Climate Change and the Economics of Adaptation

David Kraybill
Professor, Dept. of Agricultural, Environmental, and Development Economics
Director, Center for African Studies
Ohio State University

Lecture presented July 26, 2008 at
Post Graduate Course in Mountain Environment and Climate Change
IPROMO: International Programme on Research and Training on Sustainable Management of Mountain Areas
Held at University of Torino

Outline

- Case study: Mount Kilimanjaro
- Adaptation
- Adaptive capacity
- A conceptual model of economic and environmental interactions
- Applied models of impact and adaptation

Case Study: Mount Kilimanjaro

Impacts of climate change in Africa

- Rainfall
  - Sahel region: 25% reduction over past 30 years
  - Tropical rainforest zone: decrease in precipitation by about 2.4 (± 1.3 percent) per decade since mid-1970s
- Temperature
  - Warming of 0.7°C over most of the continent during 20th century
  - The 5 warmest years on record in Africa have occurred since 1988 (1995, 1998 are the 2 warmest years).

Source: Third Assessment Report, IPCC, 2001

Mount Kilimanjaro

Glaciers at the peak of Mount Kilimanjaro have been melting for more than 100 years. Widespread logging has occurred on the mountain’s slopes in the past 50 years and continues today. Rainfall patterns and the volume of rainfall are erratic.

Mt. Kilimanjaro in 1976 and 2006

A satellite image of Kilimanjaro from 1976.

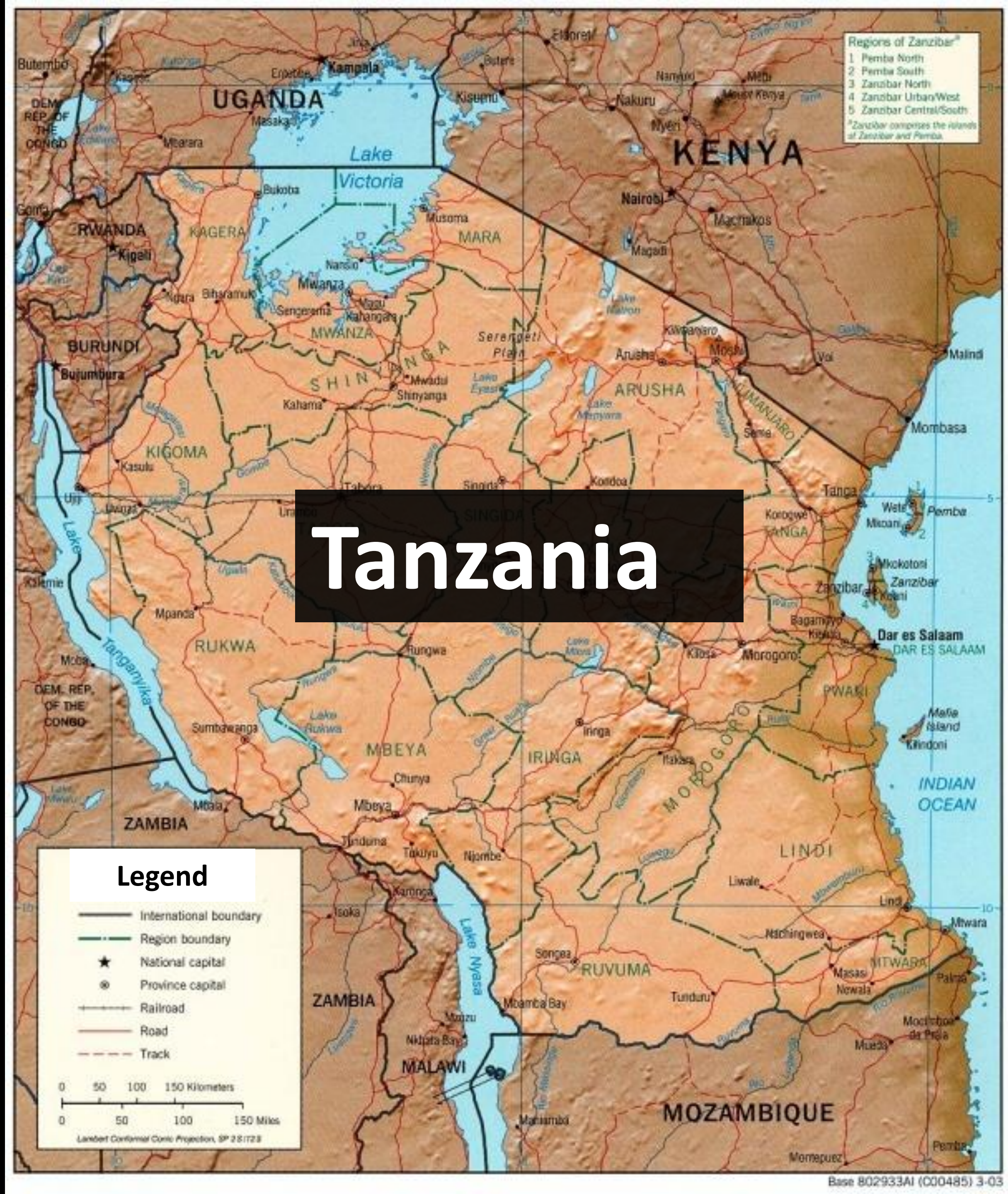
Source: UNEP

The decrease in the glacial area can be seen clearly in this image of Kilimanjaro in 2006.

Source: UNEP

The icecap on Mt. Kilimanjaro is melting and is likely to disappear by 2025 according to Dr. Lonnie Thompson, paleoclimatologist at Ohio State University. According to Thompson, the glaciers are much like the canaries once used in coal mines. They are indicators of massive changes taking place in climate in the tropics.

Tanzania



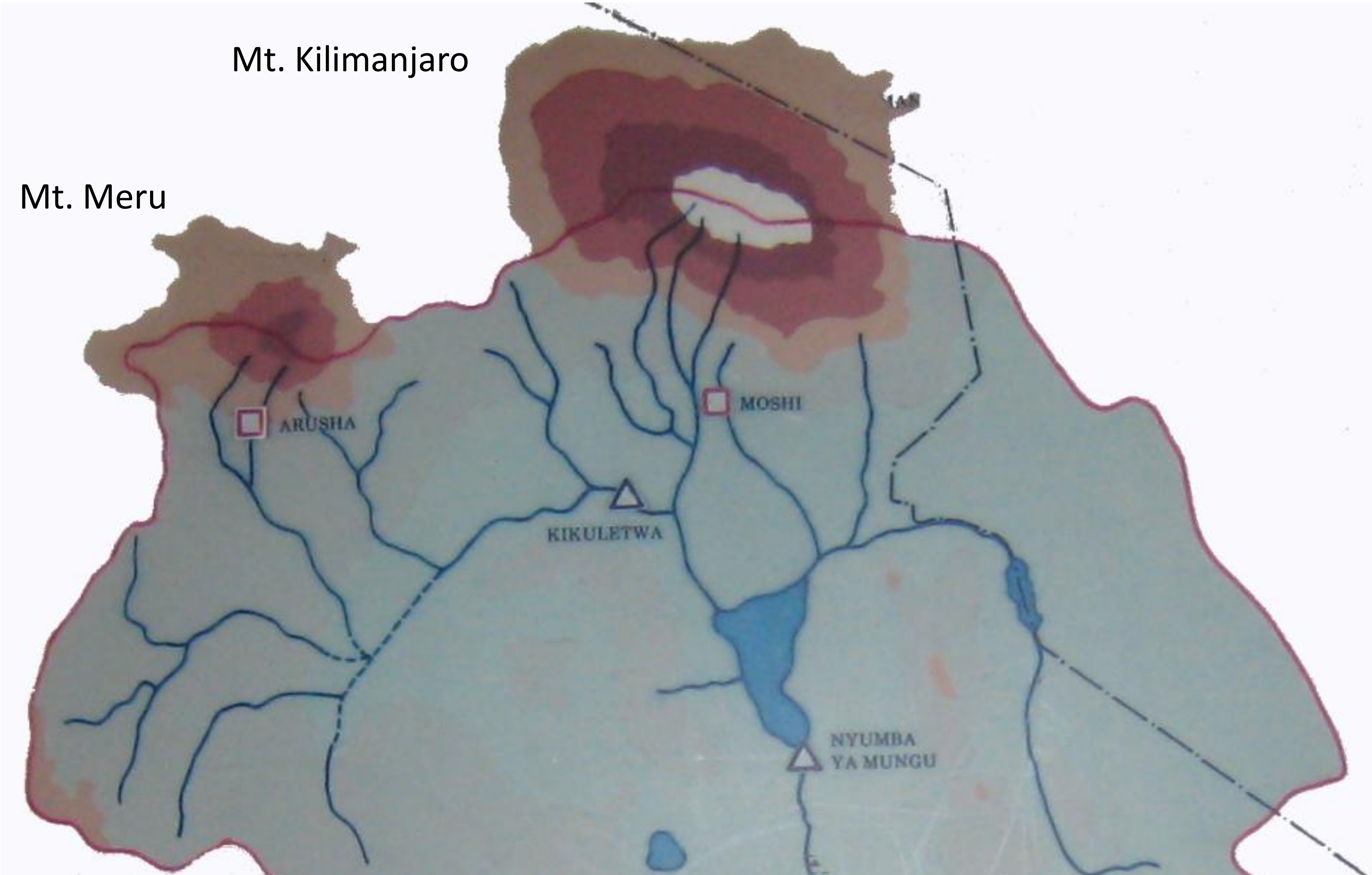
Source: Perry-Castañeda Library Map Collection, University of Texas Libraries

