CONSEQUENTIAL MODELLING

- IN LIFE CYCLE INVENTORY ANALYSIS

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Overview of videos

1) Attributional and consequential responsibility
2) ISO 14040/44: A standard for consequential LCA
3) How to fully reflect both physical and monetary causalities in LCA
4) Temporal issues in LCA
5) Learning from non-intuitive results
6) *The comparability algorithm*: Defining the functional unit
7) *The linking algorithm*: Composing a consumption mix
8) Identifying determining products
9) *The co-product algorithm*
10) Errors in background databases

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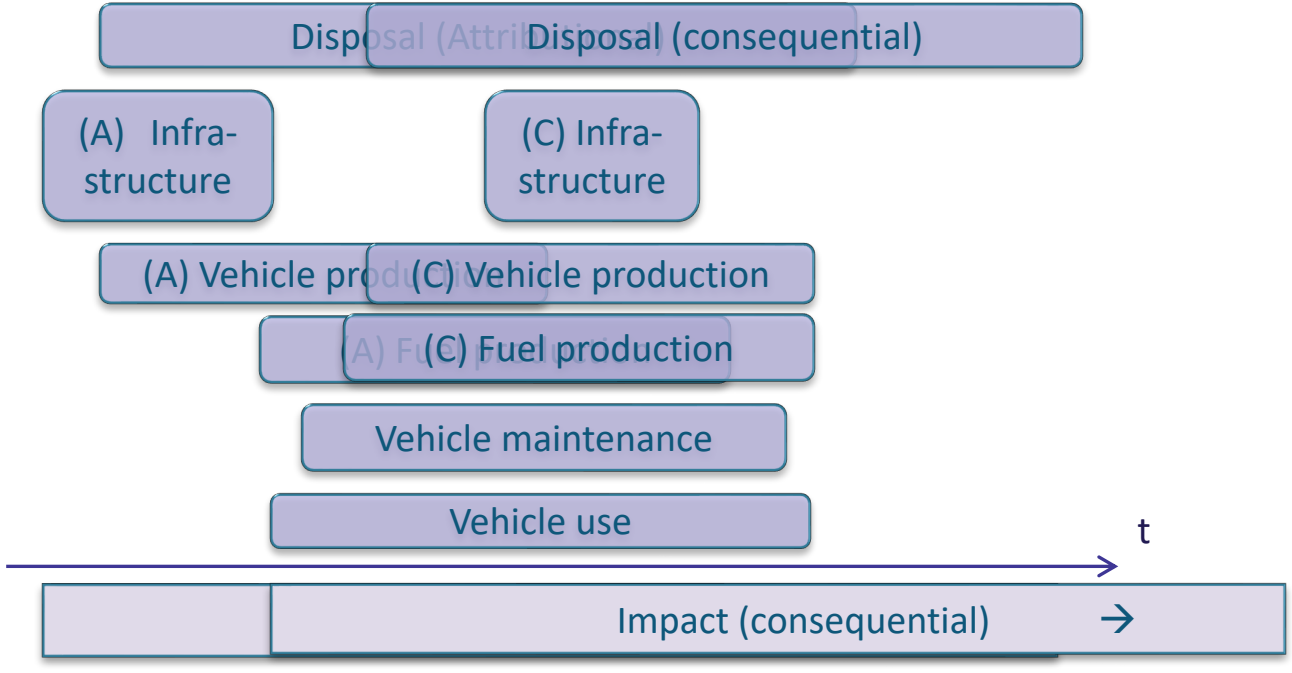
Some typical temporal errors in life cycle inventory

- Including the history of the product instead of the consequences of continued production and consumption
  - except when the consequences (impacts) are related to the product history (product *content* or *the location it comes from)*
- Placing processes at wrong places in time
- Looking at short-term changes and forgetting the long-term

Time horizon:
Consequences always go forwards in time



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Time horizon:
Affected technologies in the short and long term

- **Short-term:** Changes in capacity utilization only
  - Example: Hourly changes in peak or baseload impacts per kWh of current electricity consumption
  - Example: Increase in demand for an annual crop leads to consumption changes
- **Long-term:** Capacity changes
  - Example: Impacts per kWh from the technology of the next power plant being built to satisfy the accumulated changes in peak or baseload demand
  - Example: Demand for an annual crop leads to increased production next season
- Long-term consequences last longer and dominate the overall impacts of a decision

