

# Can Agent-Based Models of Land Use Bridge the Gap between Process and Pattern Based Models?

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*With contributions also from many others!*

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# Outline:

- Identified advantages of and challenges for ABM/LUCC (2008)
- As illustrated through some ongoing work:
  - Modeling joint effects of LUCC and land manager behavior (Residential development in the deciduous US)
  - Parameterizing models using qualitative and quantitative data (Smallholder agriculture in Uganda)
  - Knowledge synthesis and knowledge discovery (the MR POTATOHEAD framework)

# Why the interest in ABM?

- “Change” of modelling approach?
- ABM seen as a tool for building:
  - finer-scale process-based models
  - with more flexible representation compared to analytical or systems dynamic models
  - with the ability to incorporate theories and drivers from many social science perspectives
  - facilitating spatially explicit, fine scale, coupled models of human-environment interaction in the land system

# Can ABM address these challenges?

- Bridge the gap between theoretical/process-based and empirical/pattern-based modeling
- Model 3-way feedbacks between land-use/management, land cover, and landscape function
- Perceived hurdles
  - Empirical parameterization of theoretical processes
  - Data needs
  - Performance assessment standards (validation)

# Other open (perhaps useful) questions:

- What is the role for statistical models in parameterization, calibration, verification, and validation of ABMS? (See also Santa Barbara talk/position paper)
- How can local-fine scale ABMs contribute to development of:
  - Regional and global LUC models
  - Theory/frameworks of land-change science

For context: Three ongoing projects

# *Exploring changes in residential land use and land management via ABM land market models*

- Goal is to develop agent-based models of residential suburban and ex-urban land markets that:
  - Connect land market and land management behavior of residential agents
  - Allow exploration of the relative contributions of land-use vs.. land-management change (categorical change and change in intensity) to environmental changes
- Apply models to the Potomac Gorge watershed (DC metro area) and Southeastern Michigan
- Explore the value added of the land market component through comparison to comparable models without a land market component

# *Environmental impacts of residential development*

- Suburban and ex-urban development bring about environmental change
- Evaluation of impacts requires understanding of:
  - Location and timing of land-use change
  - Characteristics of new or modified development
  - Land management behavior of new land managers
- Three factors jointly determined via land market interactions

# *Residential development and water quality (Potomac Gorge)*

- Residential land use contributes to decreased water quality through increased nutrient loadings and changes in hydrology (flow)
- Main research question: What linkages exist between residential land use in the Potomac Gorge watershed (DC area) and the degradation of water quality in tributary streams (a primary threat to rare and endangered species in the Gorge)
- Pilot project in progress (nutrient modeling, land manager behavior model, participatory front-end) with proposed extensions (land market model, flow model)

# Water quality changes: Sources and impacts



# *Residential development and carbon sequestration*

- Landscaping choices in existing and new developments may have dramatically different carbon profiles
- Main research question: Will ex-urban development in Southeastern Michigan produce a landscape-scale source or sink of carbon, given observed landscaping strategies of developers and landscaping preferences of residential agents?
- Proposed collaboration with UM (Dan Brown et al.) to extend Project SLUCE

# *Residential development and landscape change*



# *Sources of environmental impacts: character/intensity of new land use*

Residential development is not homogeneous. Both water quality and carbon profiles will depend on:

- Built/constructed environment:
  - Building footprints
  - Lot sizes and setbacks (roads and driveways)
  - Construction-stage BMPs (wet/dry detention basins; pavement types)
- Landscaping choices
  - Tree removal/planting
  - Turf grass extent
  - Horticultural choices
    - Native vs. non-native
    - Annuals vs. perennials

# *Sources of environmental impacts: Behavior of resident land managers*

Land managers are not homogeneous. Water quality and carbon profiles also depend on:

- Landscaping preferences and practices
  - Tree, turf, and horticultural choices also
  - Fertilizer and pesticide use
  - Management of organic matter and debris
- Willingness to adopt BMPs:
  - Green roofs
  - Rain gardens
  - Pervious pavers
- Evidence from human ecology/environmental sociology/economics that these two factors vary with agent resources, information, attitudes, beliefs, and values & neighborhood influences