Source: Perry-Castañeda Library Map Collection, University of Texas Libraries

Source: Perry-Castañeda Library Map Collection, University of Texas Libraries

Source: Perry-Castañeda Library Map Collection, University of Texas Libraries

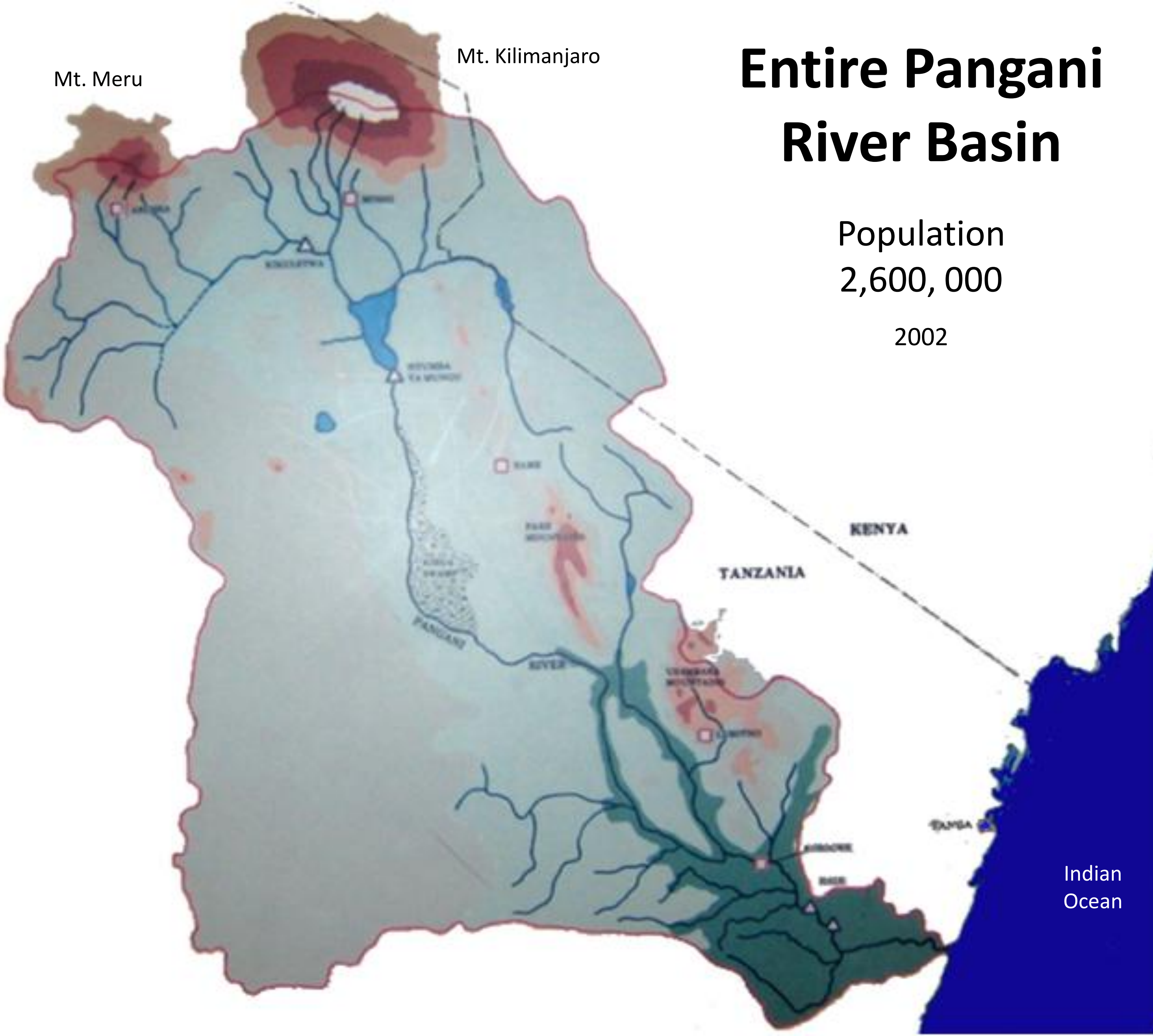
Headwaters of Pangani River Basin



Entire Pangani River Basin

Population
2,600, 000

2002



Threatened Forests

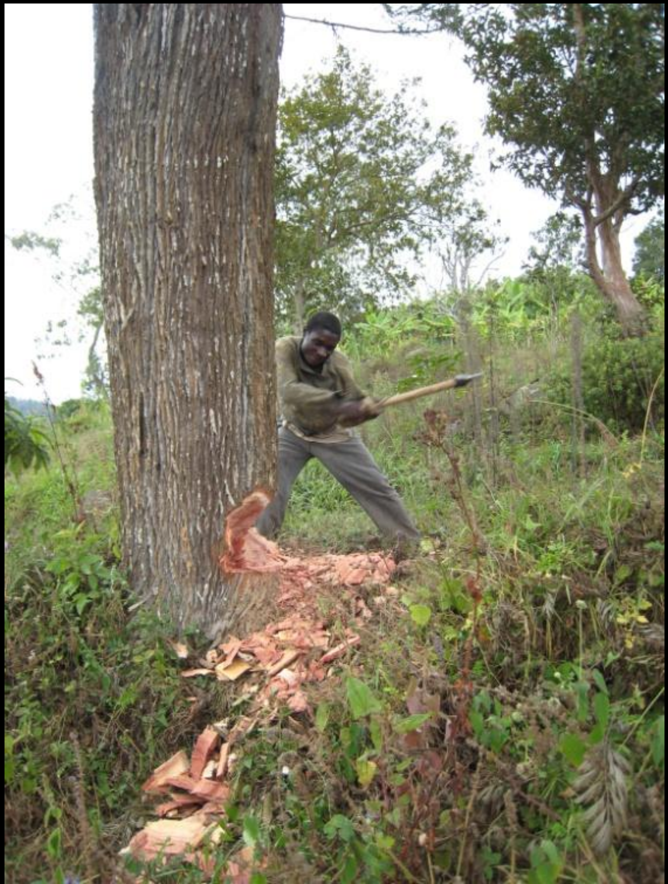
Threats to Mount Kilimanjaro forests:

- Logging of indigenous tree species
- Burnt forest areas
- Charcoal production
- Forest villages
- Shamba system of commercial forestry
- Livestock grazing
- Small fields cultivated in the traditional forest
- Landslides

From UNDP report by C.*Lambrechts, B.Woodley, A.Hemp, C.Hemp, and P.Nyiti, 2002.*

Logging of indigenous tree species

Eastern slope



Burnt forest areas

Southwestern slope

Photo: UNDP report by Lambrechts, Woodley, Hemp, Hemp, and Nyiti

Charcoal production

Eastern slope

Photo: UNDP report by Lambrechts, Woodley, Hemp, Hemp, and Nyiti

Forest villages

Rongai on Northeast slope

Shamba system of commercial forestry

Under the shamba system, farmers are allowed to raise crops during the first three years after trees are planted. In some places, the tree seedlings do not get planted and crop farming continues.

Photo: UNDP report by Lambrechts, Woodley, Hemp, Hemp, and Nyiti

Fields cultivated in traditional forest areas

Taro field in protected forest on southeastern slope

Photo: UNDP report by Lambrechts, Woodley, Hemp, Hemp, and Nyiti

Hydrological changes on Kilimanjaro

- Changes in timing of rainfall and, therefore, in growing seasons
- Increased demand for water by farmers in lower altitudes, by hydropower operators, and by the growing population
- Emergence of severe water shortages

One of many streams on Kilimanjaro

Spring in Moshi town at base of Kilimanjaro

Cloud forest zone where mist becomes water droplets when it comes into contact with leaves

Livelihoods on southern slope of Kilimanjaro

Traditional irrigation

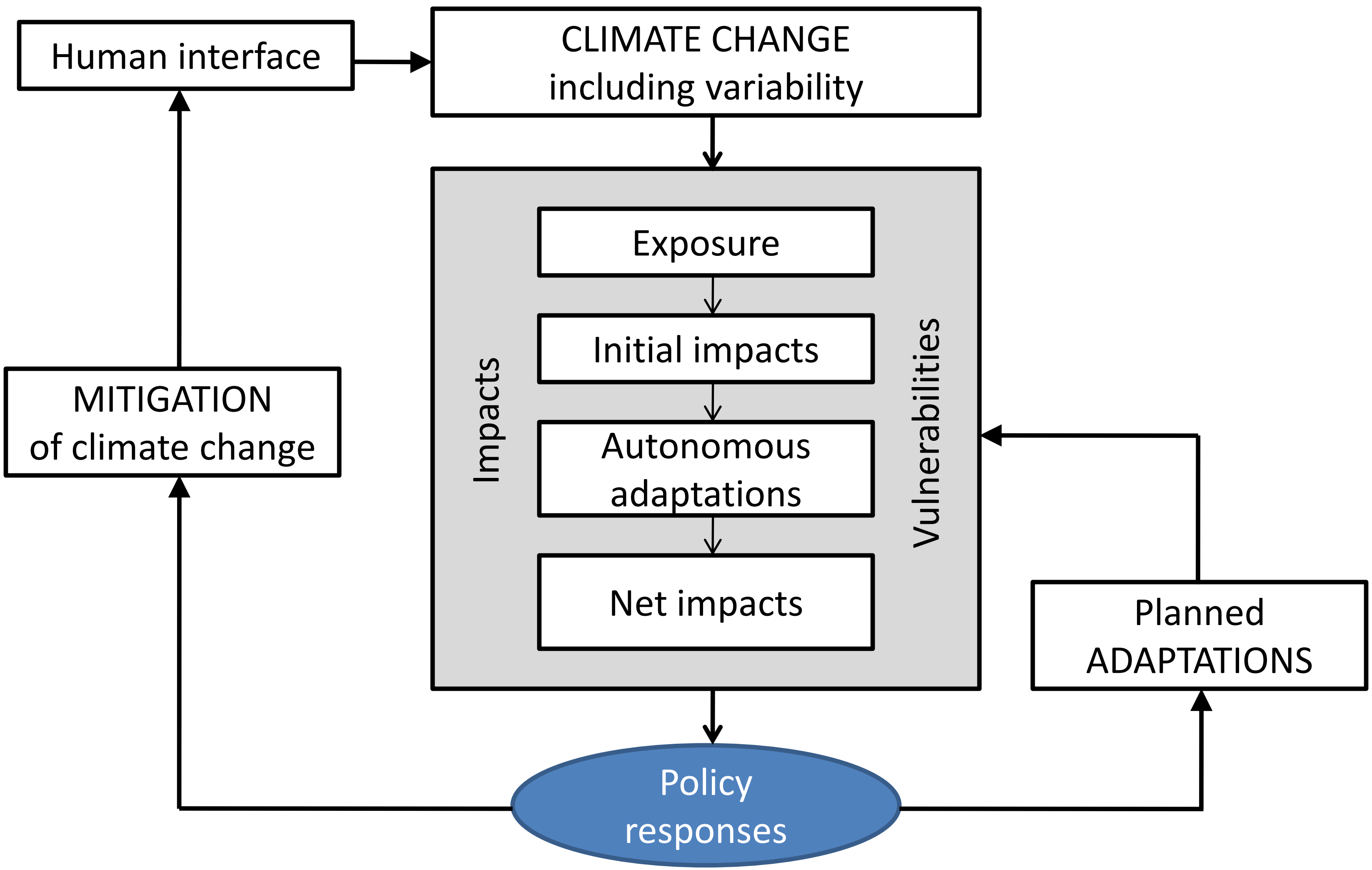
Lower Moshi Irrigation Scheme

Drip irrigation

Low pressure sprinkler

Adaptation

Role of adaptation in climate change



Source: Barry Smit and Olga Pilifosova, Adaptation to Climate Change in the Context of Sustainable Development and Equity

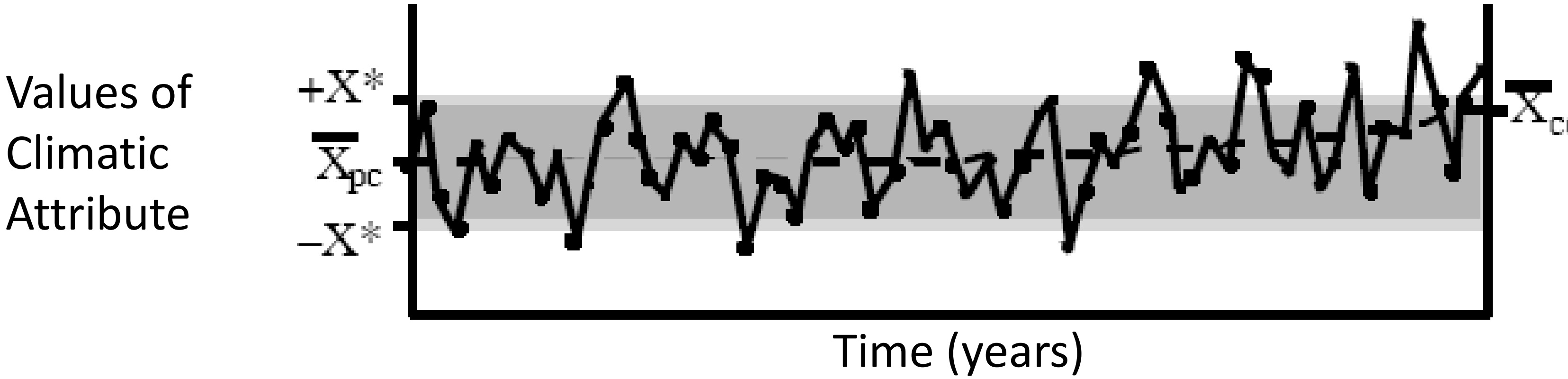
What is adaptation?