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Indirect Land Use Change (ILUC) in consequential modelling

- ILUC is treated just like any other infrastructure input:
  - What the capacity of a steel factory is to steel production ➤
  - the biomass production capacity of land is to agriculture
- ILUC is simply the required supply of biomass production capacity (measured in productivity-weighted area-time)
- Historical changes are irrelevant (as in amortisation of past land use change) because changes happens forwards in time
- Instead, we model the changes induced by the current annual demand for productive land
- Different markets for land can be distinguished: arable, forest, rangeland
- Increasing trend on the global market for arable land is met by both intensification of land already in use (40%), mainly by increasing fertiliser use, and transformation of land (60%) ➤

Proportion between expansion & intensification when occupying arable land:

Year	Production (Mn t DM)	Area (Mn ha)	Yield (t DS / ha yr)
1997	2,991	1,188	2.52
1998	3,015	1,181	2.55
1999	3,057	1,182	2.59
2000	3,054	1,183	2.58
2001	3,116	1,186	2.63
2002	3,093	1,179	2.62
2003	3,186	1,208	2.64
2004	3,401	1,229	2.77
2005	3,419	1,251	2.73
2006	3,446	1,243	2.77
2007	3,614	1,262	2.86
2008	3,836	1,289	2.98
2009	3,802	1,278	2.98
2010	3,851	1,290	2.98
2011	4,038	1,304	3.10

Year	Crop from ΔY (Mn t DM)	Crop from ΔA (Mn t DM)	Total Δcrop (Mn t DM)
1996 to 1997	42.8	4.0	46.9
1997 to 1998	39.6	-15.9	23.7
1998 to 1999	40.1	2.0	42.1
1999 to 2000	-5.9	3.2	-2.7
2000 to 2001	55.8	6.2	62.1
2001 to 2002	-5.4	-17.8	-23.2
2002 to 2003	18.3	75.7	94.0
2003 to 2004	157.6	60.2	217.8
2004 to 2005	-42.5	59.5	17.1
2005 to 2006	49.7	-23.0	26.8
2006 to 2007	115.3	53.8	169.1
2007 to 2008	144.2	81.7	225.9
2008 to 2009	0.1	-34.3	-34.2
2009 to 2010	10.2	38.3	48.4
2010 to 2011	146.5	42.9	189.3
1961 to 2009	**1956**	**650**	**2606**
	75%	**25%**	**100%**
2000 to 2010	**503**	**300**	**804**
	63%	**37%**	**100%**

