Exploring effects of factor configurations in a "toy" migration agent-based model

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Abstract

Migration is a complex and interdisciplinary problem involving multiple factors such as social interactions, resource scarcity, and geographical features. These factors must be incorporated in migration models, but how? We feel that the issue how different factors should be incorporated is not carefully addressed in existing models. Configuring factors in ways that are theoretically unsound can lead to false migration patterns and undermine the usefulness of models; indeed, factor configurations may be more critical than the factors themselves or other inputs. Therefore, we ask: i) How important is factor configuration to output results comparing with other inputs?; ii) How do different factor configurations produce different migration patterns?; and iii) How can multimodality of certain output distributions be controlled in a management perspective? To address the questions, we develop a "toy" migration agent-based model (ABM) and explore three possible configurations between two factors: i) two factors are perfectly substitutable (ADD), ii) both factors are indispensable (AND), and iii) either is enough (OR). ABM results are analyzed by global sensitivity analysis (GSA) and Monte-Carlo Filtering (MCF). The relative importance of factor configurations quantified by GSA emphasizes why we need to consider how the factors are incorporated. Depending on factor configurations, we also observe unimodal or multimodal output distributions. MCF is then applied to the ABM-GSA results to address how policymakers should control certain inputs to sustain systems with desirable outputs. Altogether, we have integrated ABM, GSA, and MCF to disentangle complexity of migration models and better understand underlying mechanisms and patterns of migration.

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1 Introduction

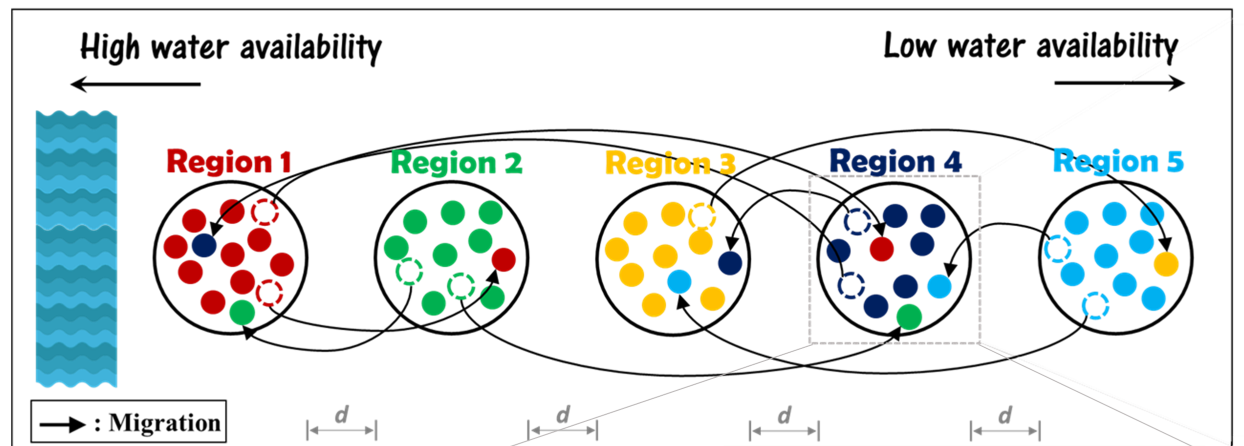
Migration is a complex problem with multiple drivers where social and natural factors must be incorporated. Many scholars have highlighted "why" different factors should be combined, yet few studies have focused on "how" they should be combined. Factor configurations without theory can yield incorrect and/or misleading migration patterns and obscure the model's usefulness.

This study uses **an ABM** to investigate the issue.

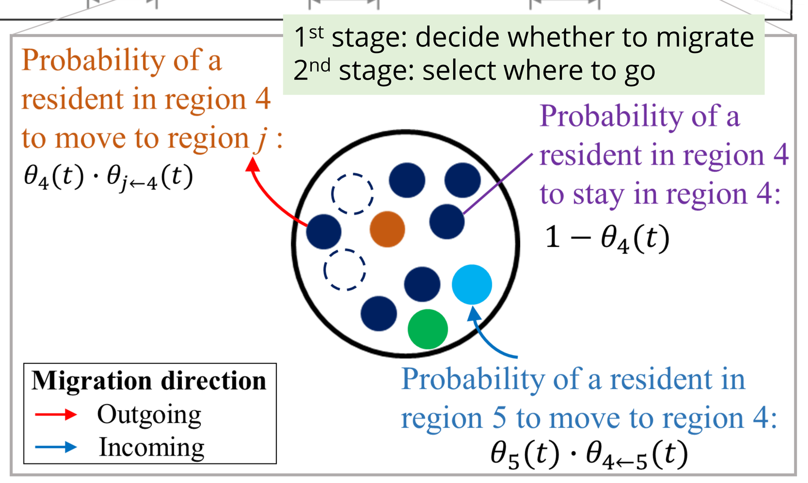
We find out whether alternative **configurations between social and natural factors are critical in migration modeling** generating **different migration patterns** and interpret **how a policymaker could manage differently in each configuration**.

2 Model design

Agent-based model (ABM) is a bottom-up approach that captures how **agents** follow different **rules** and **interact** with each other in **environments**.