- Adjustments of ecological, social, or economic systems in response to –
  - Actual climatic stimuli
  - Expected climatic changes
- Includes changes in –
  - Processes
  - Structures
  - Practices
- Aim is to –
  - Avoid or reduce potential damage from climate change, or
  - Capture benefits from climate change

Types of climate stimuli

- Impact and adaptation studies generally focus on climatic averages of temperature and moisture
- Often ignored, but very important:
  - Variability
  - Extremes
- Averages typically fall within the coping range while extremes often fall outside

Average, extremes, and coping range



- - - Trend in mean value of X

$\bar{x}_{pc}$ Mean value of climatic attribute (X) at start of time series (pre-climate change)

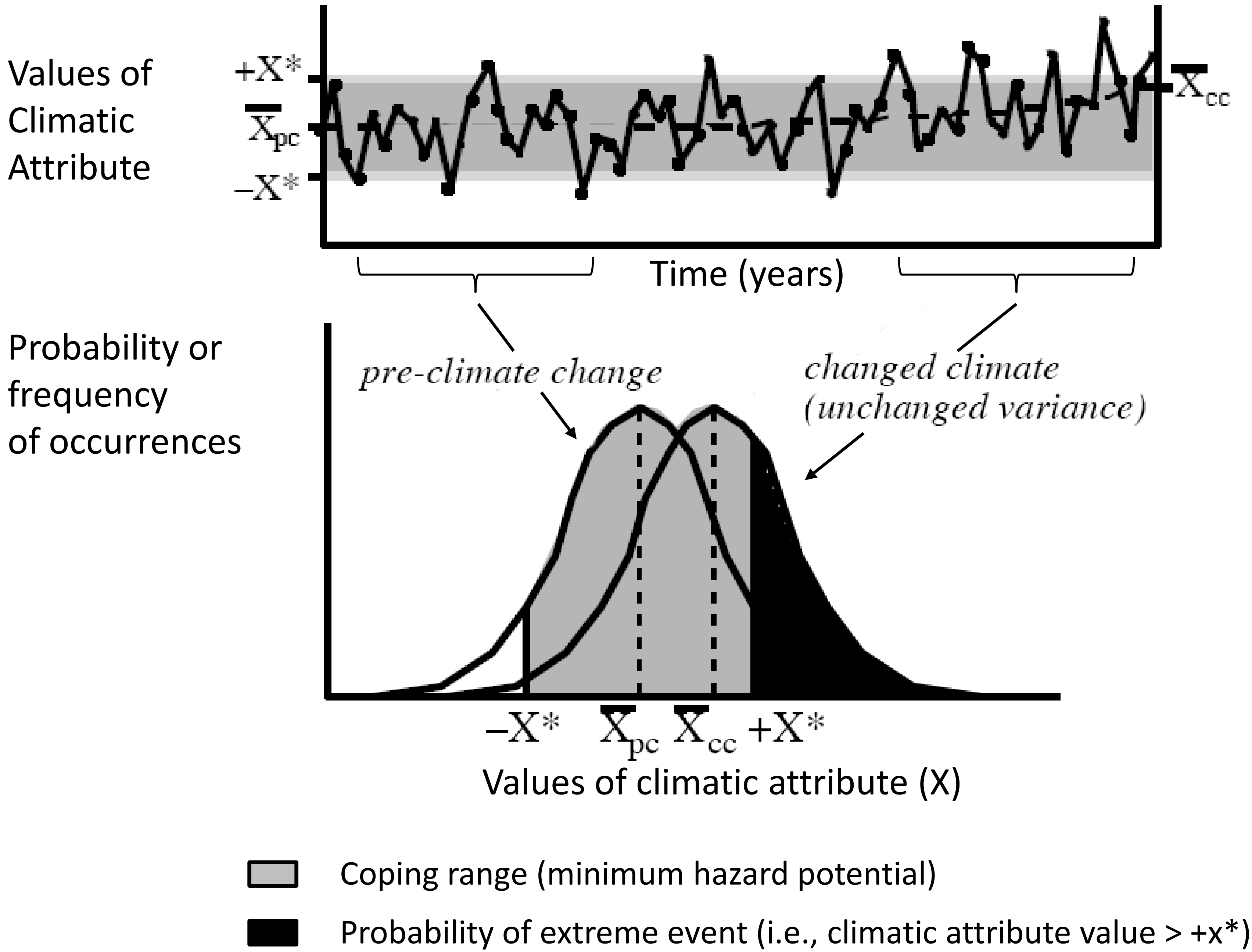
$\bar{x}_{cc}$ Mean value of climatic attribute (X) at end of time series (climate change)

$+x^*$ Upper critical value of X for system of interest; value > +x* are considered extreme and beyond "damage threshold"

$-x^*$ Lower critical value of X for system of interest; value < -x* are considered extreme and beyond "damage threshold"

▭ Coping range (minimum hazard potential)

Source: Barry Smit and Olga Pilifosova, Adaptation to Climate Change in the Context of Sustainable Development and Equity



Source: Barry Smit and Olga Pilifosova, Adaptation to Climate Change in the Context of Sustainable Development and Equity

Characterizing adaptation

Attribute or scale	Words used to characterize		
Purposefulness	**autonomous** passive	**vs.**	**planned** Active
Timing	**reactive** ex post	**vs.**	**anticipatory** ex ante
Temporal scale	**short term** tactical	**vs.**	**long term** strategic
Spatial scale	**localized**	**vs.**	**widespread**
Form	**legal, institutional, regulatory, financial, technological**		

Adaptation options

- Bear the loss
- Share the loss
- Alter resource use
- Change location
- Do research on potential responses
- Modify effects
- Provide information to bring about behavioral change

Examples of anticipatory and reactive adaptation

		Anticipatory	Reactive
Natural systems			• Changes in length of growing season • Changes in ecosystem composition
Human systems	Private	• Water harvesting (household) • Farm-level irrigation ditches • Constructing house on stilts • Planting trees	• Changes in farming practices • Changes in insurance premiums • Seasonal migration • Off-farm employment
	Public	• Early-warning systems • Community irrigation systems • Create crop insurance program • Implement vaccination program to prevent vector-borne diseases • Incentives for relocation	• Emergency food aid • Compensatory payments

Adaptive Capacity

What is adaptive capacity?

- The ability of a system, region, or community to make livelihood-enhancing changes in response to climate change
- Ability to cope with changes and uncertainties in averages, variability, and extremes of climatic variables
  - Increase in the "coping range"
- Reduces vulnerability to adverse effects of climatic changes
- Promotes sustainable development

Determinants of adaptive capacity

- Economic resources (private and public)
  - Poverty is “rough indicator of the ability to cope”
- Technology (private and public)
  - Examples: warning systems, irrigation, crop breeding, flood control measures
- Information and skills
  - Knowledge of hazards, ability to assess risks, ability to implement change
- Infrastructure
  - Examples: roads, irrigation canals, dams, weather monitoring and forecasting system

Determinants… (continued)

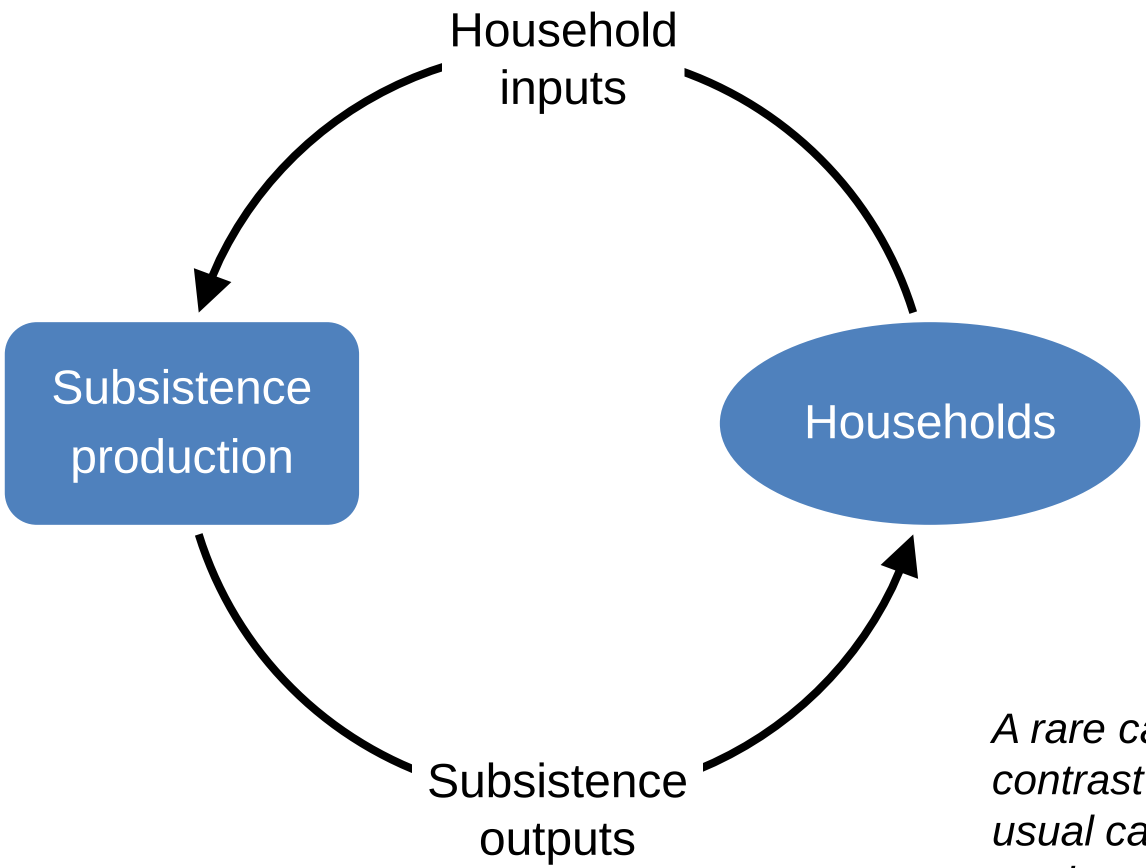
- Institutions
  - Shift risk from individuals to public
  - Examples: insurance, land use policies, water management policies and organizations, agricultural research system, financial markets, mutual aid
- Equity
  - Access to (not just availability of) resources is vital for adaptation

Adaptive capacity and sustainable development have similar requirements

- Improved access to resources
- Reduction in poverty
- Lessening of inequities in assets
- Improved education and information
- Improved infrastructure
- Active participation by concerned parties
- Respect for accumulated local experience
- Improved institutional capacity and efficiency
- Solutions that are comprehensive and integrative, not just technical