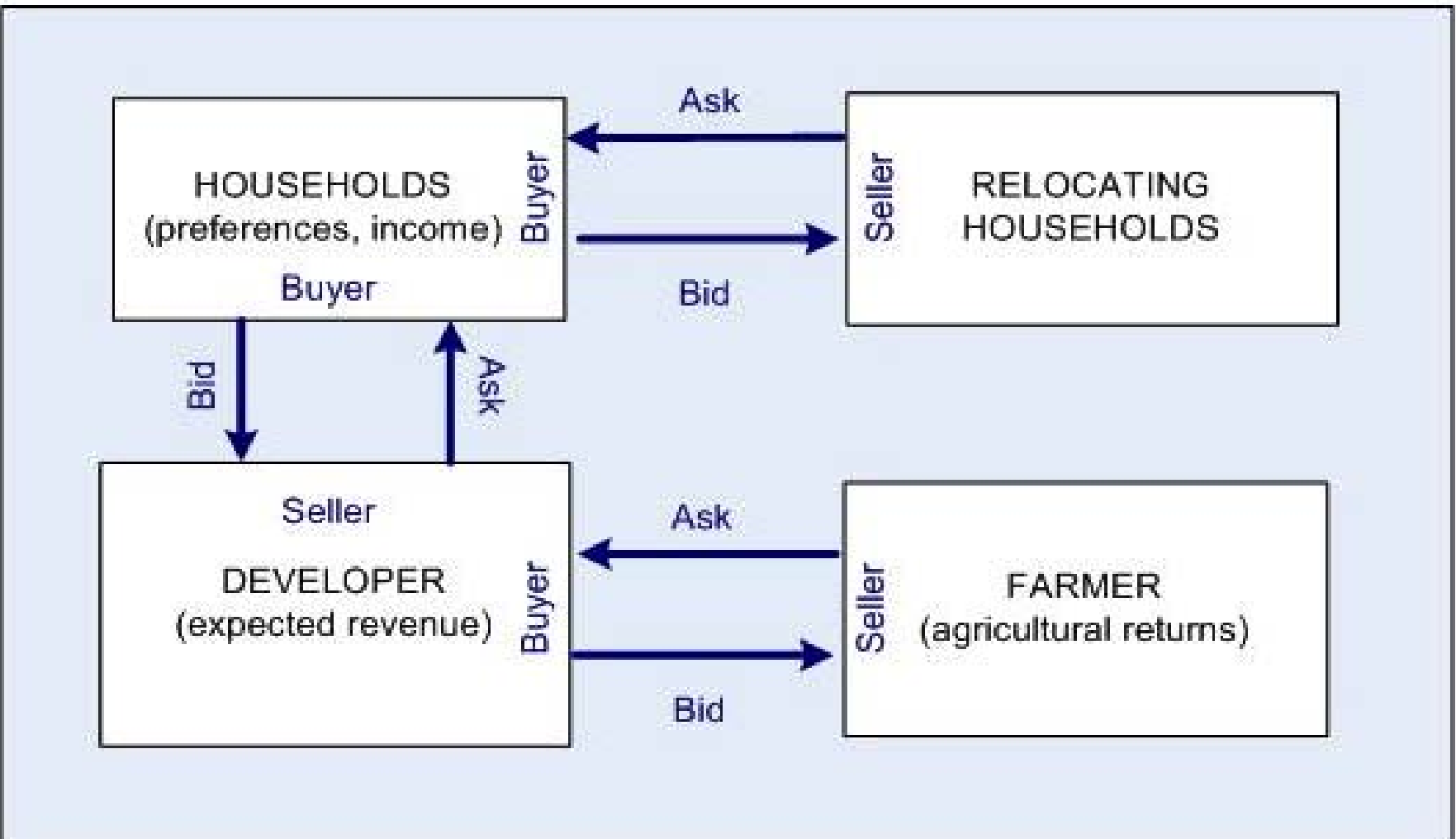
# *Role of land markets in addressing research questions*

- Land markets determine both:
  - The location, timing, and pattern of residential conversion;
  - The socioeconomic and cultural characteristics of new residents.
- These two factors influence:
  - The character/intensity of the new land use;
  - The environmental behaviors of new residents.

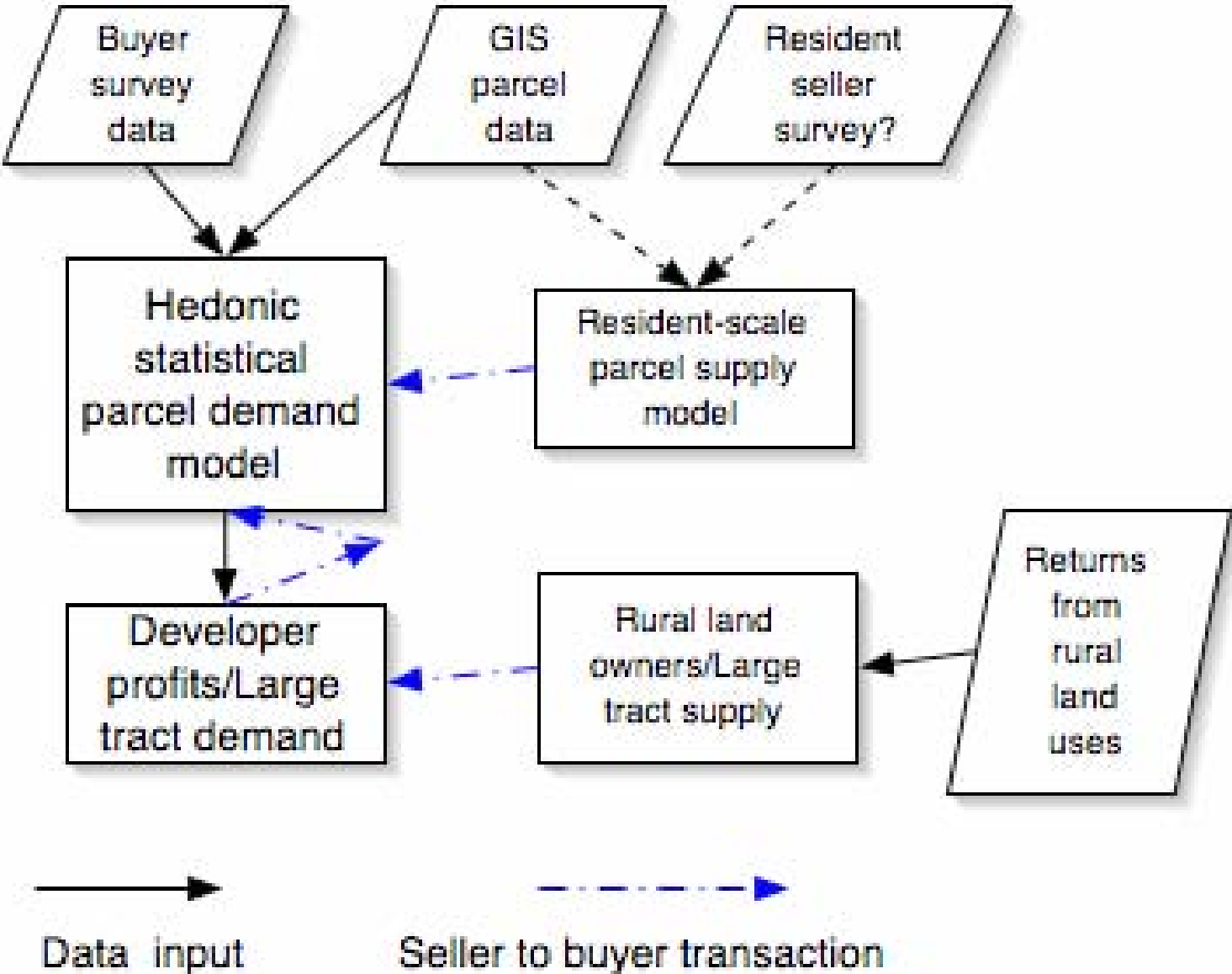
# *Potential value added from agent-based models of land markets*

