

Efficiency through evolution

Comparing Darwinian and Comprehensive
approaches in Agent-Based
economic forecast modeling

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This presentation describes a Darwinian Agent-Based Modeling methodology, applied to Macroeconomics, but which can be applied to other assemblage optimization problems.

It is based on the use of the Darwinian concept of survival of firms best adapted to their neighborhood of interaction, in a decentralized market.

The key point is that, instead of the complex and sophisticated behavioral rules derived from market analysis of large firms, agents are modeled to follow a few simple “common sense” rules, more representative of most small firms, which directly serve the final consumers, who are here assumed to be the driving force of the dynamic system.

And what we present here are some preliminary results of this exploration, still under development, and compare some with standard approaches.

Agents in Action: Decisions and Interactions

Worker (Household)

- Has unique ID and location (limited interaction neighborhood).
- Income:
 - Salaries, Transfers, owned firms' surplus.
- Activities (within personal interaction neighborhood):
 - Consumption: Purchases goods/services.
 - Trade shares/bonds.
 - Use banks.
 - Entrepreneurship: Can start new firms.

Firm

- Has unique ID and location (limited interaction neighborhood).
- Production:
 - Decide quantity, based on current stock levels and demand evolution.
 - Purchase inputs, hire/dismiss employees.
 - Produce, update Production_price.
- Finance: loans, dividends, issue shares (if big enough).

Agents in Action: Decisions and Interactions

Bank / Central Bank

Financial intermediation:

- Deposits
- Loans

Central Bank:

- Sets rates
- Manages reserves.

Government

Fiscal:

- Collects taxes
- Provides transfers

Spending, consumes:

- Goods
- Services

Debt:

- Issues bonds

External Sector firms

They are interface firms. They can trade with domestic firms and other countries' external sector firms.

- Trade: Handle imports and exports.
- Transfers: Remittances with households.

Agents in Action: Decisions and Interactions

Behavioral Rules

The aim of this project is to explore what can be achieved using only **a few**, supposedly **dominant**, mechanisms of the economic system, based on “common sense” behavioral rules:

- **Price setting:** after every trade attempt, both buyer and seller increment/decrement their price estimation by a small, calibrated Price_Adapt_Factor. If successful, the seller increases (and the buyer lowers) the price, and the reverse if the attempt failed.
- **Households' expenditure:** proportional (to be calibrated) to the household's wealth, constrained by liquidity.
- **Households' firm-startup decision:** country-idiosyncratic probability, to be calibrated for each country to fit Firms_Birth per year or N_Total_Firms.
- **Firms' supply (stock) level:** proportional (> 1.0) to last month demand.

Agents in Action: Decisions and Interactions

Behavioral Rules

Some reasons for starting from these simple rules as **dominant mechanisms** are:

1. These simulations mainly try to reproduce the daily activity of final consumers, as the driving force of the economic system.
2. Final consumers usually interact directly with small firms.
3. Small firms do not conduct elaborate market analyses.
4. Large firms interact with small firms and not directly with households. The final selling price of a can of Coca-Cola is not set by the company, but by its local vendors, and may even differ from each other. The market price, and the volume traded, for each sector will emerge from the results of the monthly activity (simulation).

A real economic system can be described by a Social Accounting Matrix

like this simple one (**six sectors**) for Spain in 2008

Firms are created following the pattern of each sector: when a firm from the AgroPesc sector sells 48021€ pays 4259€ as wages.

	P01_AgroPesc	P02_EnerPetro	P03_Indust	P04_Construc	P05_ServVenta	N06_ServNoVenta	F07_GFCF
P01_AgroPesc	1701	1	24972	24	2877	302	811
P02_EnerPetro	1119	41384	19205	2678	21061	6438	292
P03_Indust	8616	5037	209653	64805	76816	21507	65355
P04_Construc	190	793	1909	108372	25997	3654	176136
P05_ServVenta	3682	10762	94805	31726	244738	49376	54460
N06_ServNoVenta	0	0	0	0	0	0	0
F07_GFCF	0	0	0	0	0	0	0
X08_SectExt	8742	35259	238669	804	60405	1085	0
L09_CompEmployees	4259	4220	62958	50681	200109	88364	0
K10_GrossOpSurplus	19803	17740	48917	46113	321169	14029	0
T11_SSoc	624	1543	19007	15518	53763	26223	0
T12_TaxProduction	-244	120	-137	204	1118	53	0
T13_TaxProducts	-471	307	-1062	1555	12274	4100	21578
T14_IRPF	0	0	0	0	0	0	0
G15_Government	0	0	0	0	0	0	0
H16_Households	0	0	0	0	0	0	0
colSUM	48021	117166	718896	322480	1020327	215131	318632

Intermediate consumption

Value added

Gross output

Wages

Dividends

Action begins with idiosyncratic demand of Final Consumers.

Firms act in response to demand. Survival of the fittest.