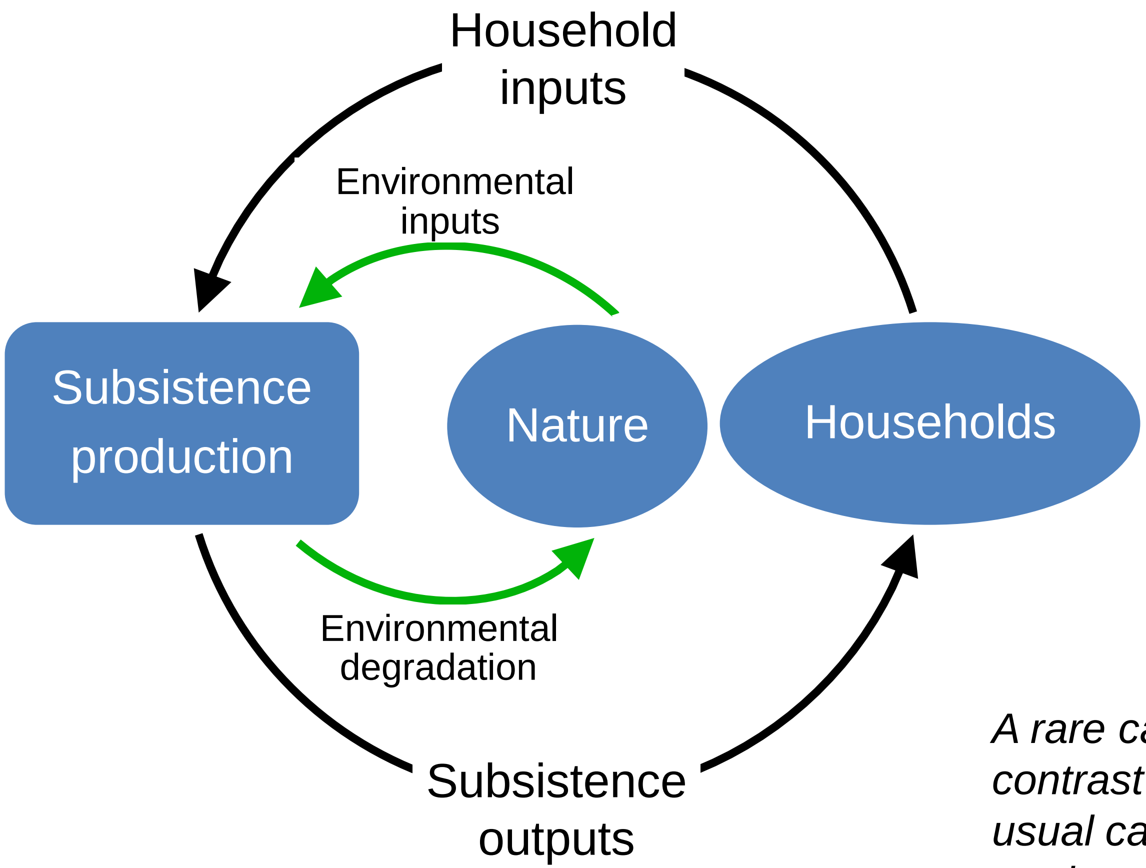
A conceptual model of economic and environmental interactions

Economic flows in mountain regions with no market relations



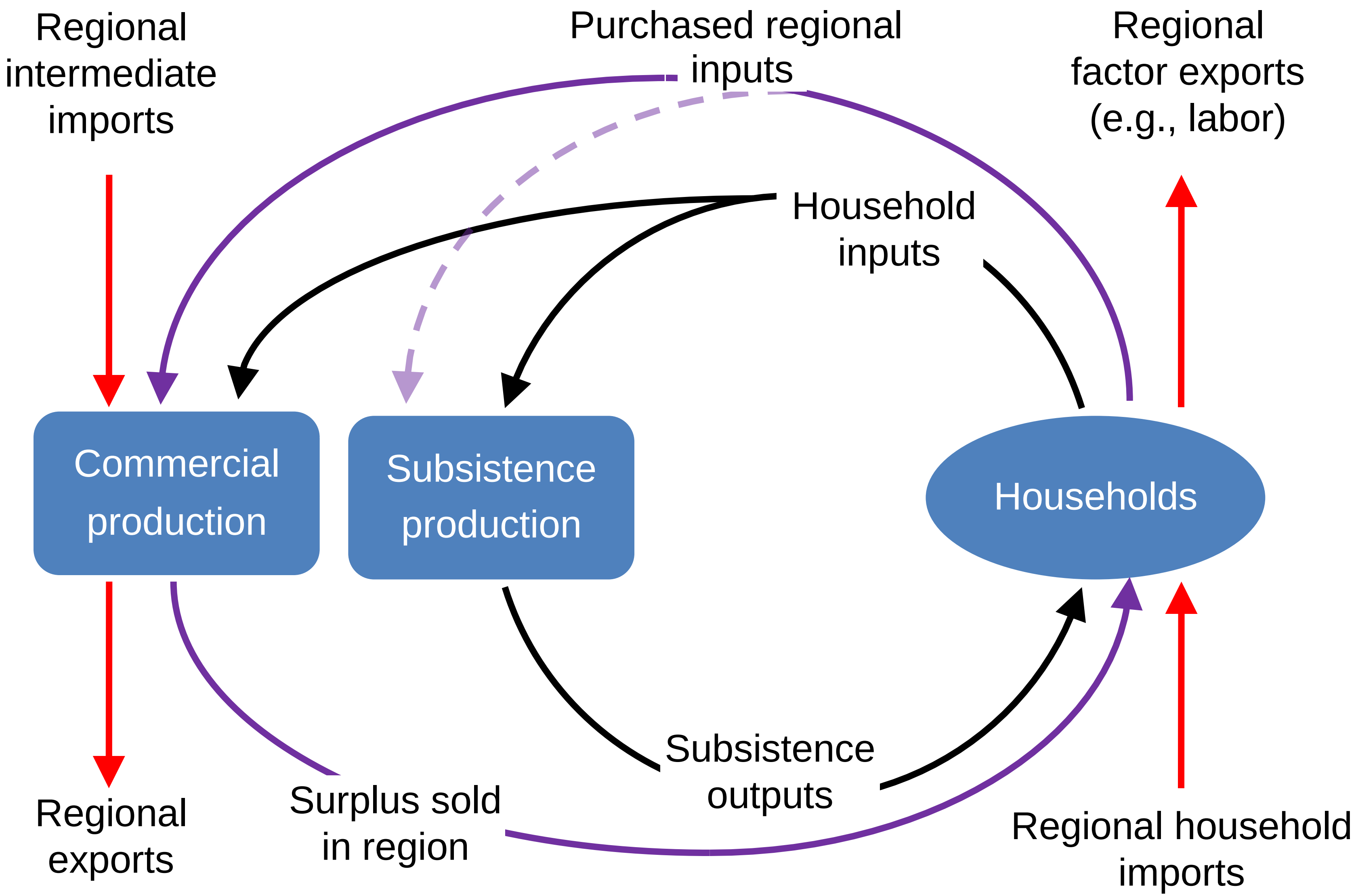
A rare case intended for contrast with the more usual case of moderate market relations

Economic and environmental flows in mountain regions with no market relations

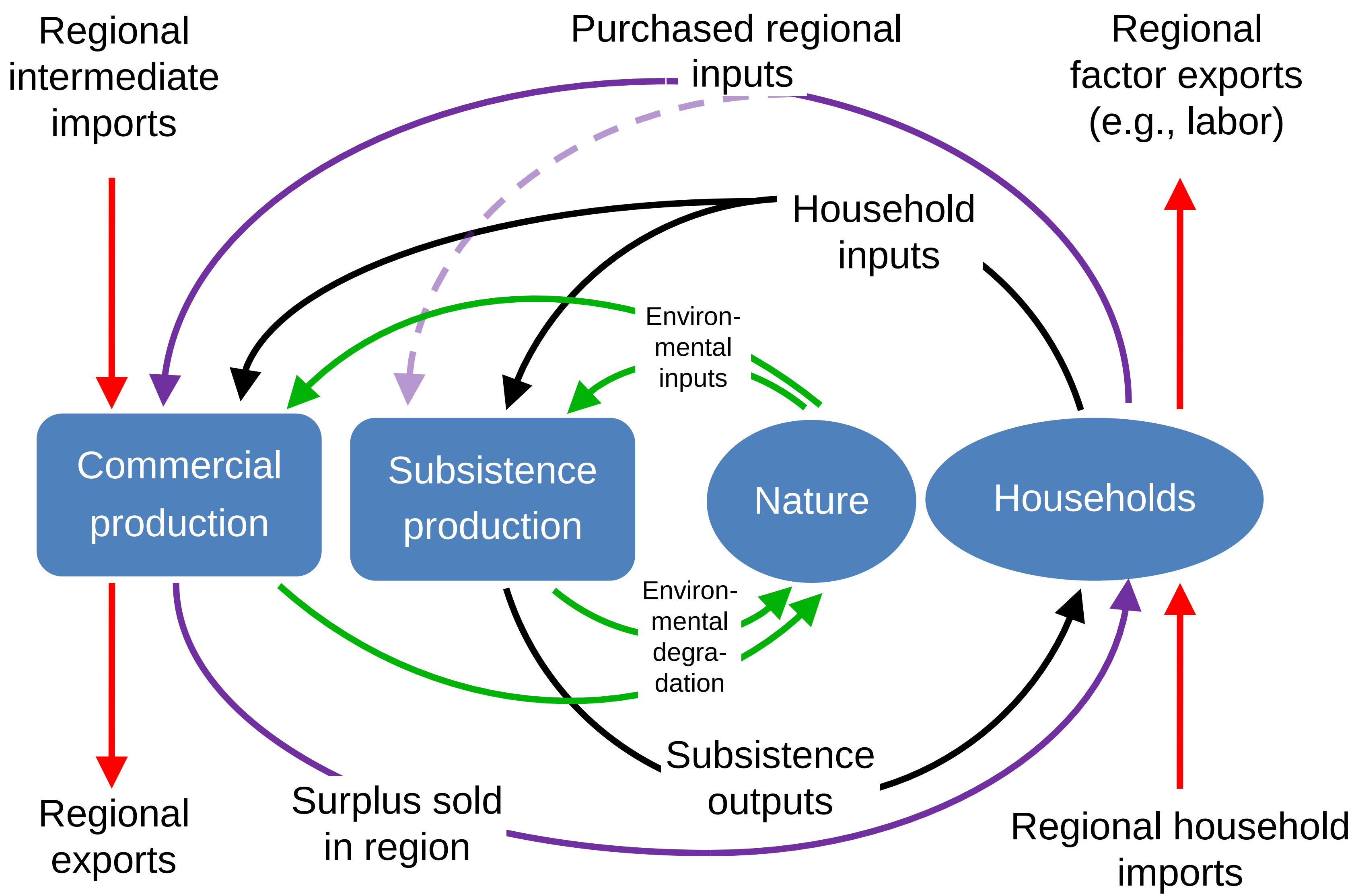


A rare case intended for contrast with the more usual case of moderate market relations

Economic flows in mountain regions with some market relations



Economic and environmental flows in mountain regions with some market relations



Applied models of impact and adaptation

Alternative adaptation assumptions

1. **No adaptation** – an assumption adopted by early studies of impacts of climate change ("dumb farmer" assumption)
2. **Exogenous levels of adaptation** – many studies examine impact of climate change assuming given levels of adaption
3. **Endogenous, rational, full-information adaptation** – assumes profit-maximization under condition of perfect information ("clairvoyant farmer" assumption)
4. **Endogenous, rational adaptation with uncertainty –** assumes utility maximization subject to information constraints

---

Assumptions 2, 3, and 4 imply that impacts of climate change cannot be assessed accurately without accounting for adaptation

