives

Biodiversity and the economy

- Capital-rich economies
  - Ecosystem services more likely to be constraining factor of production
  - Higher incentives for preservation today

- Capital-poor economies
  - Nature comparably more abundant → Incentive to use land for production now, partially compensating for lack of other capital
  - Degradation of biodiversity destroys opportunities for future development
  - Myopic decision makers overexploit ecosystems

    → Welfare improvements from regulating / incentivizing conservation

Conclusion

- **Economics of Biodiversity Loss**
  - Model role of biodiversity in producing ecosystem services
  - Two-way interaction between biodiversity and economy
  - Empirical evidence that asset markets incorporate biodiversity risks
- **Conceptual framework** for range of policy applications
- Starting point for collaboration with ecologists to **measure** relevant objects.