FAOSTAT (2013)
DM% all crops: various references

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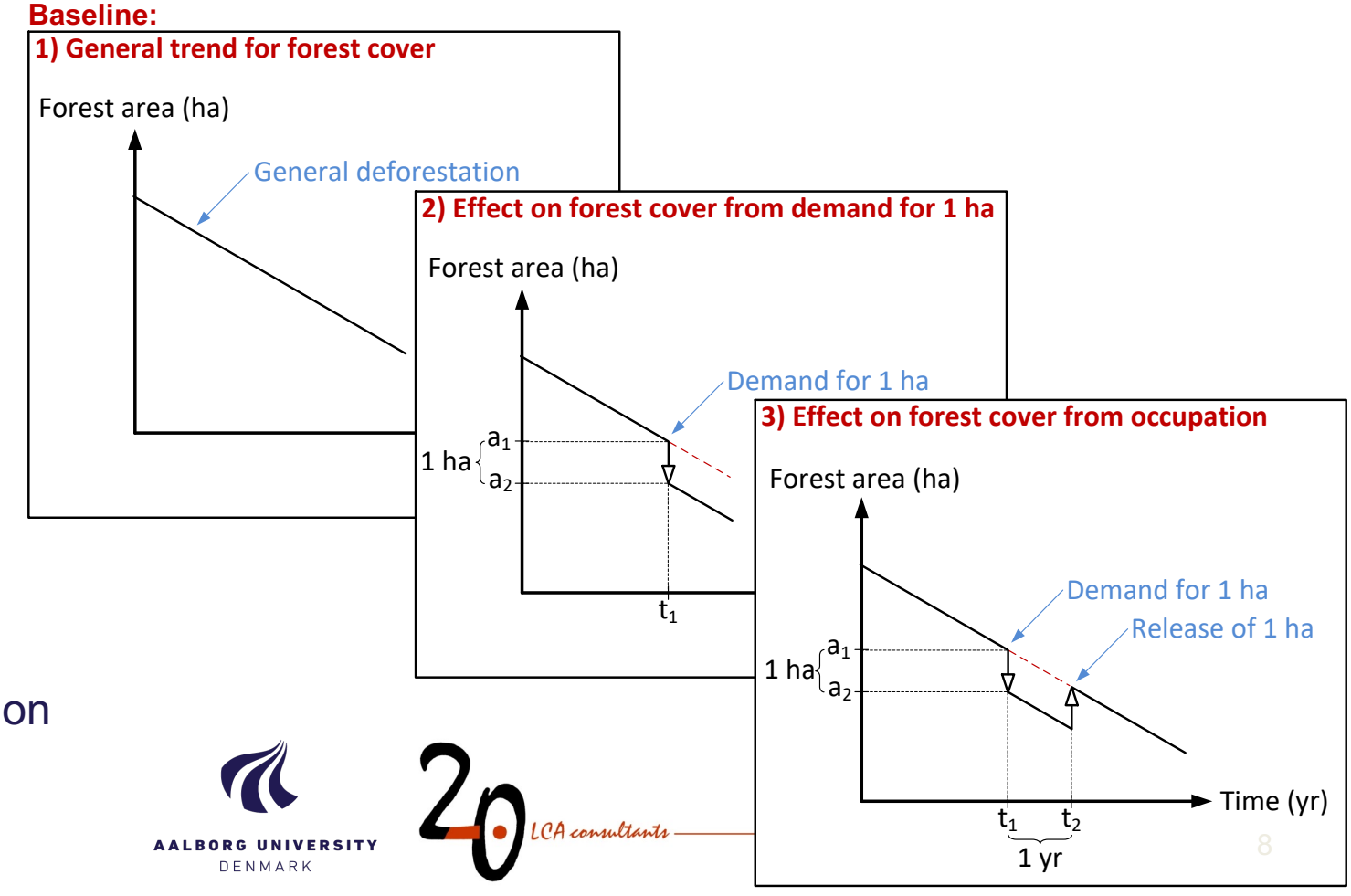
Indirect Land Use Change (ILUC) in consequential modelling

Land transformation effect of land occupation ➤



Occupation causes a preponement of deforestation for the duration of the occupation

Schmidt J, Weidema B P, Brandão M (2015). *A framework for modelling indirect land use changes in life* cycle *assessment.* Journal of Cleaner Production 99:230-238

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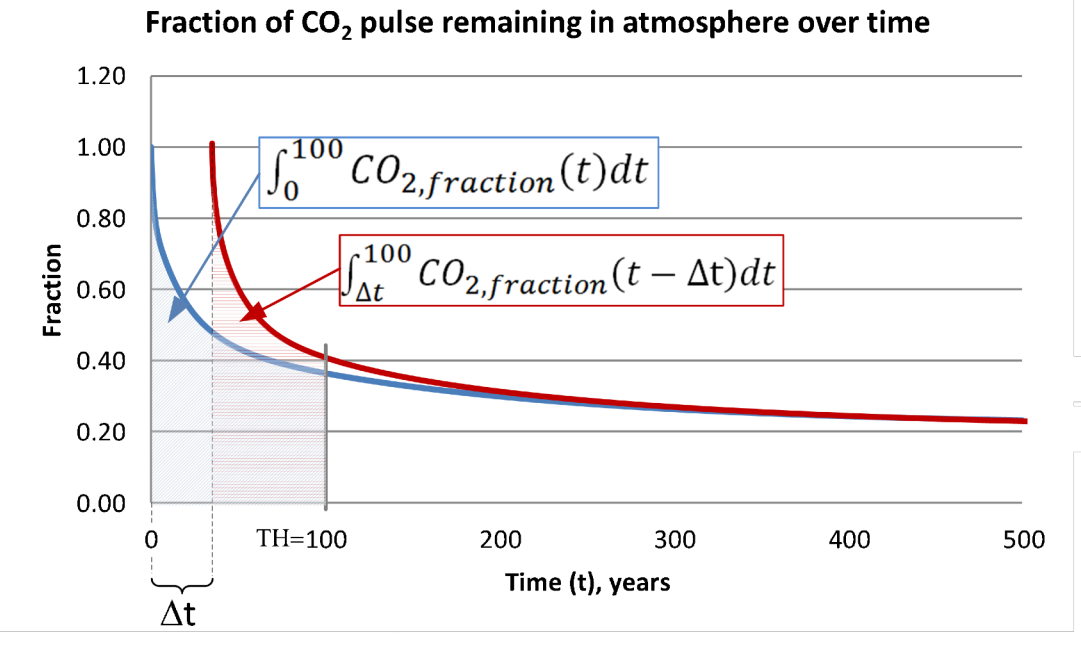
The GWP100 effect of preponing deforestation