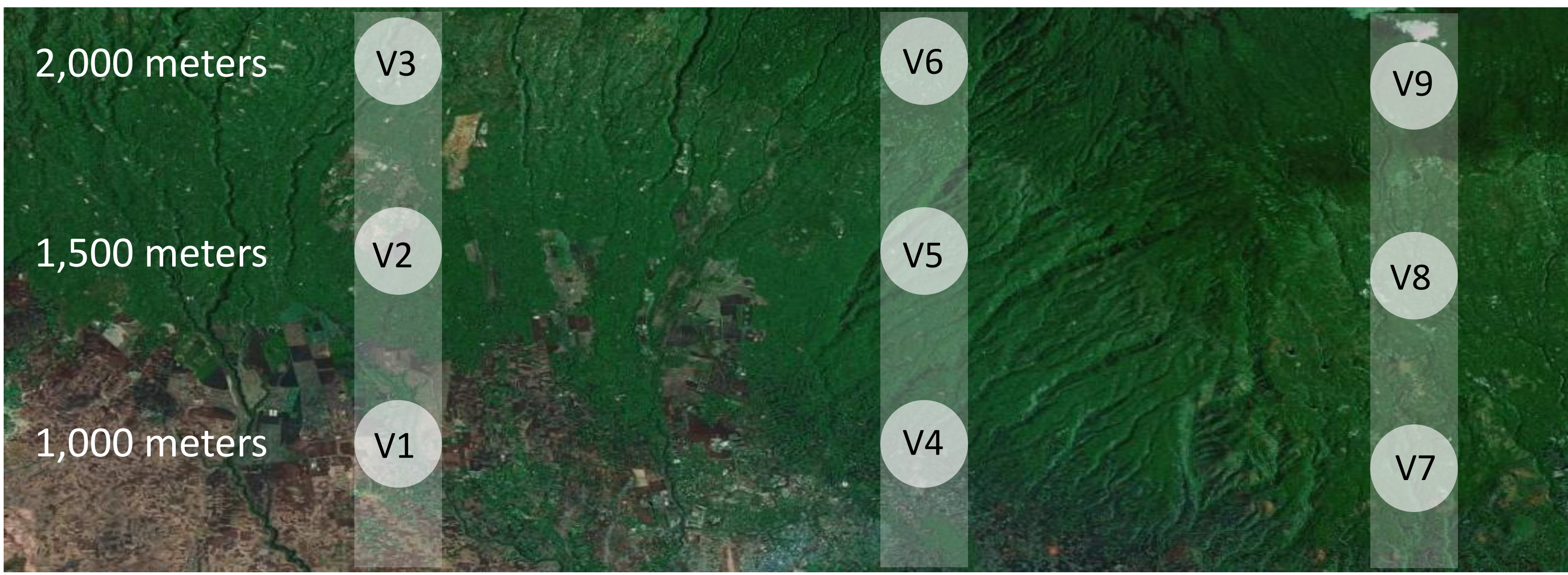
Models of autonomous adaptation

- **Spatial analog models**
  - Response parameters from actual climatic regions are used to predict response to similar climatic conditions in other regions. Do not explicitly model adaptation.
- **Integrated economic-biological process models**
  - Producer (household) microeconomic models and crop or hydrological process models are estimated for a warm region. Estimated parameters are then used in simulation model of adaptation-adjusted impacts in a currently cooler region.
  - This approach allows assessment of the tradeoffs (relative costs and benefits) of different policies.

Modeling adaptation on Mount Kilimanjaro

Modeling households

- Data to be gathered from 200 farm households on southern slope
- Three transects, each with a village at high, middle, and low altitudes
- Survey conducted over two years (four growing seasons)



Response parameter estimation

- Simple input-output ratios: $$\frac{L_i}{X_i} = a_{Li}\ ; \quad \frac{K_i}{X_i} = a_{Ki}\ ; \quad \frac{W_i}{X_i} = a_{Wi}$$

  where X_i = output of commodity i = 1,2,…,n

  L_i = labor used in production of commodity i

  K_i = capital used in production of commodity i

  W_i = water used in production of commodity i

  a_{Li} = labor required to produce 1 unit of commodity i

  a_{Ki} = capital required to produce 1 unit of commodity i

  a_{Wi} = water required to produce 1 unit of commodity i

- Alternative: econometric estimation of crop production functions

$$X_i = f(\text{land}_i, \text{labor}_i, \text{capital}_i, \text{water}_i, \text{fertilizer}_i, \text{pesticide}_i, \varepsilon_i)$$

Assumptions (for simplicity in discussion)

- The household produces two commodities
  - In practice, we can easily increase the number of commodities to include all activities of a real household
- The household uses three inputs: labor, capital, water
  - In practice, we can easily increase the number of inputs.
  - We can include intermediate inputs such as fertilizers and agricultural chemicals
- Inputs are available to the household in limited quantities
- The household is semi-subsistent: it consumes some of what it produces
- “Technology” pertains to crop variety, use of irrigation, use of capital, farming practices (such as mulching)

Semi-subsistent household decision model

$$\text{Maximize} \quad Z = p_1X_1 + p_2X_2 + wX_L$$

subject to

$$a_{L1}X_1 + a_{L2}X_2 + X_L \leq R_L$$

$$a_{K1}X_1 + a_{K2}X_2 \leq R_K$$

$$a_{W1}X_1 + a_{W2}X_2 \leq R_W$$

$$X_1 \geq S_1, X_2 \geq S_2$$

----

where Z = revenue (gross benefit)
w = wage rate
X_L = household labor hired out (“commodified” labor)
R_L = units of household labor available
R_K = units of capital available
R_W = units of water available
S_i = subsistence consumption of commodity i

Semi-subsistent household decision model with adaptation

$$\text{Maximize} \quad Z = p_1(X_1^C + X_1^N) + p_2(X_2^C + X_2^N) + wX_L$$

subject to

$$(a_{L1}^C X_1^C + a_{L1}^N X_1^N) + (a_{L2}^C X_2^C + a_{L2}^N X_2^N) + X_L \le R_L$$

$$(a_{K1}^C X_1^C + a_{K1}^N X_1^N) + (a_{K2}^C X_2^C + a_{K2}^N X_2^N) \le R_K$$

$$(a_{W1}^C X_1^C + a_{W1}^N X_1^N) + (a_{W2}^C X_2^C + a_{W2}^N X_2^N) \le R_W$$

$$X_1 \ge S_1, X_2 \ge S_2$$

----

where X_i^C = output of commodity i using conventional technology

X_i^N = output of commodity i using adaptive technology

a_{Li}^C, a_{Ki}^C, a_{Wi}^C = input-output coefficients for commodity i produced using conventional technology

a_{Li}^N, a_{Ki}^N, a_{Wi}^N = input-output coefficients for commodity i produced using adaptive technology

What insights can the model give us?

- Benefit-maximizing output levels of $X_1^C, X_1^N, X_2^C, X_2^N, X_L$ for particular values of the constraints
  - Amount of adaptation given its relative costs and benefits
- Shadow value of resources (the marginal benefit of an additional unit of a resource, R)

$$\text{Maximize} \quad Z = p_1(X_1^C + X_1^N) + p_2(X_2^C + X_2^N) + wX_L$$

subject to

$$(a_{L1}^C X_1^C + a_{L1}^N X_1^N) + (a_{L2}^C X_2^C + a_{L2}^N X_2^N) + X_L \leq R_L$$

$$(a_{K1}^C X_1^C + a_{K1}^N X_1^N) + (a_{K2}^C X_2^C + a_{K2}^N X_2^N) \leq R_K$$

$$(a_{W1}^C X_1^C + a_{W1}^N X_1^N) + (a_{W2}^C X_2^C + a_{W2}^N X_2^N) \leq R_W$$

$$X_1 \geq S_1, X_2 \geq S_2$$

Modeling the community economy

- A <u>social accounting matrix</u> (SAM) shows flows among sectors
- Data can be assembled at level of village, region, nation
- Columns are expenditures, rows are receipts
- For each sector, total expenditure (column sum) must equal total receipts (column sum)

		Expenditures			Injections
		Sector A	Sector B	Sector C	
Receipts	Sector A				
	Sector B				
	Sector C				
Leakages					

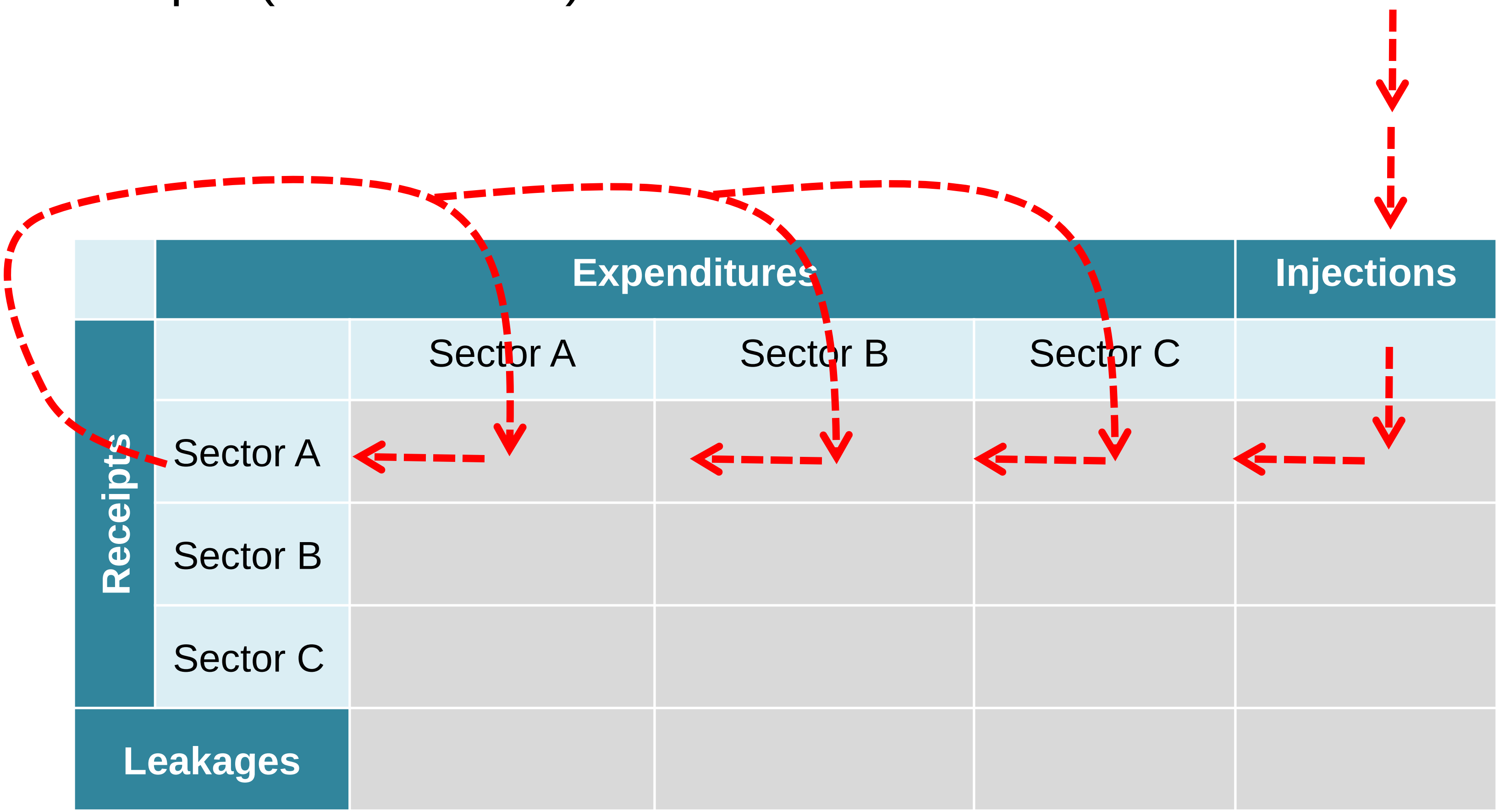
Modeling the community economy

- A <u>social accounting matrix</u> (SAM) shows flows among sectors
- Data can be assembled at level of village, region, nation
- Columns are expenditures, rows are receipts
- For each sector, total expenditure (column sum) must equal total receipts (column sum)

		Expenditures			Injections
		Sector A	Sector B	Sector C	
Receipts	Sector A				
	Sector B				
	Sector C				
Leakages					