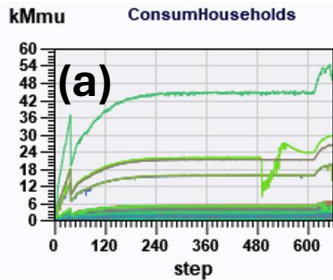
Final consumers



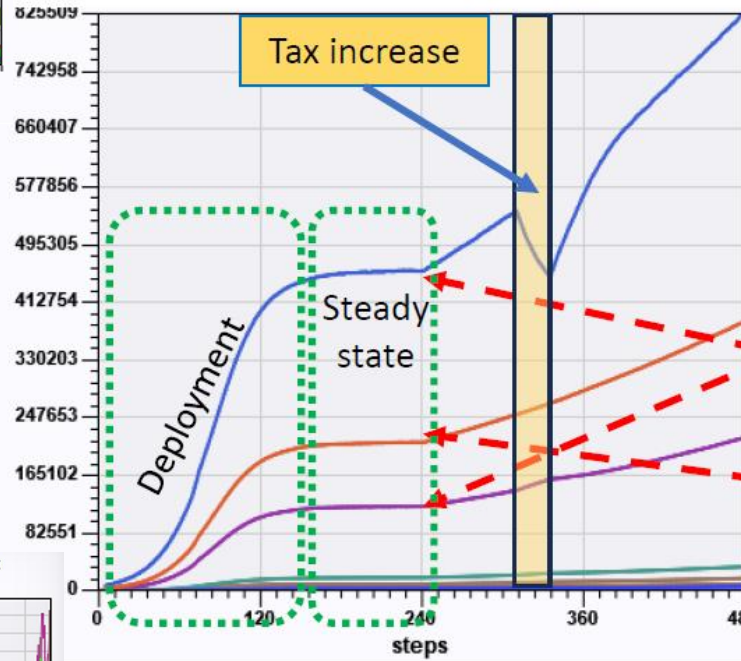
X08_SectExt	L09_CompEmplo	K10_GrossOpSur	T11_SSoc	T12_TaxProduction	T13_TaxProducts	T14_IRPF	G15_Government	H16_Households
7834	0	0	0	0	0	0	0	9499
6740	0	0	0	0	0	0	0	18249
144645	0	0	0	0	0	0	7620	114842
144	0	0	0	0	0	0	0	5285
70689	0	0	0	0	0	0	21238	438851
0	0	0	0	0	0	0	211972	3159
103916	0	0	0	0	0	0	12014	202702
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	20074
0	0	0	0	0	0	0	0	0
-92	0	0	0	0	0	0	401	53758
0	0	0	0	0	0	0	0	117483
0	0	0	136752	1114	92348	117483	0	0
11088	410591	467771	0	0	0	0	94452	0
344964	410591	467771	136752	1114	92348	117483	347697	983902

The economic system deployment starts without firms

The stabilization stage ends when the economic system reaches a **steady state** with the desired level of activity (output, unemployment...)



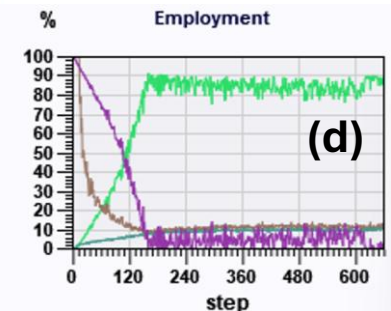
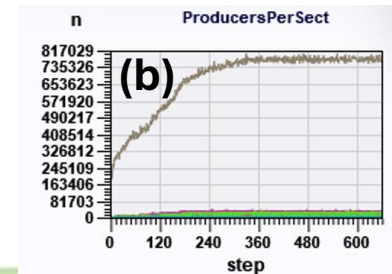
Household consumpt. by sector



Deployment example

SAM

H16_Households	
9499	
18249	
114842	
5285	
438851	
3159	
202702	

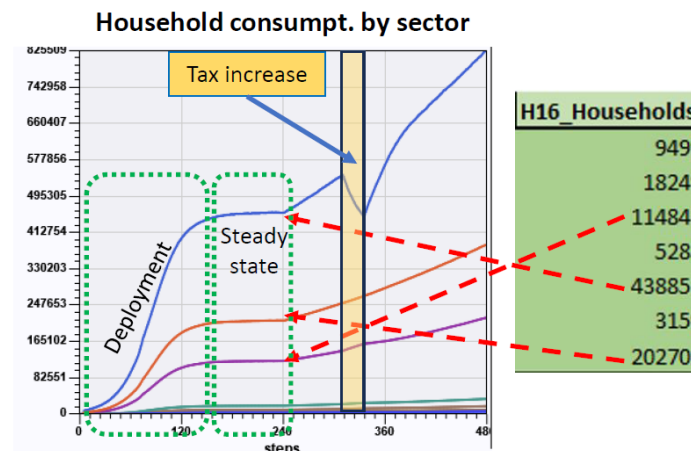


There are two results data categories: calibrated and emergent

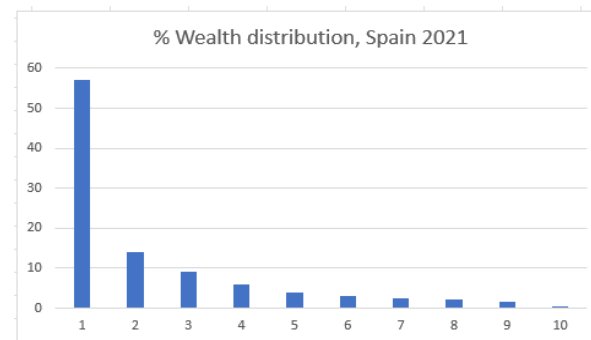
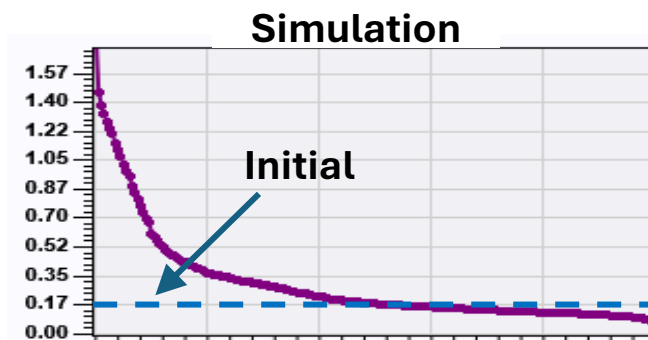
Example:

- **We calibrate** k to achieve a good fit to the households **Consumption SAM** values:

$$C_{h,t}^* = I_{h,t}^{Mean} + \kappa \cdot (W_{h,t} - \Phi \cdot I_{h,t}^{Mean})$$



- **We observe** the evolutionary **emergence** of a non-predefined **Wealth Distribution**