- Emitting CO_2 emissions in year 0 instead of year 1:

$$GWP_{CO2,\Delta t} = \frac{\int_{\Delta t}^{100} CO_{2,fraction}(t-\Delta t)dt}{\int_{0}^{100} CO_{2,fraction}(t)dt}$$

$GWP_{CO2,\Delta t=0}$ = 1 kg CO_2-eq.
$GWP_{CO2,\Delta t=1}$ = 0.9922 kg CO_2-eq.

$GWP100_{CO2,t=1\rightarrow 0}$
= 1 – 0.9922
= 0.00783 kg CO_2-eq.



IPCC (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia]. Cambridge, United Kingdom and New York.

When is forecasting needed?

When data for the recent past are not adequate…

i.e., it is a data quality issue

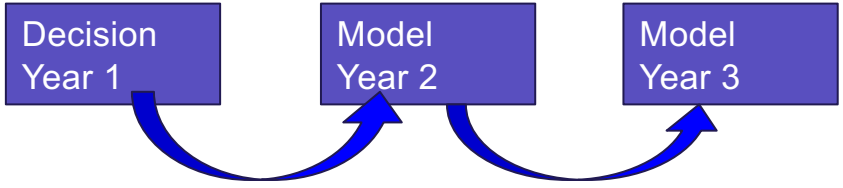
What time horizon is relevant?

- E.g.: “Will a demand in the current year influence the investment decisions in year 0-5, 5-10, and/or 10-15?”
- Should reflect the time gap (delay) between the decision and the actual availability of the new capacity
- Usual implied assumption: Currently identified marginal technology (e.g., for year 5-10 for electricity) does not influence what is identified as marginal technology in the later periods (10-15 years, etc.)

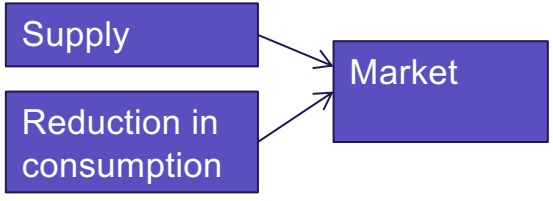
Consequential models:
Static, dynamic or equilibrium models?

1. Standard LCA practice: Yearly static models

2. A dynamic model: Decisions influence the future model

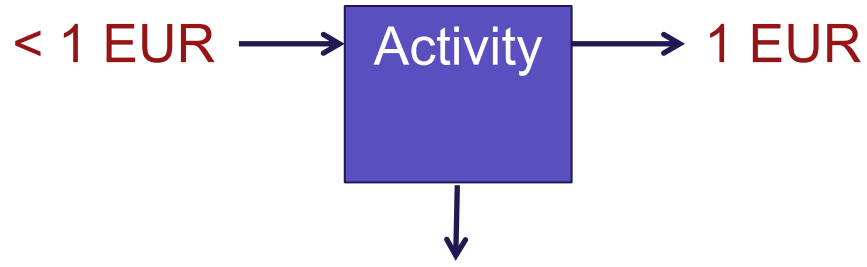


3. Equilibrium model: Effects of short-term price changes



Dampens the effects because part of the reaction is taken up by reduction in consumption. Realistic for short-term constraints.