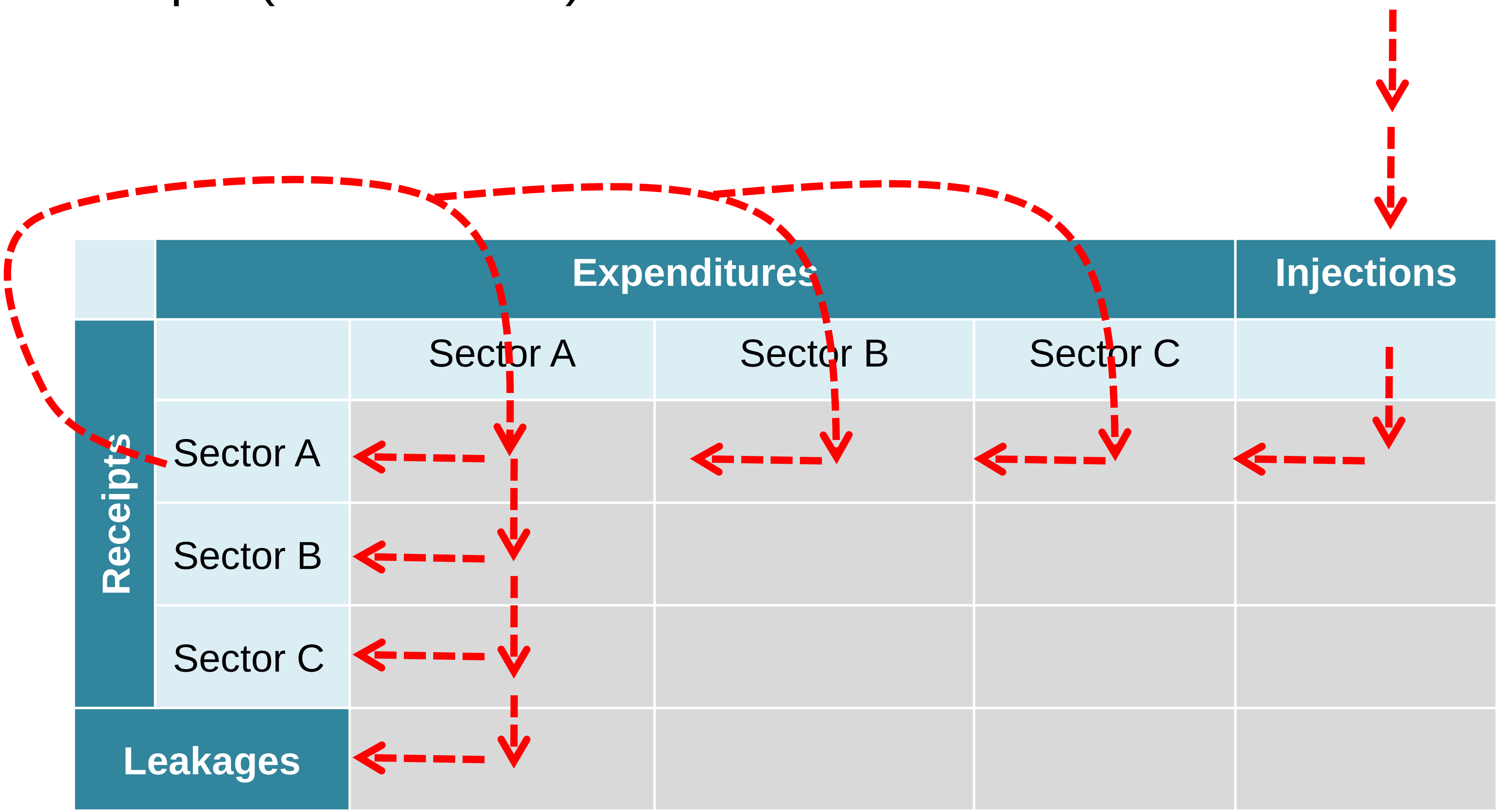
Modeling the community economy

- A <u>social accounting matrix</u> (SAM) shows flows among sectors
- Data can be assembled at level of village, region, nation
- Columns are expenditures, rows are receipts
- For each sector, total expenditure (column sum) must equal total receipts (column sum)



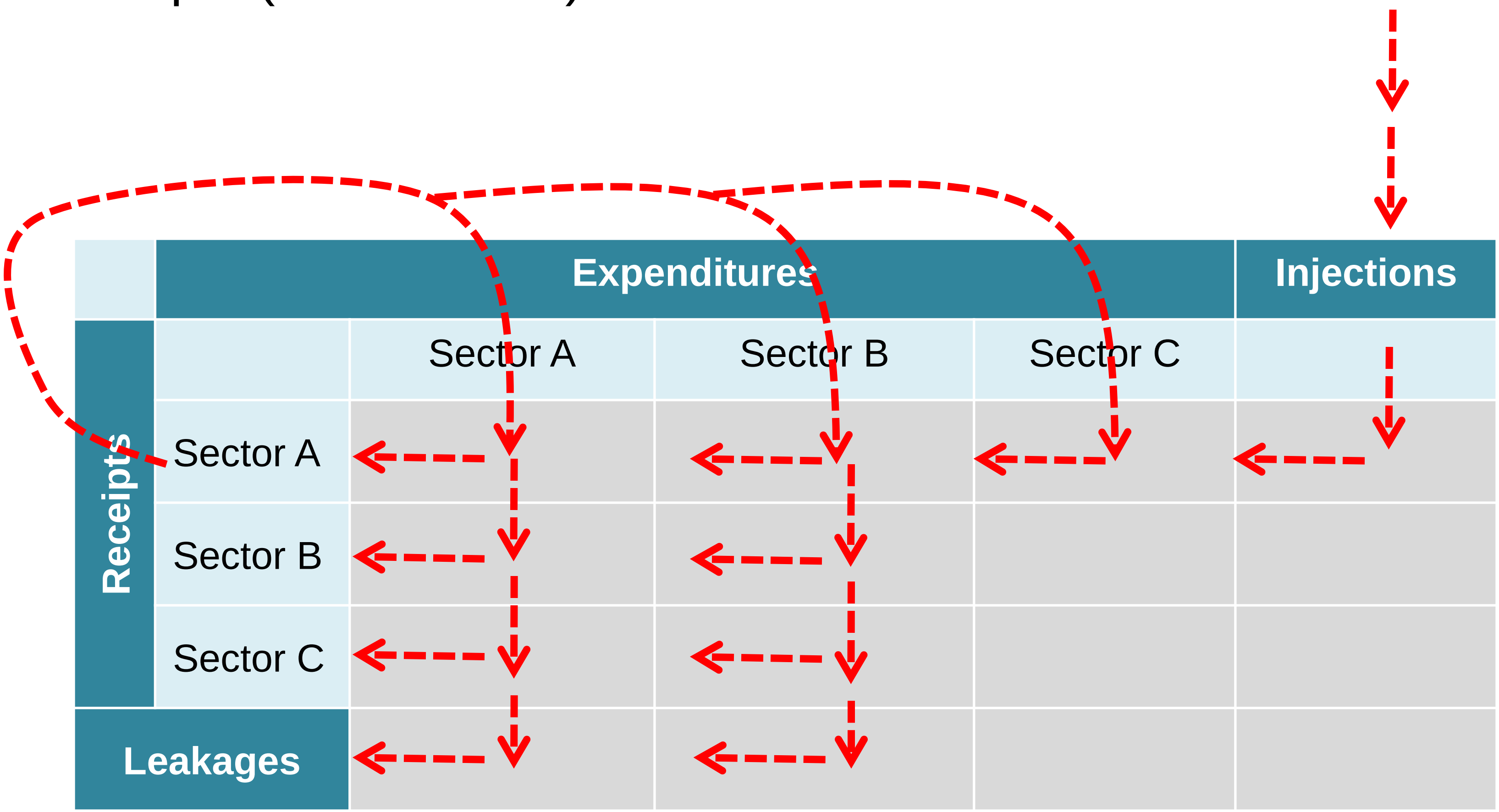
Modeling the community economy

- A <u>social accounting matrix</u> (SAM) shows flows among sectors
- Data can be assembled at level of village, region, nation
- Columns are expenditures, rows are receipts
- For each sector, total expenditure (column sum) must equal total receipts (column sum)



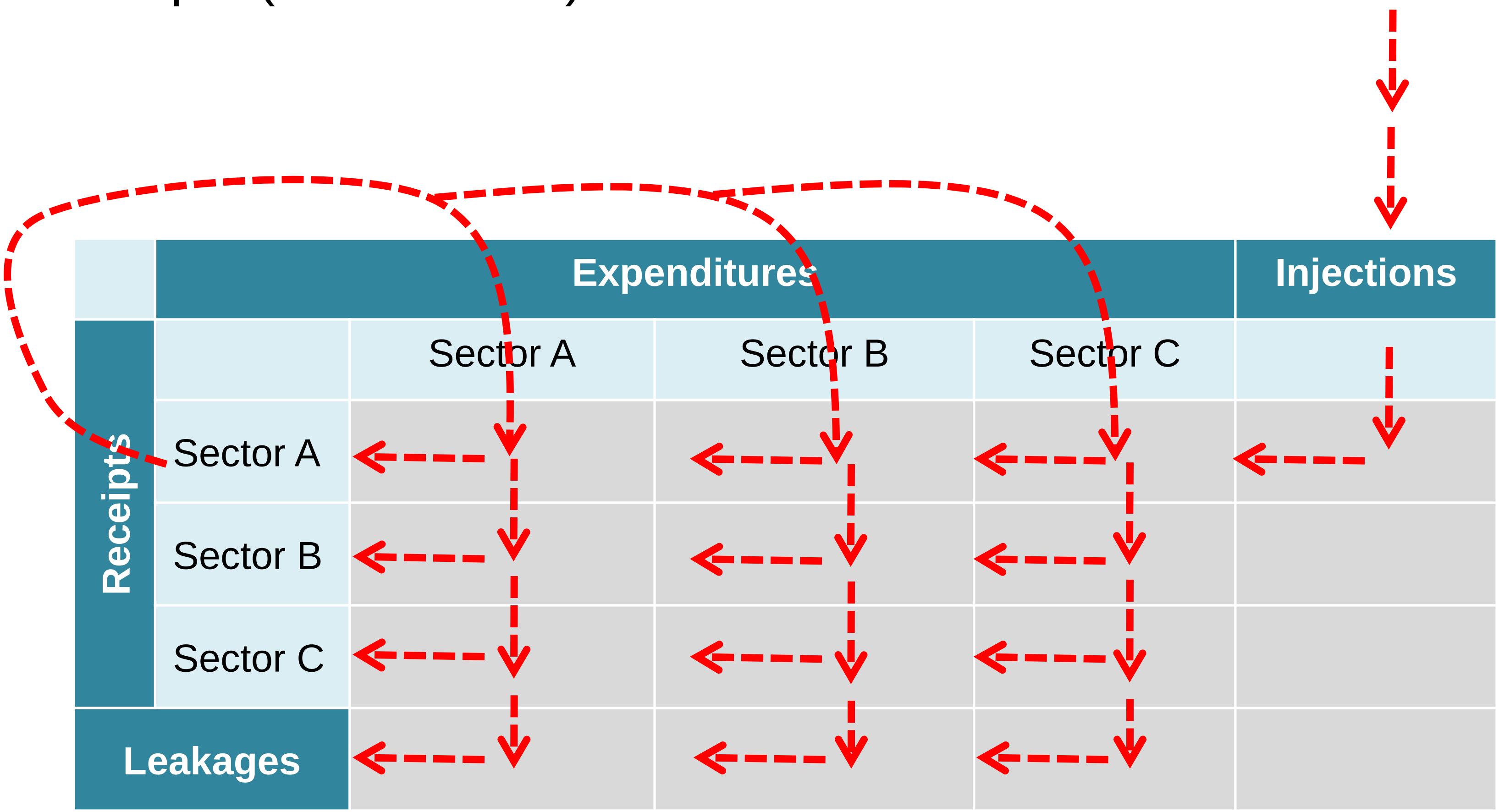
Modeling the community economy

- A <u>social accounting matrix</u> (SAM) shows flows among sectors
- Data can be assembled at level of village, region, nation
- Columns are expenditures, rows are receipts
- For each sector, total expenditure (column sum) must equal total receipts (column sum)