Households

```

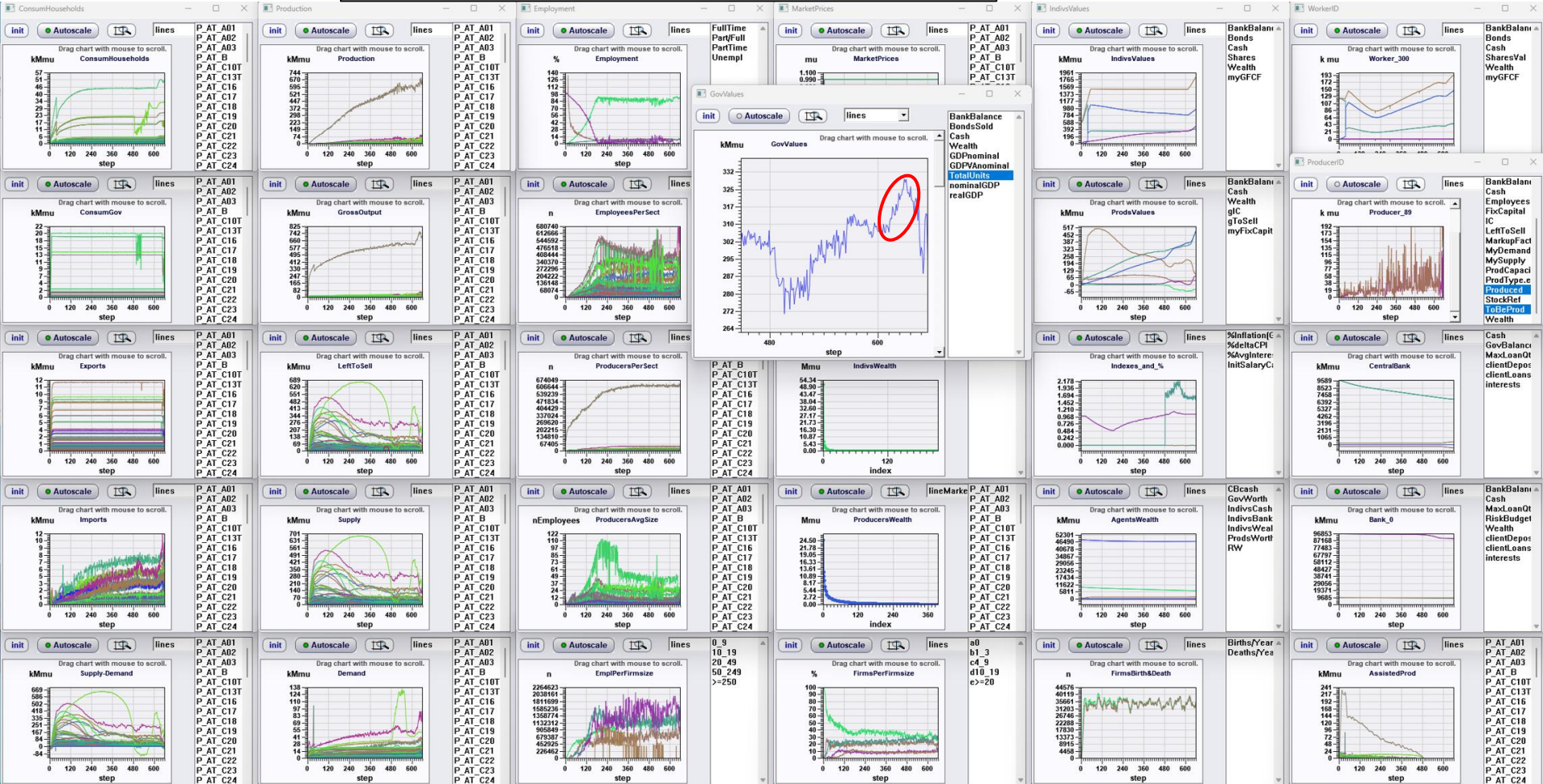
1 A01 Products of agriculture, hunting and related services
2 A02 Products of forestry, logging and related services
3 A03 Fish and other fishing products; aquaculture products; support services to fishing
4 B MINING AND QUARRYING
5 C10T12 Food products, Beverages, Tobacco products
6 C13T15 Textiles, Wearing apparel, Leather and related products
7 C16 Wood and of products of wood and cork, except furniture
8 C17 Paper and paper products
9 C18 Printing and recording services
10 C19 Coke and refined petroleum products
11 C20 Chemicals and chemical products
12 C21 Basic pharmaceutical products
13 C22 Rubber and plastics products
14 C23 Other non-metallic mineral products
15 C24 Basic metals
16 C25 Fabricated metal products, except machinery and equipment
17 C26 Computer, electronic and optical products
18 C27 Electrical equipment
19 C28 Machinery and equipment n.e.c.
20 C29 Motor vehicles, trailers and semi-trailers
21 C30 Other transport equipment
22 C31_32 Furniture, Other manufactured goods
23 C33 Repair and installation services of machinery and equipment
24 D35 Electricity, gas, steam and air conditioning
25 E36 Natural water; water treatment and supply services
26 E37T39 Sewerage services; sewage sludge, Waste collection, treatment, Remediation services
27 F CONSTRUCTIONS AND CONSTRUCTION WORKS
28 G45 Wholesale and retail trade and repair services of motor vehicles
29 G46 Wholesale trade services, except of motor vehicles
30 G47 Retail trade services, except of motor vehicles
31 H49 Land transport services and transport services via pipelines
32 H50 Water transport services
33 H51 Air transport services
34 H52 Warehousing and support services for transportation
35 H53 Postal and courier services
36 I ACCOMMODATION AND FOOD SERVICES
37 J58 Publishing services
38 J59_60 Motion picture, video and television programme production, Programming and broadcasting
39 J61 Telecommunications services
40 J62_63 Computer programming and consultancy services, Information services
41 K64 Financial services, except insurance and pension funding
42 K65 Insurance and pension funding, except compulsory social security
43 K66 Services auxiliary to financial services and insurance services
44 L REAL ESTATE SERVICES
45 M69_70 Legal and accounting services, Services of head offices management
46 M71 Architectural and engineering services
47 M72 Scientific research and development services
48 M73 Advertising and market research services
49 M74_75 Other professional, scientific and technical services, Veterinary services
50 N77 Rental and leasing services
51 N78 Employment services
52 N79 Travel agency, tour operator and other reservation services
53 N80T82 Security and investigation, Servs to buildings, landscape, office and business
54 O84 Public administration and defence services; compulsory social security services
55 P85 Education services
56 Q86 Human health services
57 Q87_88 Residential care services, Social work services without accommodation
58 R90T92 Arts and entertainment, Museum and cultural, Gambling and betting services
59 R93 Sporting services and amusement and recreation services
60 S94 Services furnished by membership organisations
61 S95 Repair services of computers and personal and household goods
62 S96 Other personal services
63 T SERVICES OF HOUSEHOLDS AS EMPLOYERS; GOODS AND SERVICES PRODUCED BY HOUSEHOLDS FOR OWN USE
64 U SERVICES PROVIDED BY EXTRATERRITORIAL ORGANISATIONS AND BODIES