Do the consequences go on forever?



Without leakage, consequences would go on forever

Attributional: Without leakage, contributions would include everything since the beginning of history

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The delimitation of the product life cycle

The activities included are limited to those that react to the change in revenue, corresponding to the first-order effects of the original spending

Implicitly:

- when comparing products with different prices, a consequential model will include first-order price rebound effects,
- while excluding second order effects of education, research and technological development, or changes that may result from the redistribution of the initial spending

Advanced question:

- Could we more systematically include also second-order effects while maintaining unambiguous delimitation criteria?

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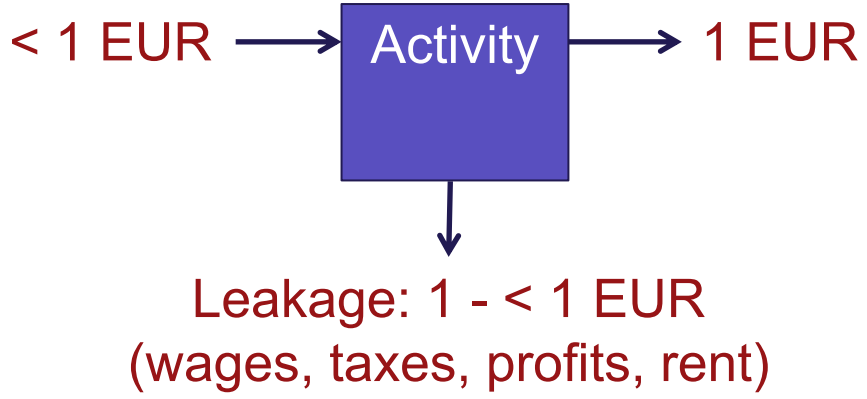
Do the consequences go on forever?



- Leakage is an arbitrary cut-off (also in a consequential model)
- Only valid if leakage does not affect consumption patterns
- Monetary redistribution *does* affect consumption patterns
- A more consistent modelling would include consequences of monetary redistribution

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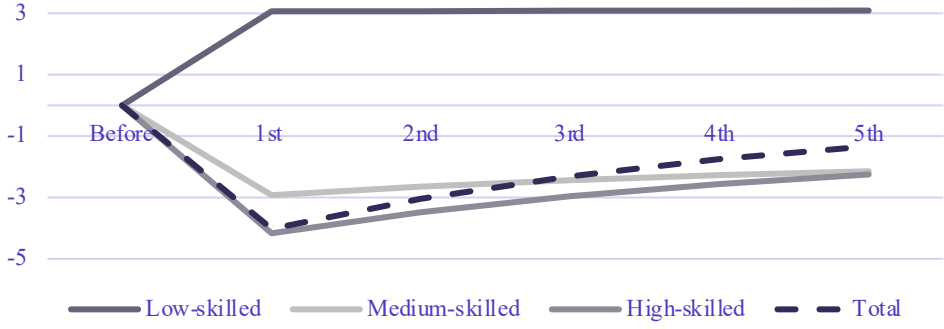
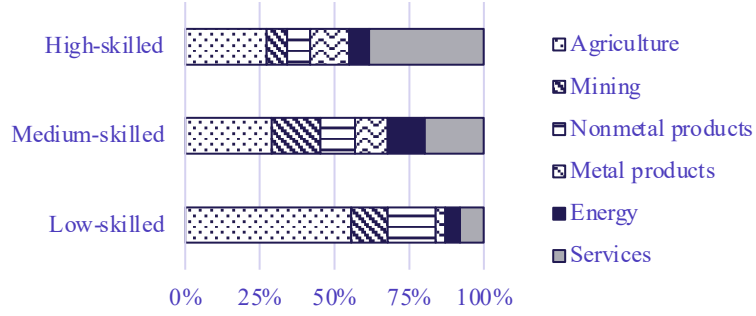
Almeida D, Weidema B P, Godin A. (2022). *Beyond normative system boundaries in life* cycle *assessment.* Cleaner Environmental Systems 4:100072 (9 pages)