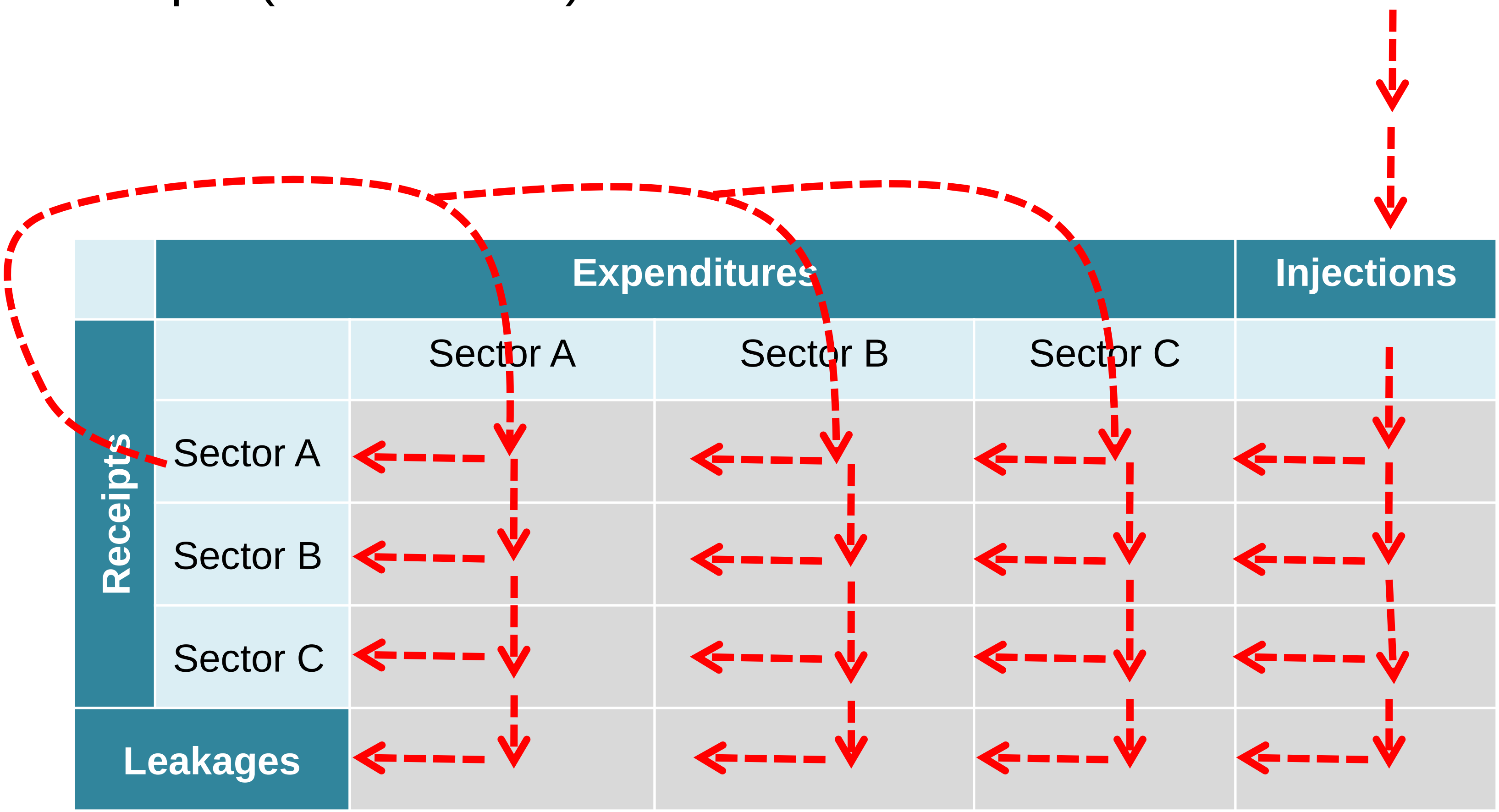
Modeling the community economy

- A <u>social accounting matrix</u> (SAM) shows flows among sectors
- Data can be assembled at level of village, region, nation
- Columns are expenditures, rows are receipts
- For each sector, total expenditure (column sum) must equal total receipts (column sum)



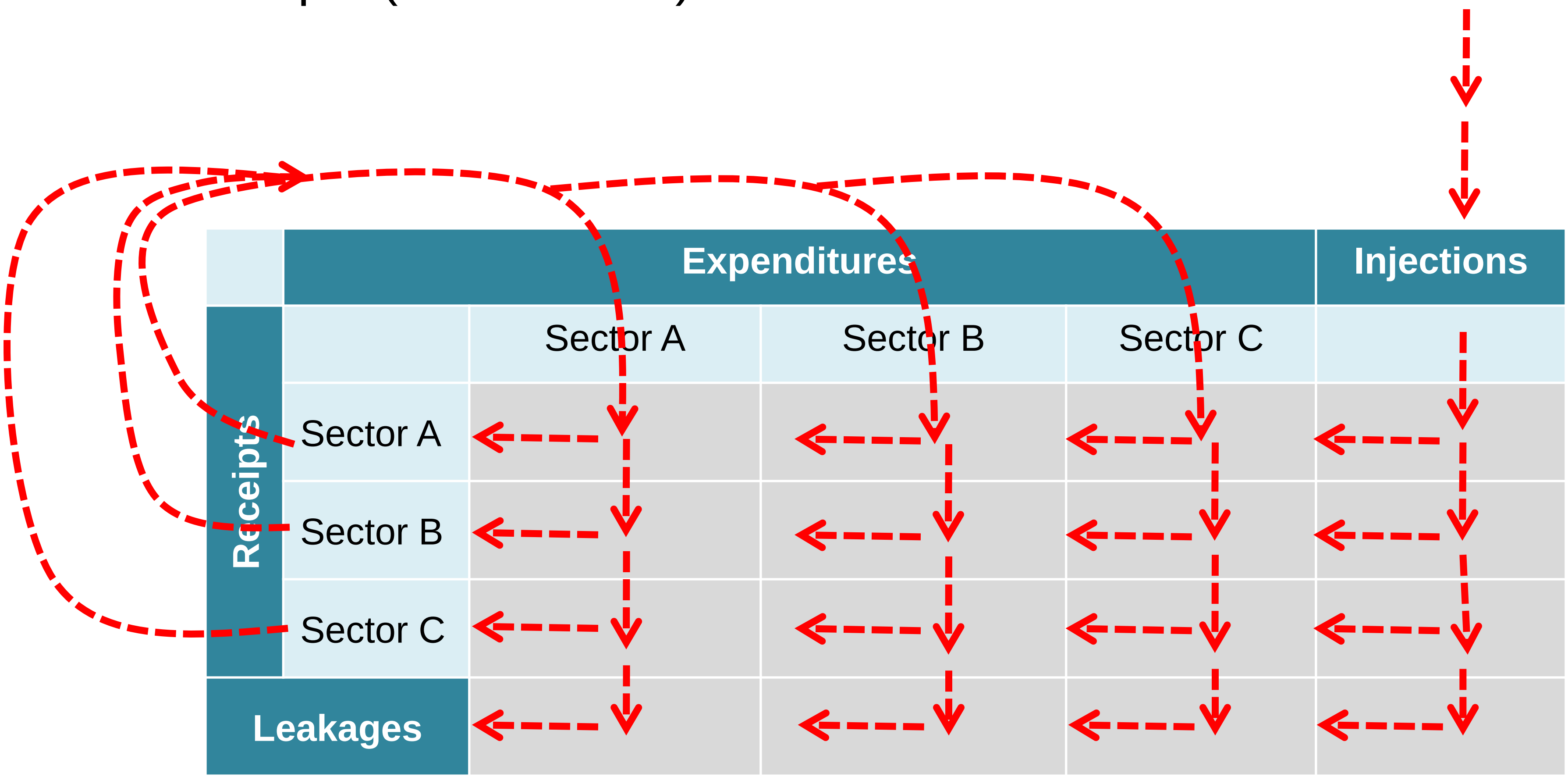
Modeling the community economy

- A <u>social accounting matrix</u> (SAM) shows flows among sectors
- Data can be assembled at level of village, region, nation
- Columns are expenditures, rows are receipts
- For each sector, total expenditure (column sum) must equal total receipts (column sum)



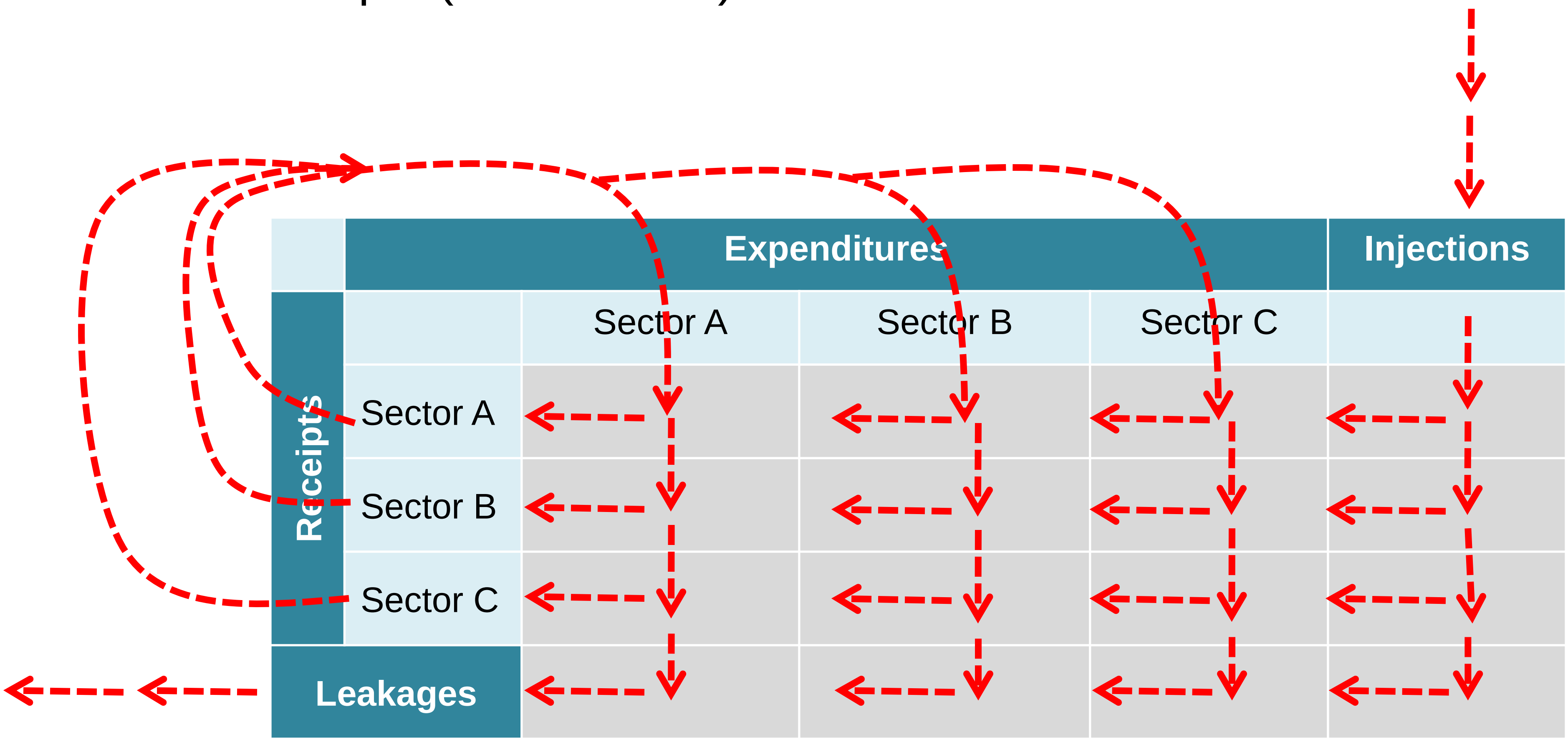
Modeling the community economy

- A <u>social accounting matrix</u> (SAM) shows flows among sectors
- Data can be assembled at level of village, region, nation
- Columns are expenditures, rows are receipts
- For each sector, total expenditure (column sum) must equal total receipts (column sum)