- Ability to include both agent-level drivers such as:
  - Resources (income, credit availability)
  - Preferences (open-space amenities, commuting tolerance)
- And spatial drivers:
  - Open space amenities/surrounding development
  - Transport costs
- Allows sensitivity analysis w.r.t. both, and exploration of the interactions between agent-level and spatial drivers of LUCC

# Representing complex buyer-seller relationships (Parker and Filatova, in review)



# Empirical land market conceptual diagram



# Surveys: WTP and management behavior

- Potomac Gorge survey: location, location preferences, land management behavior, socioeconomic and cultural characteristics
- UM project: location, web-based landscape preference “shopping” experiments, new planned land management behavior survey, linked via development types
- In both cases, statistical models will be used to parameterize agent decision models (Robinson et al. 2007)

# Resident preference surveys (Nassauer)

		
<p>Conventional land cover</p>	<p>Increased area in tree cover</p>	<p>Increased area in tree cover and deep-rooted herbaceous species with stormwater detention.</p>

# Combining Quantitative and Qualitative Information to Parameterize an MAS Model of HIV-Affected Agricultural Households in Uganda



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Schreinemachers, University of  
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# Study objectives

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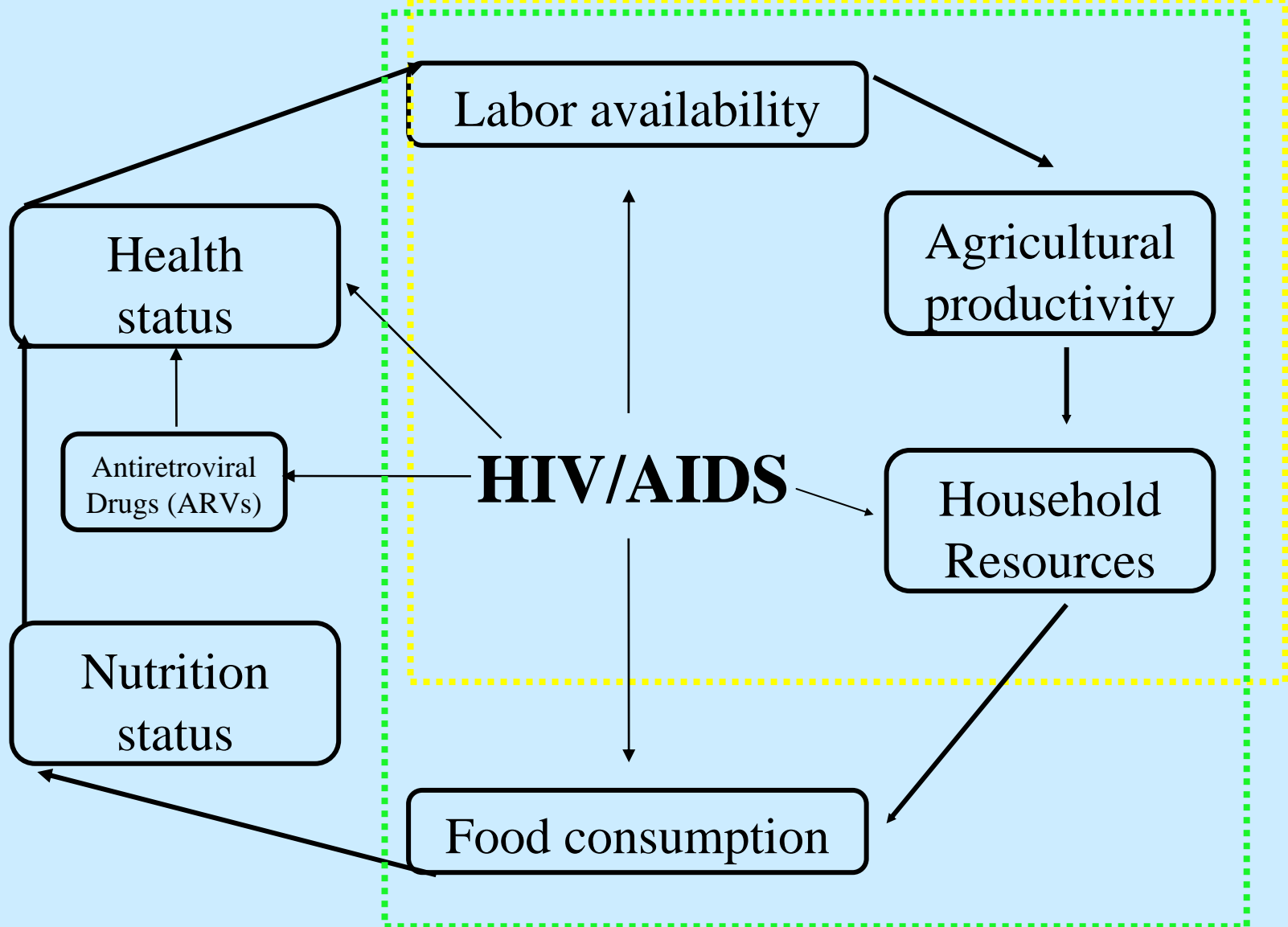
- To evaluate the impact of HIV/AIDS on agriculture households, including household labor availability, cropping choices, and household livelihoods.
- To explore the relationship between HIV/AIDS, food production, and nutrition in the affected households.
- To build a dynamic simulation model that integrates the following factors:
  - HIV/AIDS prevalence in a household;
  - household nutrition and health status;
  - labor availability;
  - agricultural production