```

Next: 1 country simulation with **64 CPA sectors**,
FIGARO I-O tables of 46 countries

code	Country (iso-2)
01) BE	Belgium
02) BG	Bulgaria
03) CZ	Czechia
04) DK	Denmark
05) DE	Germany
06) EE	Estonia
07) IE	Ireland
08) GR	Greece
09) ES	Spain
10) FR	France
11) HR	Croatia
12) IT	Italy
13) CY	Cyprus
14) LV	Latvia
15) LT	Lithuania
16) LU	Luxembourg
17) HU	Hungary
18) MT	Malta
19) NL	Netherlands
20) AT	Austria
21) PL	Poland
22) PT	Portugal
23) RO	Romania
24) SI	Slovenia
25) SK	Slovakia
26) FI	Finland
27) SE	Sweden
28) GB	United Kingdom
29) NO	Norway
30) CH	Switzerland
31) TR	Turkey
32) US	United States of America
33) CA	Canada
34) MX	Mexico
35) AR	Argentina
36) BR	Brazil
37) RU	Russian Federation
38) IN	India
39) CN	China
40) ZA	South Africa
41) JP	Japan
42) KR	Korea, Republic of
43) ID	Indonesia
44) AU	Australia
45) SA	Saudi Arabia
46) RoW	Rest of the World

Next: Analysis of emergent macroeconomic properties
(Simulation screen snapshot)



Input data needed

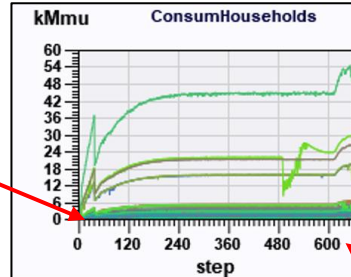
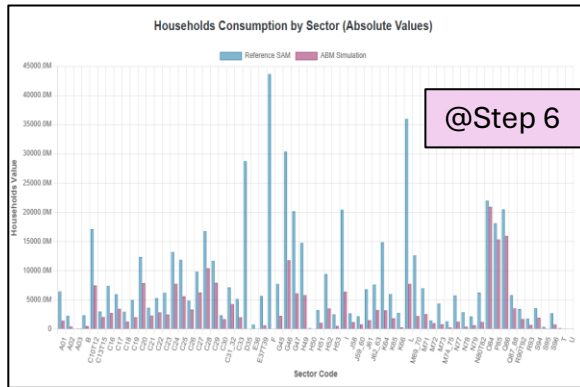
for the Deployers simulation analysis shown next

- Desired simulation size: 3200 workers (10 workers per million, per sector)
- **FIGARO I-O table:** download “*matrix_eu-ic-io_ind-by-ind_24ed_2010.csv*”

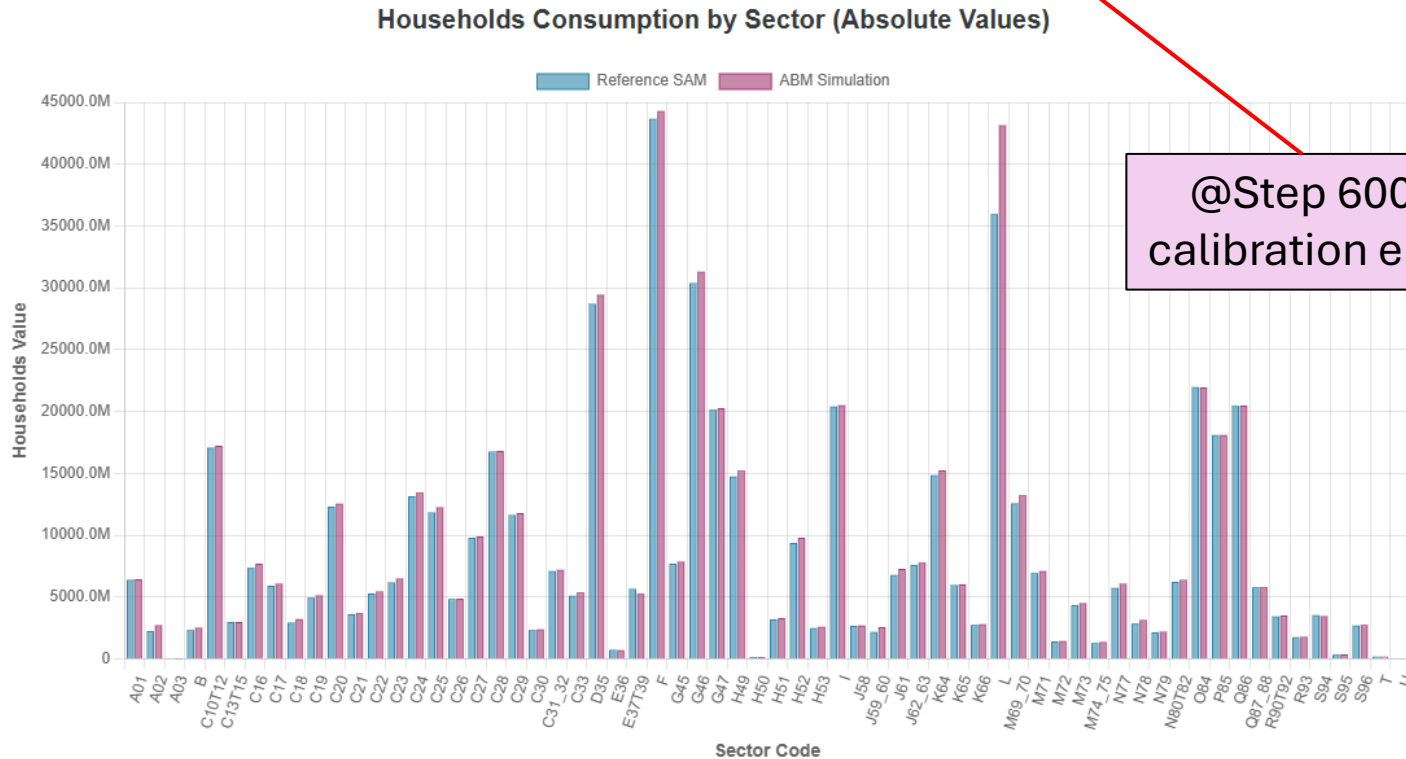
----- Complementary **country-specific data** (AUSTRIA 2010): -----