Including consequences of monetary redistribution

Industry	Output perturbation (MUSD)	1st	2nd	3rd	4th	5th
Agriculture	0	705	2	1.1	0.8	0.6
Mining	0	2	1	0.7	0.5	0.4
Nonmetal products	1750	2114	2	1.4	1.1	0.8
Metal products	0	-38	2	1.4	1.0	0.8
Energy	-1750	-3048	1	0.6	0.4	0.3
Services	0	-434	5	3.8	2.9	2.2



Households net changes in wealth (MUSD)



Income share from each productive industry for each household type

	Before perturbation	Distribution 1st	2nd	3rd	4th	5th
Total CO_2 emissions (Tg)	2000	-40.6	0.041	0.029	0.022	0.017

Change in CO2 emissions from income distribution and re-spending

- The first round of re-distribution dominates and is non-negligible
- Results reflect a permanent change: A new steady state

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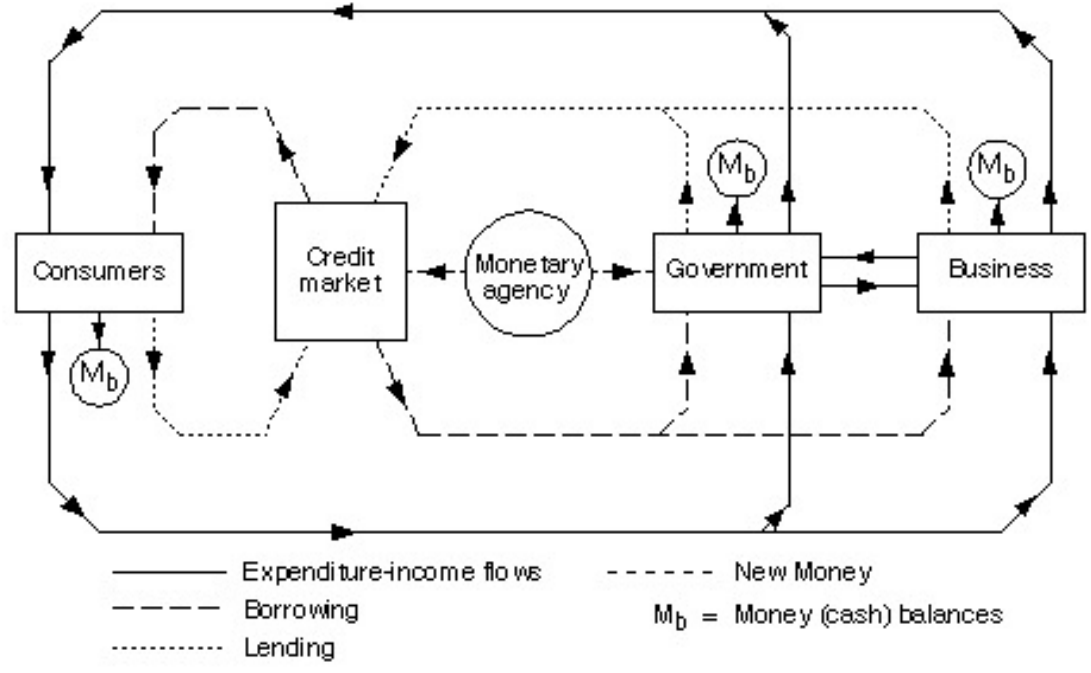
Economic modelling: Social Accounting Matrices

Adding more balance conditions:

- to households: Consumption = Income – Taxes – Savings
- to financial flows: Investments = Savings
- to assets: Assets - Liabilities = Equity (net worth)



Building an economic model

Temporal steps:

- Opening assets + assets changes = closing assets

From accounting balances to behavioural rules that solve real-life imbalances between supply and demand:

- General Equilibrium models (neo-classical):
  - Driven by supply and optimisation rationales
  - No unemployment
  - No inventories of goods; prices adjust to clear markets
  - Money supply exogeneous
- Stock-Flow Consistent models (post-Keynesian):
  - Driven by demand and agents' expectations (procedural rationality)
  - Unemployment possible
  - Prices set in advance; inventories adjust
  - Money supplied in proportion to investment demand and balanced by changes in household savings

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Why include economic modelling?

To account for the impacts of monetary re-distribution

To include the distributional impacts of business cycles

To model the physical consequences of economic policies

THANKS FOR YOUR ATTENTION

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