# Research questions

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- What effects does the presence in the household of a person living with HIV/AIDS (PWA) have on both farming and non-farm activities?
- What are the effects of an individual living with HIV/AIDS on the health and nutritional status of the person with AIDS and other members of HIV/AIDS affected rural households?
- How do land tenure patterns and land ownership dynamics associated with HIV/AIDS affect the welfare of individual households and the distribution of wealth between households?
- Under what circumstances can the presence in the household of a PWA lead to a downward spiral of degradation of household welfare?
- What policy interventions would be most effective in reversing this spiral?

# Conceptual Framework-Household



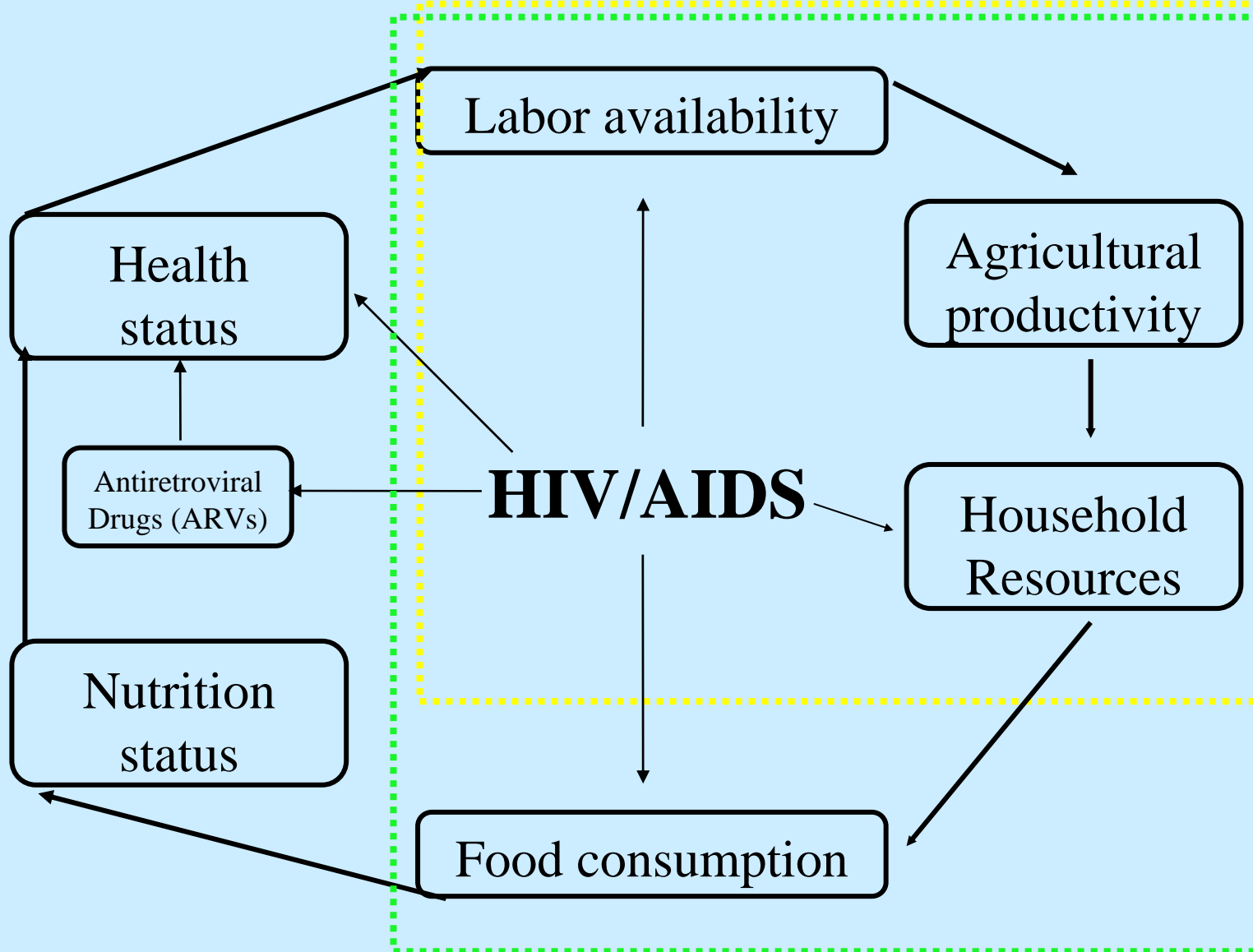
# Methodology

- Develop a series of multi-agent systems simulation models to explore research questions/hypotheses
- Model development supported by fieldwork to gather qualitative and quantitative data:
  - IFPRI household surveys
  - Household cropping survey (Schreinemachers, 2005)
  - Semi-structured interviews (Komwa, summer 2006)
  - Household surveys (Komwa, summer 2007)

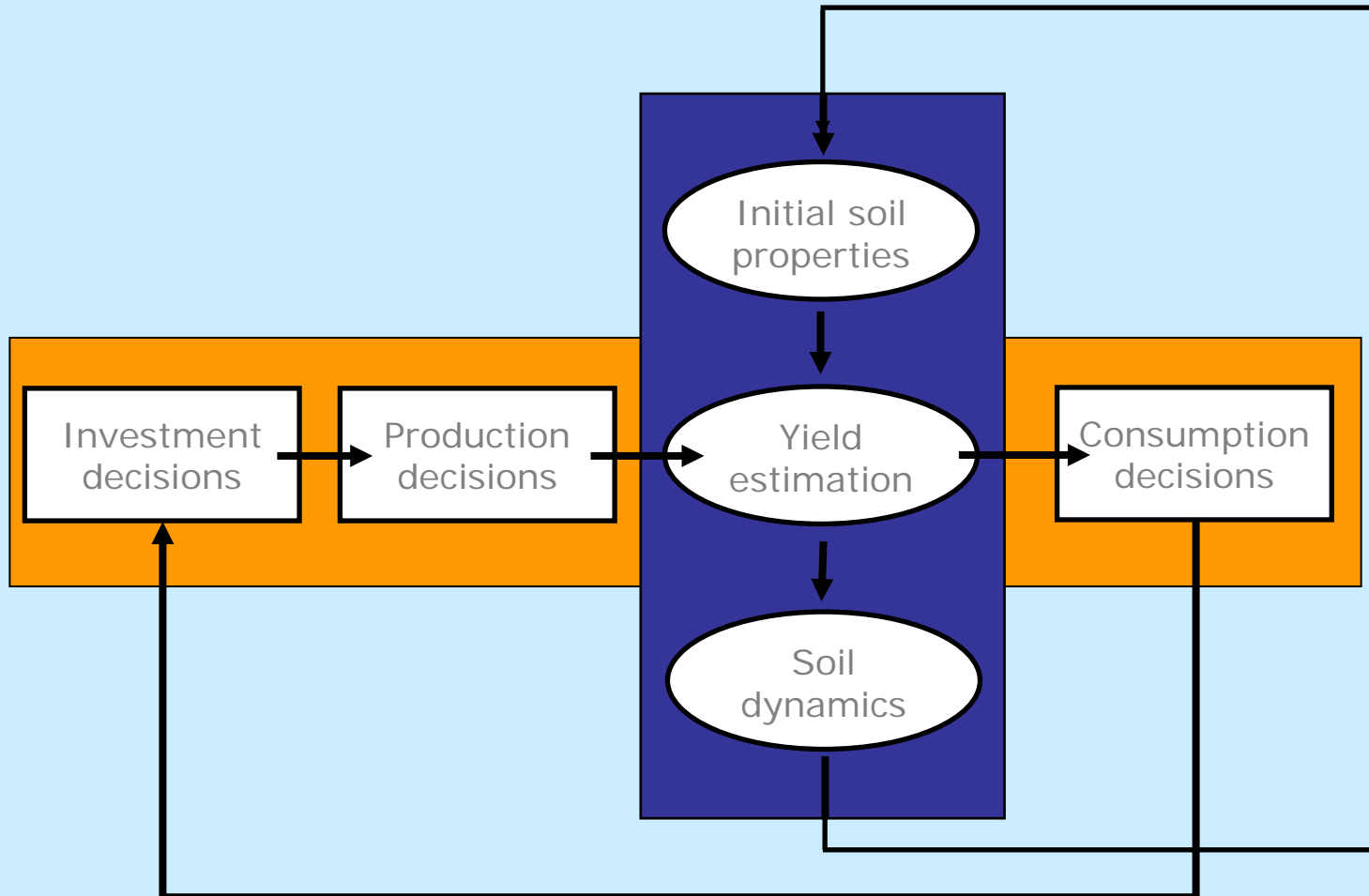
# Research stage 1 (Schreinemachers, PhD thesis)