- Active_Population: 5.0e6
- Unemployment: 4.4%
- Households_Wealth_Target: 1.5e12 €
- Propensity_To_Consume: 0.55
- Firms_Birth_Per_Year: 36000 (or total NFirms)
- Producer_Startup_Probabilty (calibrated to fit Firms_Birth or NFirms): 0.007
- rc and other banking model parameters

The deployed economic system **reproduces** the desired SAM values (calibration)



Reference SAM (Actual Values) Deployers, step 600

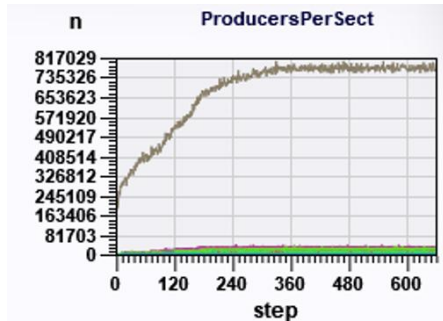


Results **emerging** from FIGARO I-O + basic **data** and **behavioral** rules

■ Data from Poledna et al. 2023, for 2010Q4

■ Deployers, @step 600. Started without firms and no pre-defined final number.

Distribution of **Firms** Across Sectors (%)

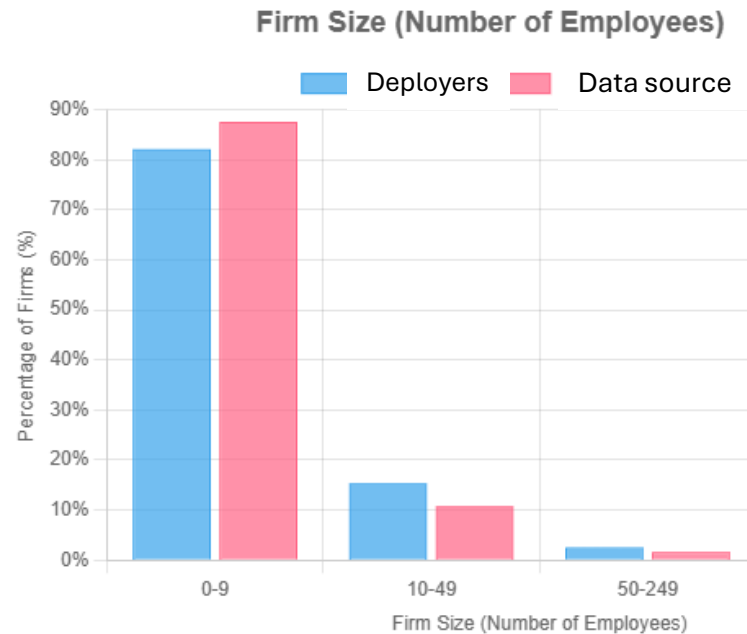


@Step 600
calibration end



Results **emerging** from **FIGARO I-O + basic data and behavioral rules**

Distribution by Number of Firms (%)



Data source: European Commission (Statista, 2022). Approximate data from 2018.

Firm distribution:

Micro firms (0-9 employees): 87.6%

Small firms (10-49 employees): 10.8%

Medium firms (50-249 employees): 1.6%

Large firms (250+ employees): 0.3%

Employee distribution:

Micro firms (0-9 employees): ~36.6%

Small firms (10-49 employees): ~35.2%

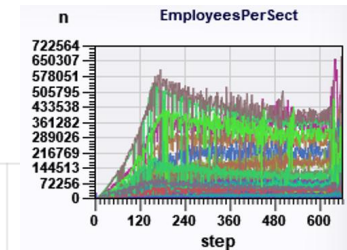
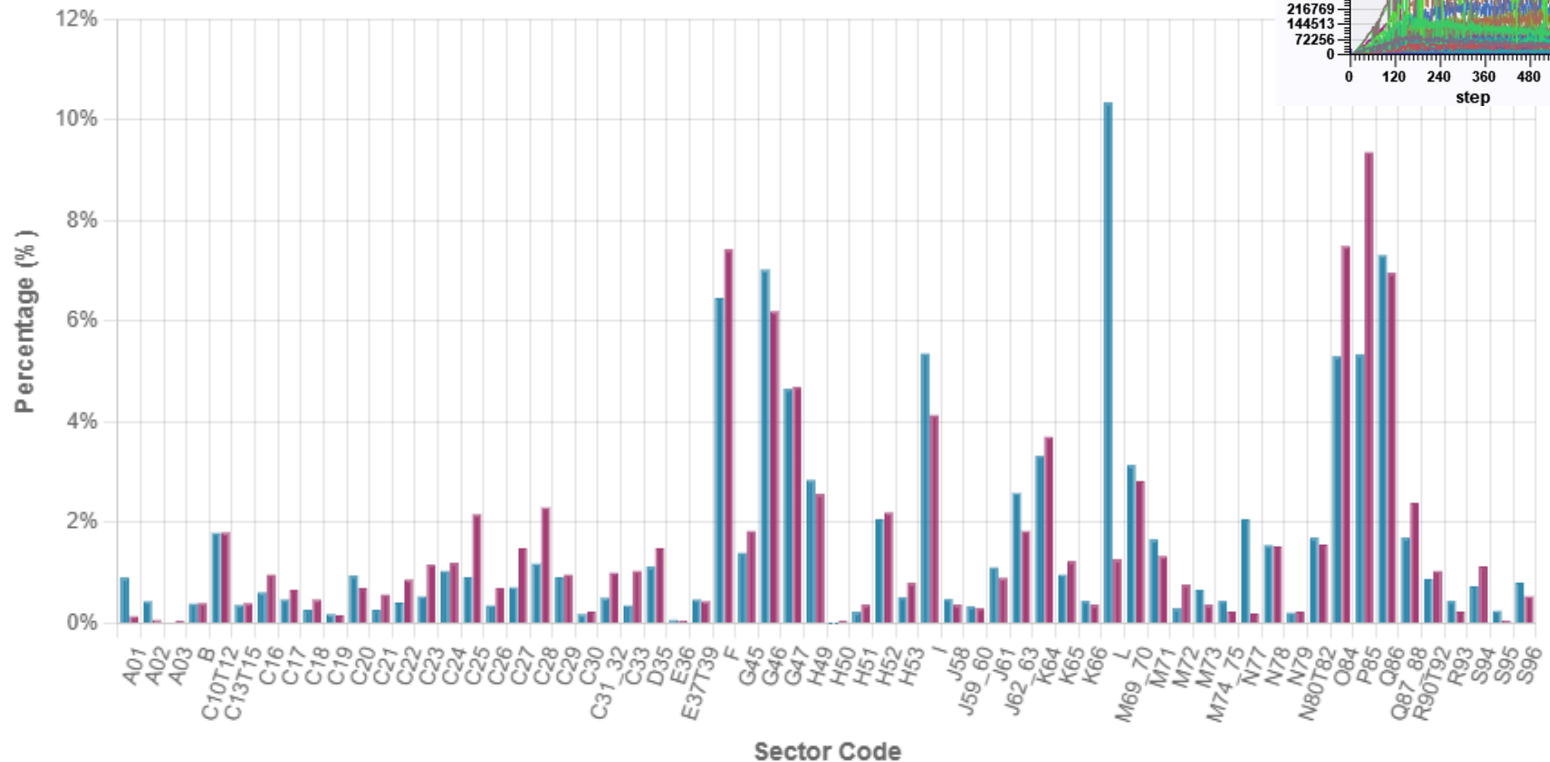
Medium firms (50-249 employees): ~28.2%

Results **emerging** from FIGARO I-O + basic **data** and **behavioral** rules

■ Data from Poledna et al. 2023, for 2010Q4

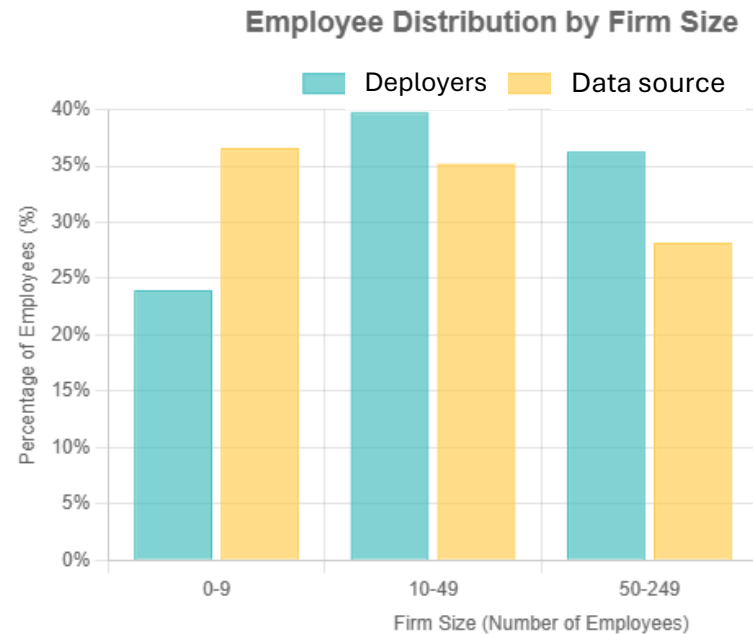
■ Deployers, @step 600. Started without firms and no pre-defined final number.

Distribution of **Employees** Across Sectors (%)



Results **emerging** from **FIGARO I-O + basic data and behavioral rules**

Distribution by Number of Employees (%)



Data source: European Commission (Statista, 2022). Approximate data from 2018.

Firm distribution:

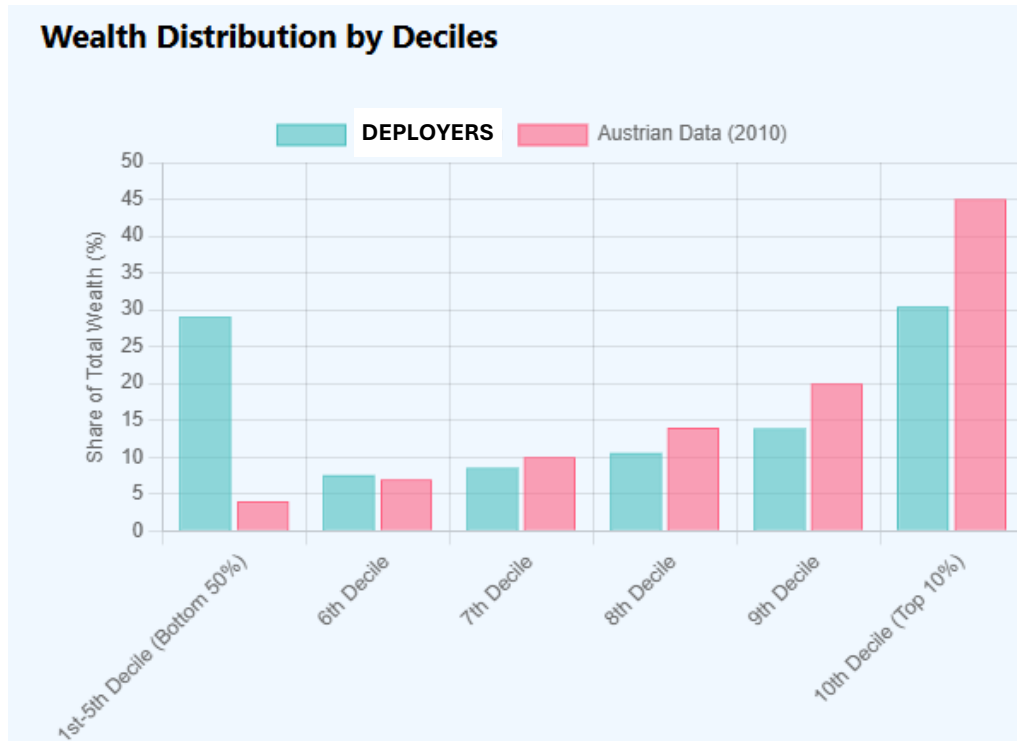
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Results **emerging** from FIGARO I-O + basic data and behavioral rules