Modeling the community economy

- A <u>social accounting matrix</u> (SAM) shows flows among sectors
- Data can be assembled at level of village, region, nation
- Columns are expenditures, rows are receipts
- For each sector, total expenditure (column sum) must equal total receipts (column sum)



Aggregated Social Accounting Matrix

Receipts	Expenditures					
	Activities	Factors	Institu-tions	Capital	External flows	TOTALS
Activities						
Factors						
Institu-tions						
Capital						
External flows						
TOTALS						

Breakdown of mountain-region SAM accounts

1. Economic activities
    A. Farming
        A. Irrigated small-holder farming
        B. Rain-fed small-holder farming
        C. Large-scale farming
    B. Livestock
    C. Forestry
        A. Timber cutting
        B. Firewood production
        C. Charcoal production
        D. Sawmilling
    D. Manufacturing
        A. Small-scale manufacturing
        B. Large-scale manufacturing
    E. Construction
    F. Retail
    G. Tourism
    H. Other services

Breakdown of mountain-region SAM accounts

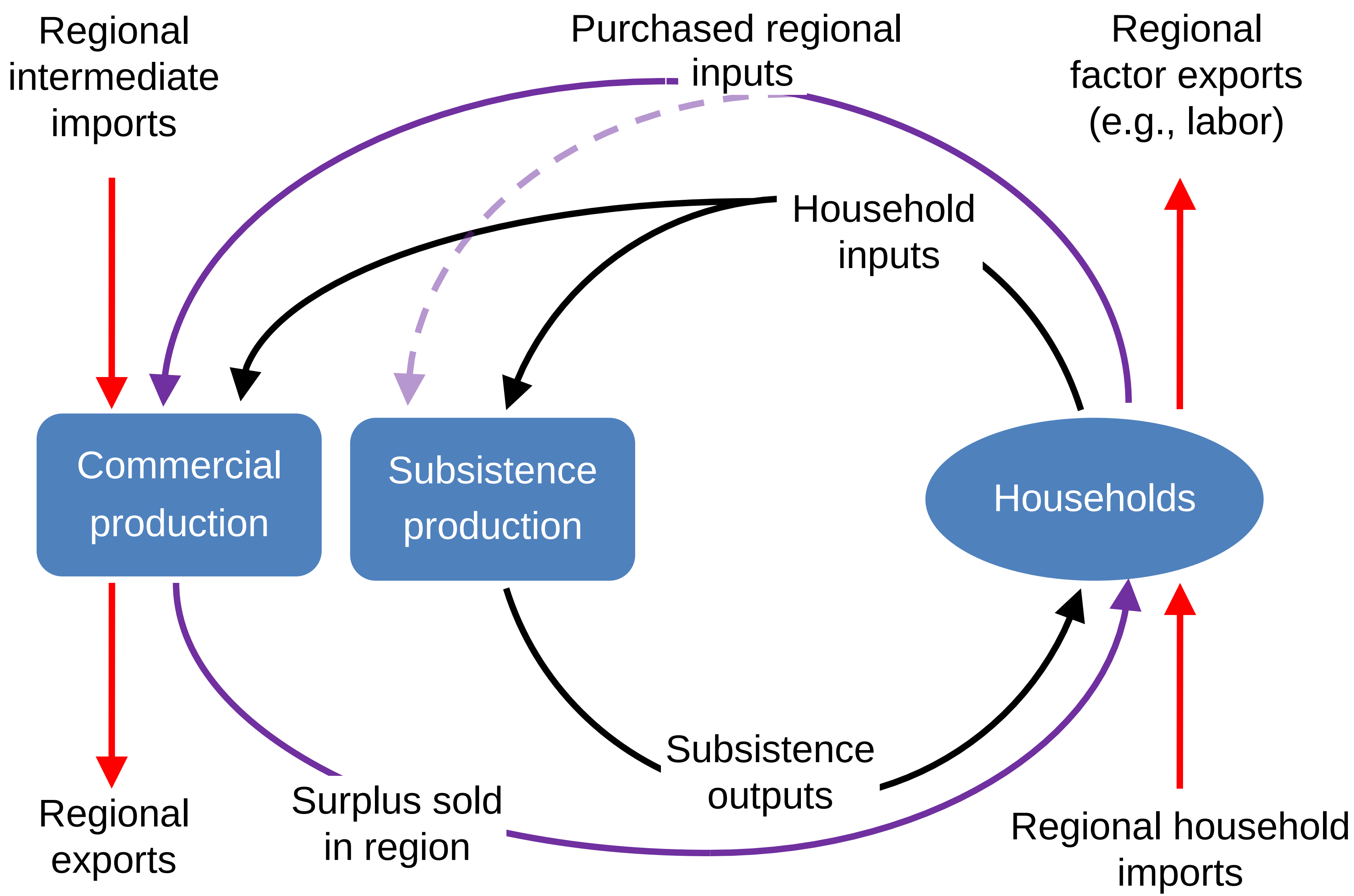
(continued)

2. Factors of production
   A. Physical capital
   B. Natural capital
      1) Forest stock
      2) Water stock
   C. Family labor
   D. Hired labor
3. Institutions
   A. Landless households
   B. Small-holder households
   C. Large-holder households
   D. Local government
   E. Regional (provincial) government
   F. National government
4. Savings-investment
5. External flows

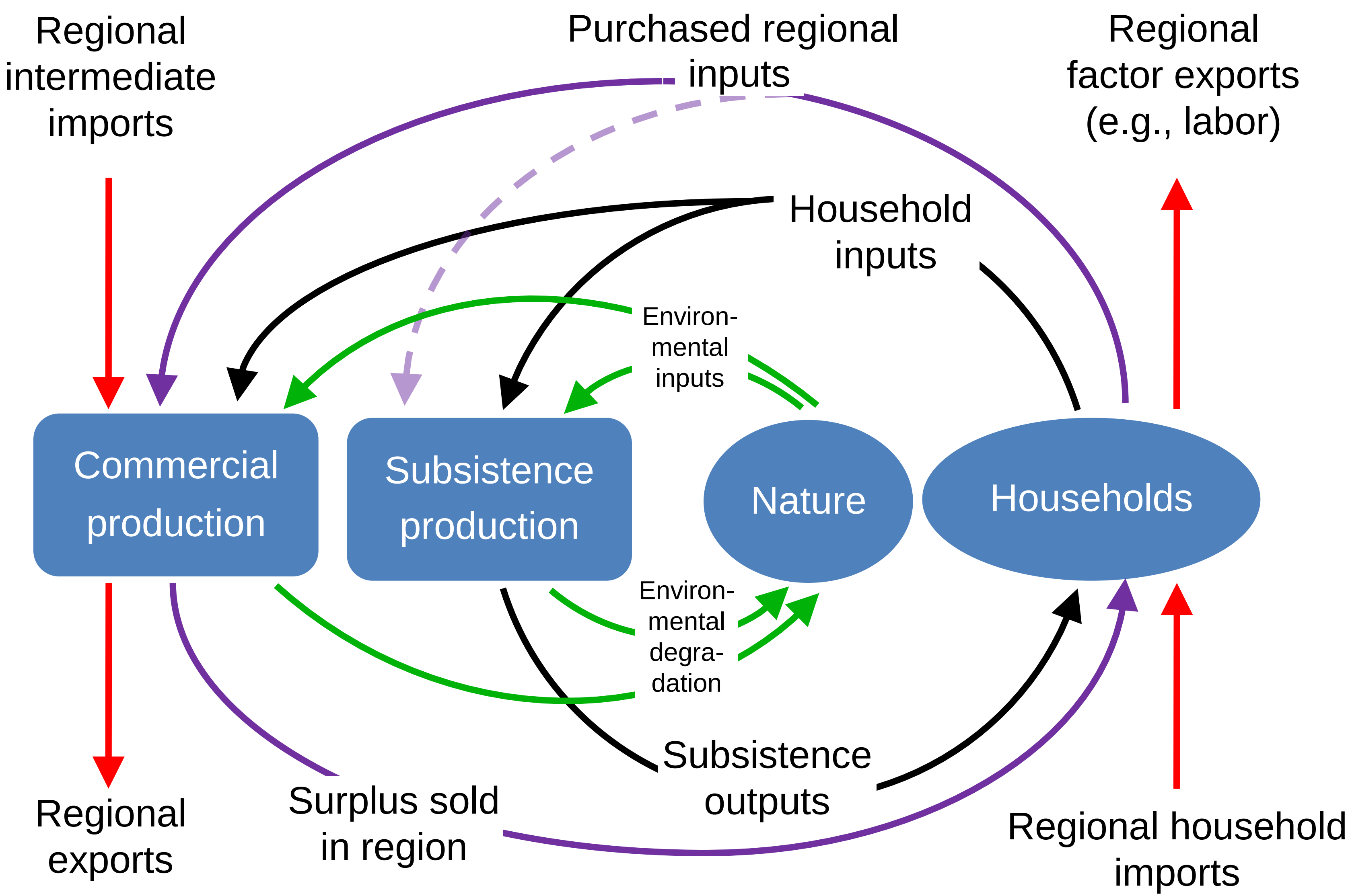
Content of aggregated mountain-region SAM

Receipts		Expenditures					
		1 Activities	2 Factors	3 Institu-tions	4 Capital	5 External flows	6 TOTAL
1	Activities	Local intermediate inputs		Consumption & government purchases	Local investment goods	Exports	Gross value of output
2	Factors	Value added					Total value added
3	Institu-tions	Activity taxes	Payments to HH for factor services	Income taxes & transfers		Migrant remittances	Total HH and government income
4	Capital			HH savings & government surplus		External savings inflows	Total savings
5	External flows	Commodity imports			Imported investment goods		Gross outflows
6	TOTAL	Gross cost of production	Total factor income	Total household income	Total investment	Gross inflows	

Computable General Equilibrium Model



Environmental Computable General Equilibrium Model



Economic modeling

- Geographical levels
  - Household level
  - Village level
  - Region level (upstream → downstream)
- Solution stragegy
  - Initial equilibrium in period 1
  - Update stocks of factors and resources
  - Solve model for period 2
  - Update stock of factors and resources
  - Iterate through multiple periods
  - Counterfactual analysis: introduce changes
    - Timing and availability of water; soil quality changes; technological change; crop price changes; etc.

The end