- Core model combines:
  - Mathematical programming model of household decision making, calibrated using regression analysis of survey data
  - Soil fertility and crop yield model based on locally calibrated Tropical Soil Fertility Calculator
- Simple assumptions regarding labor losses and mortality from aggregate statistics

# Stage 1: gold box



# Berger/Schreinemachers household decision model

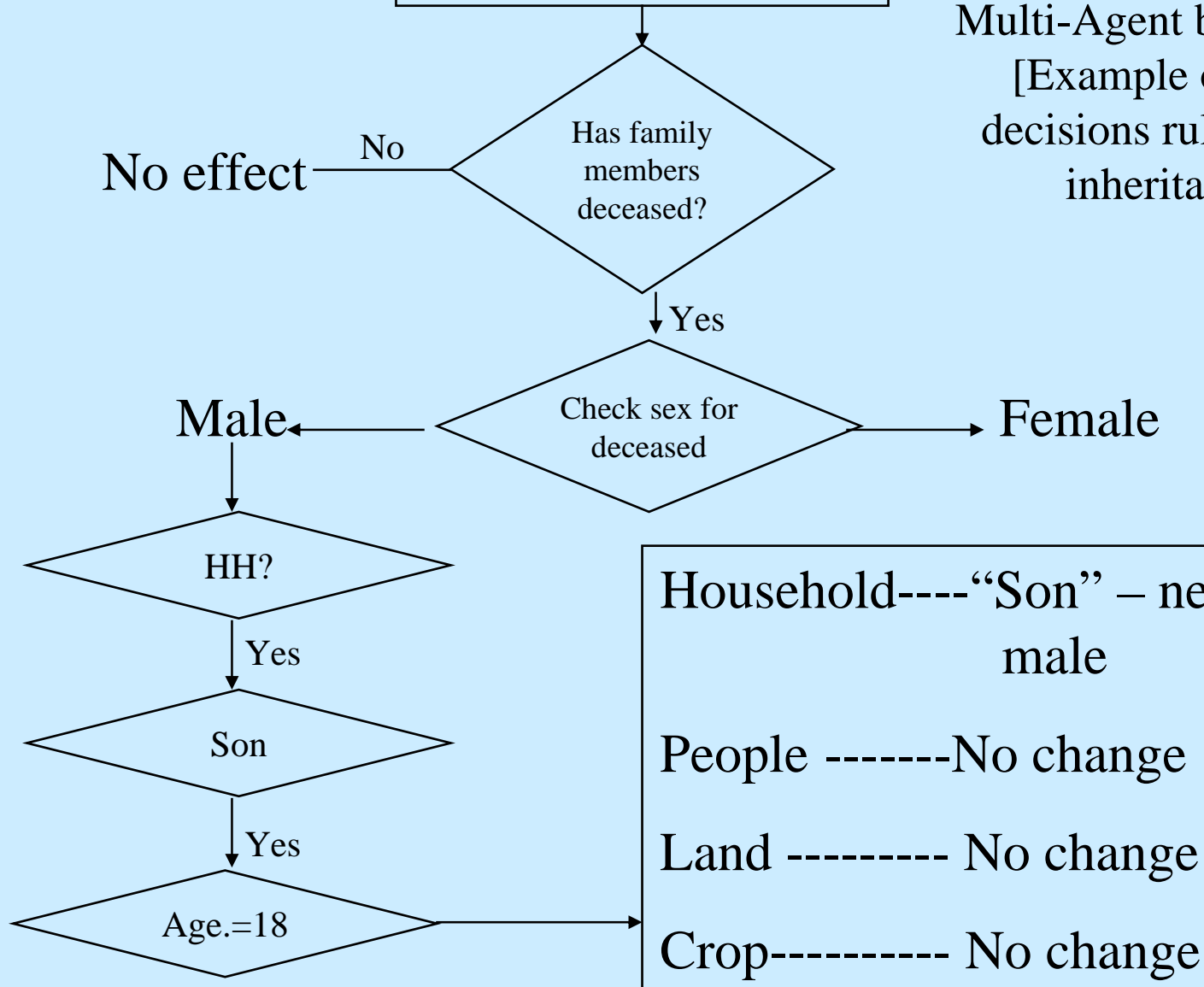


# Research Stage 2 (Komwa, Parker, Berger, Schreinemachers)

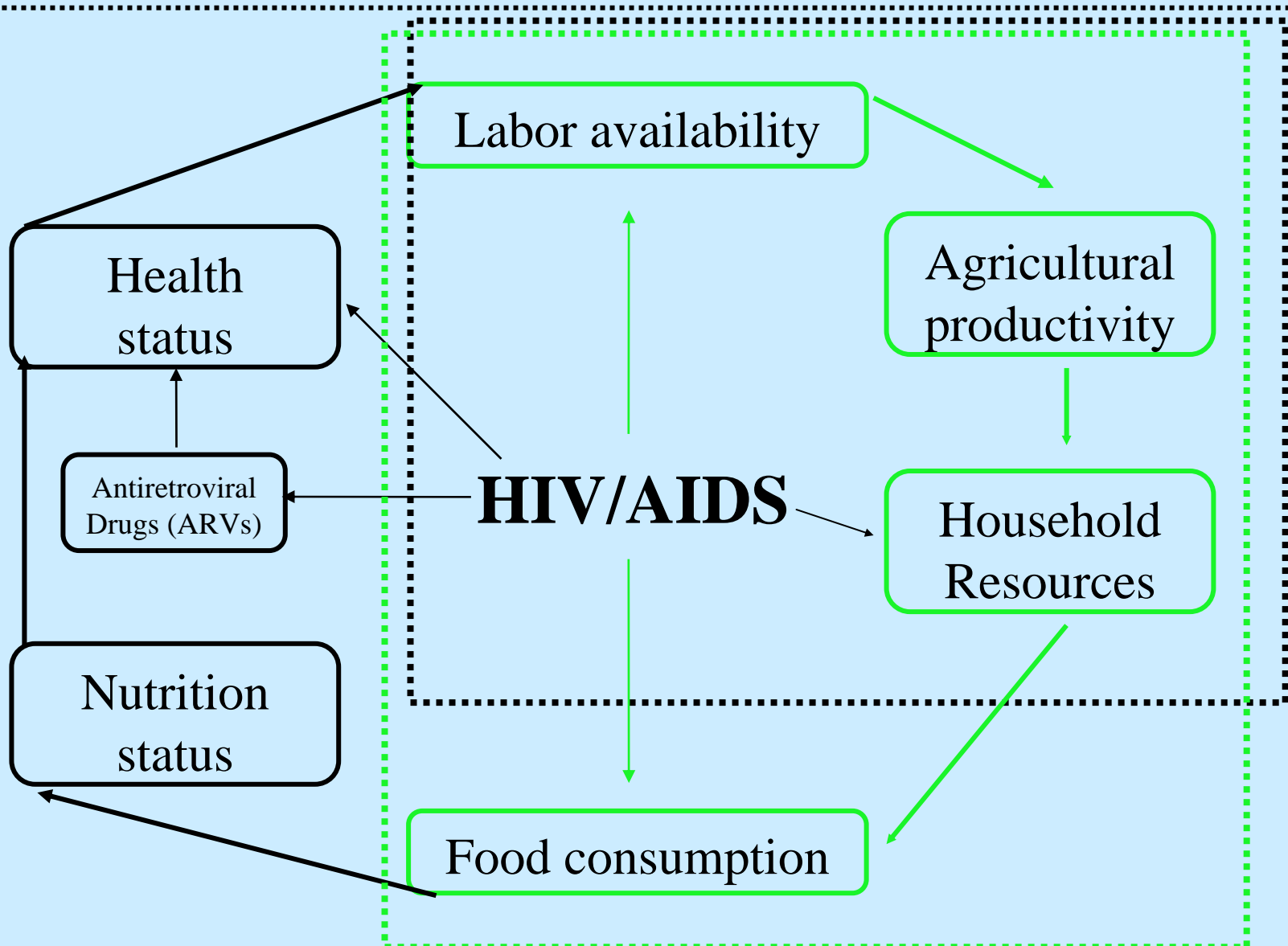
- **Model 2** seeks location-specific data on changes in:
  - Household structure and composition
  - Labor losses throughout household
  - Fate of household assets (land, livestock, household members) following a death
  - HIV-related expenses
  - Crops grown
- Focus of 2006 semi-structured interviews
- Data used to modify rules from first MAS model
- New model rules are both quantitative (eg, expenses) and qualitative

# Inheritance within family

Multi-Agent based model  
[Example of sets of decisions rules on land inheritance]--