Wealth Distribution by Deciles



Summary Metrics

Gini Coefficient

0.3295

Shannon Entropy

2.4214

Total Agents

320

Mean Wealth

312096.84

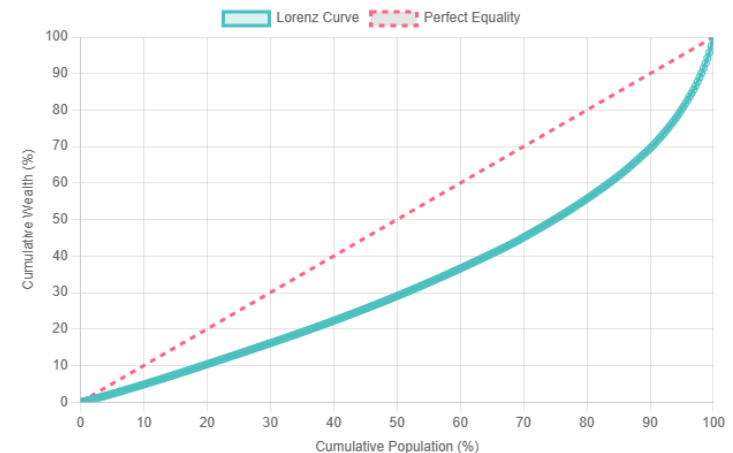
Median Wealth

222636.00

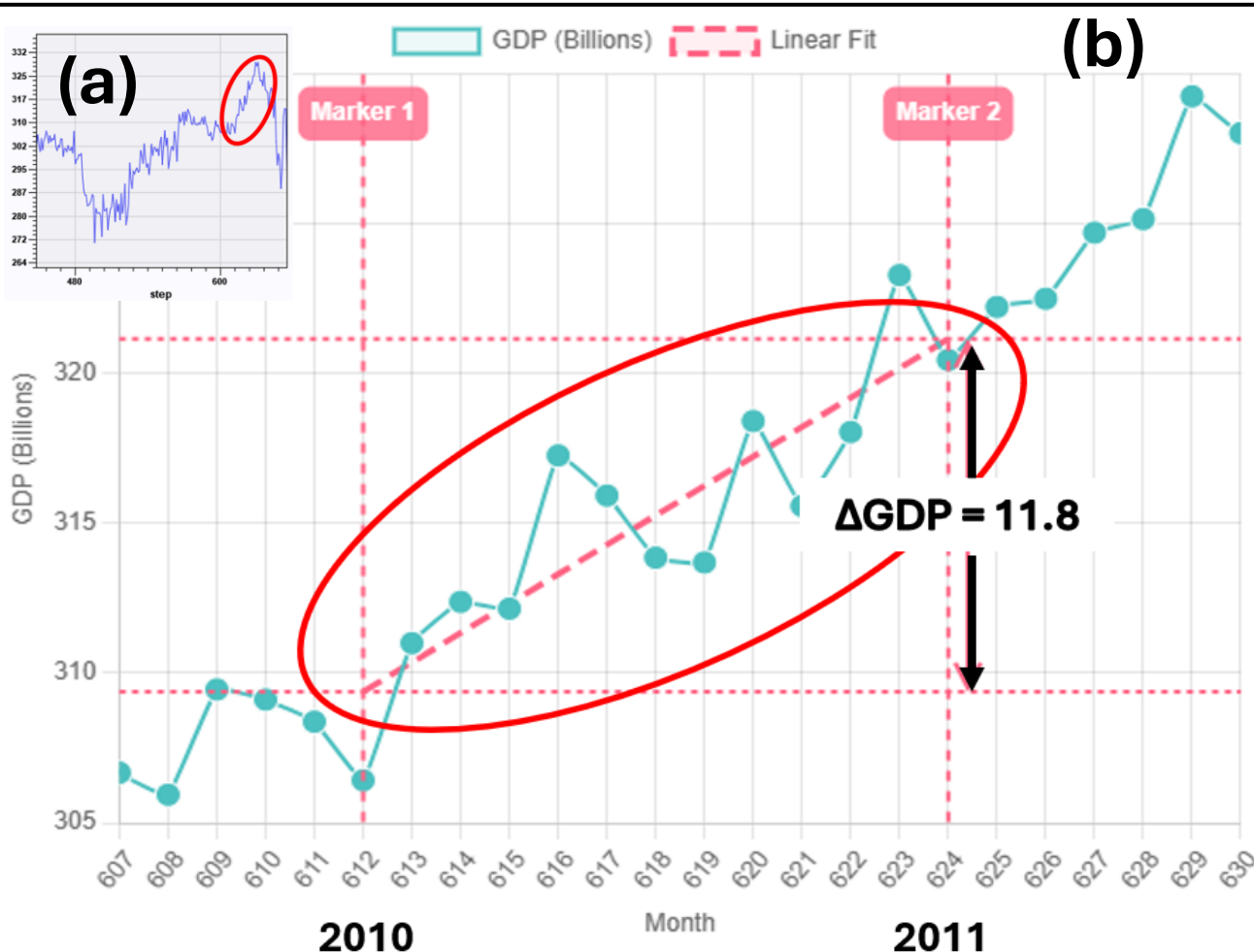
Top 10% Share

30.44%

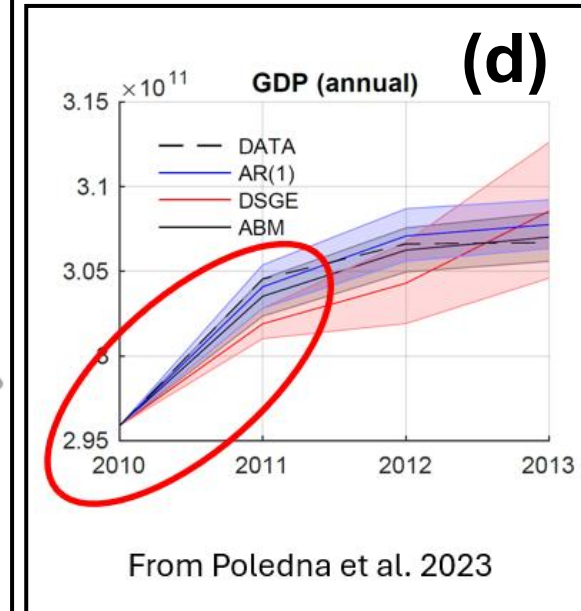
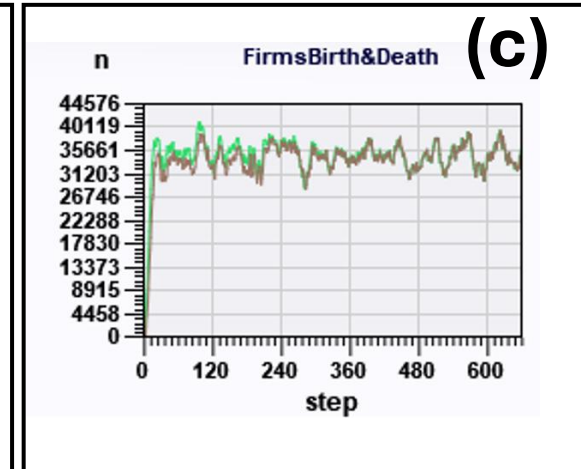
Lorenz Curve



Results **emerging** from FIGARO I-O + basic data and behavioral rules



Note: preliminary results (constant price).
DEPLOYERS is still under development.



From Poledna et al. 2023

Performance

Deployers simulation shown:

Simulated workers: 3200

Simulated firms $\approx$ 400

- Deployers.exe run **on a Windows laptop**
- Single core, CPU times:
 - Calibration (600 steps=months): **90 minutes**
 - Experiment run (12 steps = 1 year): **2 minutes**

The Darwinian Agent-Based Modeling approach

1. **Emergent Realism:** Simple behavioral rules + simulation of market activity in everyday life suffice to generate realistic economic patterns without complex prior specifications.
2. **Leveraging data:** The emergence of these realistic patterns is made possible by the wealth of information about the economic system conveyed by the I-O tables, used as constraints for the fitness of firms and agents' behaviors.
3. **Policy robustness:** The models capture creative and decentralized market adaptations, providing more reliable insights than fixed behavioral frameworks.
4. **Discovery capability:** Evolutionary dynamics reveal unexpected phenomena beyond modelers' assumptions, crucial for crises and transitions.
5. **Calibration parsimony:** Natural selection reproduces empirical regularities without large parameter adjustments or risks of overfitting.
6. **Computational efficiency:** The problem of the high complexity of ABM model parameters is solved without the need for sophisticated optimization algorithms. This approach drastically reduces the computing resources required, moving from clusters of supercomputers to ordinary laptops.