# Stage 2: green box



# Potential value added from Model II

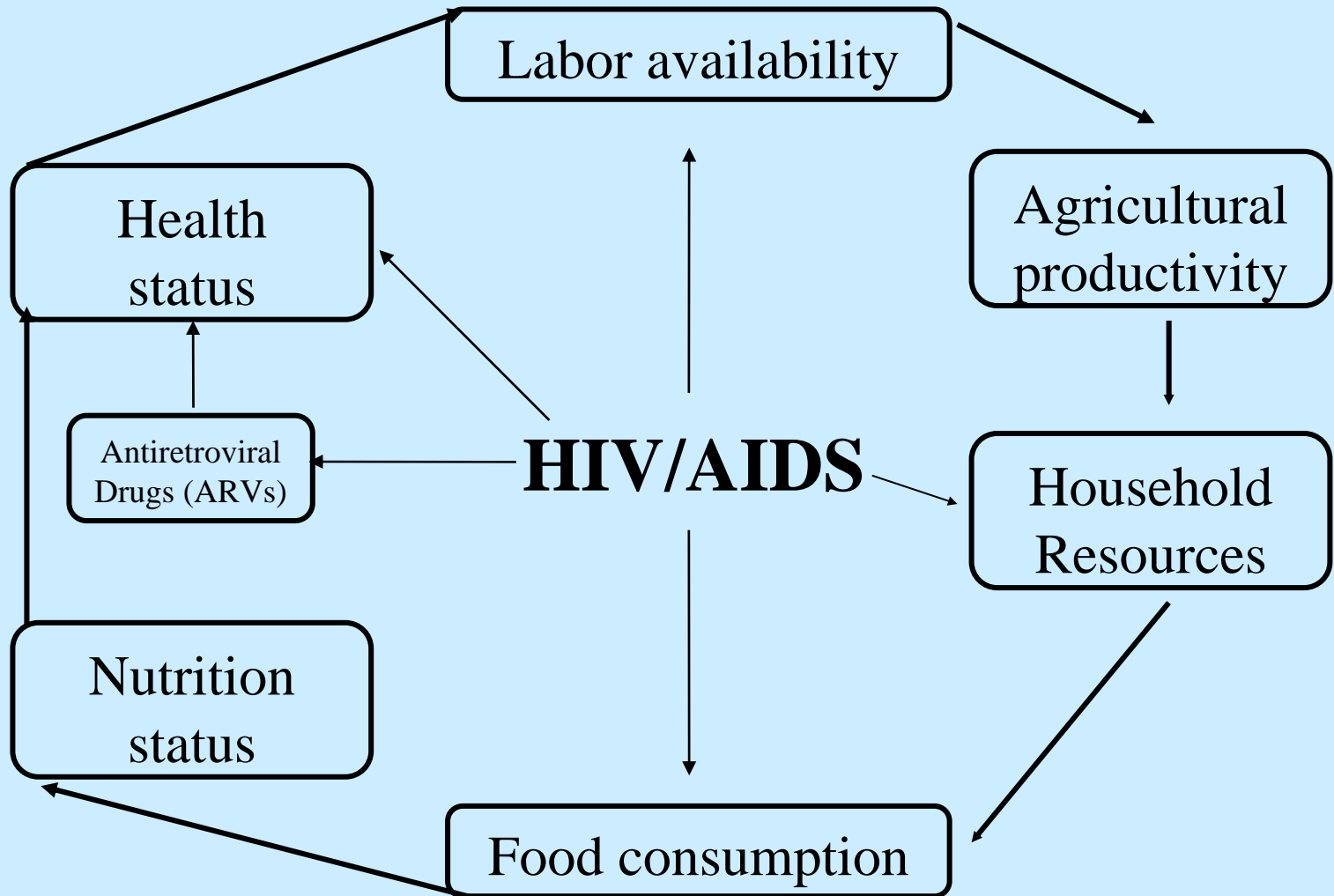
- More robust labor loss and expense estimates  
-> more robust answer to main research question
- Better understanding of heterogeneous roles and impacts--especially related to gender and initial economic status
- May help identify which households are most vulnerable to a downward spiral of livelihood degradation, and which policy interventions might be most effective

# Research stage 3: Nutrition and health

- **Model 3:** seeks to endogenize the effects of household nutrition on health status
- Collaboration with social epidemiologist from Mason (K. Jacobsen)
- Development to be supported by detailed household survey (expanded geographic area, 247 surveys); providing data on food consumption, health status (height/weight and self reports) as well as cropping decision, labor, and land tenure
- Will allow us to validate previous rules, estimate new rules, and simulate effects of a broader range of policy interventions

# Stage 3: Endogenizing health and nutrition

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# Initial comparisons of two surveys

- “Special foods” to support health of PWAs:
  - Qualitative surveys revealed reported importance of these foods
  - Quantitative data seem to support their importance and consumption
- Labor effects
  - Qualitative and quantitative surveys report belief that PWAs should voluntarily reduce work hours
  - Not yet revealed in analysis of survey data
  - Difference between stated and actual behavior

# Relevance for development of ABM

Opportunity to compare results of models whose decision rules are parameterized using three alternative approaches:

- Simple rules based on aggregate data
- Local data obtained via qualitative and quantitative expert/stakeholder interviews
- Rules based on quantitative analysis of household-and-individual level survey data

# Relevance for ABM, cont.

Opportunity to compare alternative statistical approaches for parameterizing ABMS

- Regression analysis to create labor supply and food demand functions
- Cluster analysis to identify household types
- Other ideas?

# ABM, knowledge synthesis, and discovery

- Can contribute to knowledge synthesis by integrating interdisciplinary sub-models
- Can contribute to knowledge discovery
  - During model building (esp. stakeholder participation and companion modeling)
  - Through experiments that link human and biophysical drivers of LUCC and outcomes
- Proposed as a framework to extend and synthesize LUCC theory

# The MR POTATOHEAD framework (Parker et al. in press a,b)

- Expressed as a conceptual, object-oriented classification of elements that are essential for an ABM/LUCC model, with alternative instances
- Seven ABM/LUCC models described via MR POTATOHEAD as special cases of the general meta-model
- Model instantiated in Web Ontology Language with the goal of model comparison and meta-model creation

# MR POTATOHEAD: longer-term goals

- Create a simple code base that nest the 7 models (perhaps more) as special cases
  - Allows for formal comparison of model structures and results
  - Facilitates comparative experiments to explore alternative parameter spaces
  - Provides code base for new model creation
- Build a graphical modeling front-end
  - Educational use
  - Reduces barriers to entry to the field
- Start over with a new model built around land use/management, land cover, and landscape function?

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