WHAT'S NEXT?

Because of its Agent-Based foundations, other layers from extended databases, like **ecology**, **social networks** or **epidemiology**, that can interact with economics, could be added in the future.

The image shows a screenshot of the SEEA Ecosystem Accounting website. The URL is <https://seea.un.org/ecosystem-accounting>. The page features the United Nations logo and the title "SYSTEM OF ENVIRONMENTAL ECONOMIC ACCOUNTING". A navigation menu includes links to Home, About SEEA, Methodology, Tools and Learning, Data, Knowledge Base, Applications, Meetings, Projects, and News. Below the menu, the page is titled "Ecosystem Accounting" and displays a photograph of a forest landscape. To the right of the photograph is a diagram illustrating the spatial relationship between ecosystem assets and services. The diagram shows a landscape with a forest (1), soil depth (2), water filtration (3), clean water (4), and people (5). Arrows indicate the flow of services from the forest to the people.

Home » Methodology » Ecosystem Accounting

Ecosystem Accounting

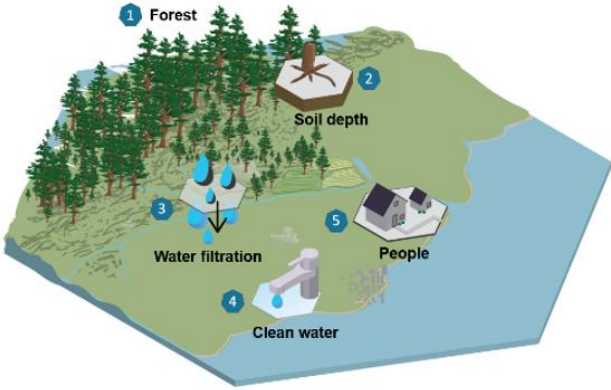


Figure 2: How ecosystem assets generate ecosystem services to beneficiaries in a spatial relationship

The SEEA Ecosystem Accounting (SEEA EA) constitutes an integrated and comprehensive statistical framework for organizing data about habitats and landscapes, measuring the ecosystem services, tracking changes in ecosystem assets, and linking this information to economic and other human activity.

SEEA Ecosystem Accounting

The Future of Economic Modeling

Combining the empirical rigor of Input-Output analysis with the dynamic richness of Darwinian Agent-Based Modeling, starting from dominant mechanisms, provides a powerful new technology for modeling and understanding economic systems in all their complexity. And accessible on standard laptops!

Thanks for your attention