Agent: Residents
Environment: Cities
Interactions/rules:
- People are more likely to move to regions with stronger cultural affinity and enough water.
- Water is distributed with the same amount to residents within the region.



3 How are social & natural factors combined?

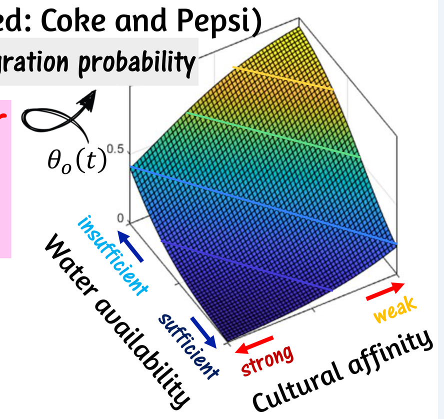
ADD configuration (ex. The total of cola soft drink consumed: Coke and Pepsi)
One factor is obtained at the expense of another factor.

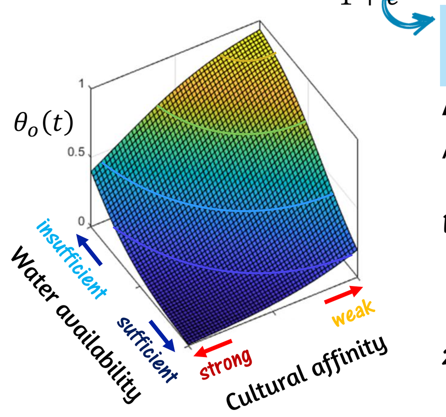
1st stage $$\theta_o(t)=\frac{e^{\beta_1^{(1)}(\alpha_1-x^{(1)})+\beta_1^{(2)}(\alpha_2-x^{(2)})}}{1+e^{\beta_1^{(1)}(\alpha_1-x^{(1)})+\beta_1^{(2)}(\alpha_2-x^{(2)})}}$$

2nd stage $$\theta_{j\leftarrow o}(t)=C_{ADD}\frac{e^{\beta_2^{(1)}\Delta x_{jo}^{(1)}+\beta_2^{(2)}\Delta x_{jo}^{(2)}+\beta_2^{(3)}\Delta x_{jo}^{(3)}}}{1+e^{\beta_2^{(1)}\Delta x_{jo}^{(1)}+\beta_2^{(2)}\Delta x_{jo}^{(2)}+\beta_2^{(3)}\Delta x_{jo}^{(3)}}}$$

Social factor related to cultural affinity

Natural factor related to water availability





AND configuration (ex. water and sunlight for plants)
A resident migrates when both factors are insufficient.

1st stage $$\theta_o(t)=\left(\frac{e^{\beta_1^{(1)}(\alpha_1-x^{(1)})}}{1+e^{\beta_1^{(1)}(\alpha_1-x^{(1)})}}\right)\left(\frac{e^{\beta_1^{(2)}(\alpha_2-x^{(2)})}}{1+e^{\beta_1^{(2)}(\alpha_2-x^{(2)})}}\right)$$

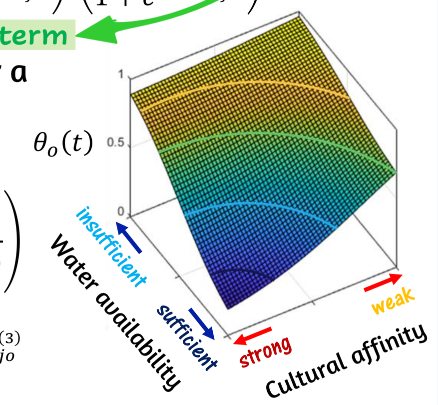
2nd stage $$\theta_{j\leftarrow o}(t)=C_{AND}\left(\frac{e^{\beta_2^{(1)}\Delta x_{jo}^{(1)}}}{1+e^{\beta_2^{(1)}\Delta x_{jo}^{(1)}}}\right)\left(\frac{e^{\beta_2^{(2)}\Delta x_{jo}^{(2)}}}{1+e^{\beta_2^{(2)}\Delta x_{jo}^{(2)}}}\right)e^{\beta_2^{(3)}\Delta x_{jo}^{(3)}}$$

Distance-related term

OR configuration (e.g., You need either a driver's license or a passport in the airport to take a flight)
Effect of one factor alone is sufficient for a resident to migrate.

1st stage $$\theta_o(t)=1-\left(1-\frac{e^{\beta_1^{(1)}(\alpha_1-x^{(1)})}}{1+e^{\beta_1^{(1)}(\alpha_1-x^{(1)})}}\right)\left(1-\frac{e^{\beta_1^{(2)}(\alpha_2-x^{(2)})}}{1+e^{\beta_1^{(2)}(\alpha_2-x^{(2)})}}\right)$$

2nd stage $$\theta_{j\leftarrow o}(t)=C_{OR}\left\{1-\left(\frac{1}{1+e^{\beta_2^{(1)}\Delta x_{jo}^{(1)}}}\right)\left(\frac{1}{1+e^{\beta_2^{(2)}\Delta x_{jo}^{(2)}}}\right)\right\}e^{\beta_2^{(3)}\Delta x_{jo}^{(3)}}$$



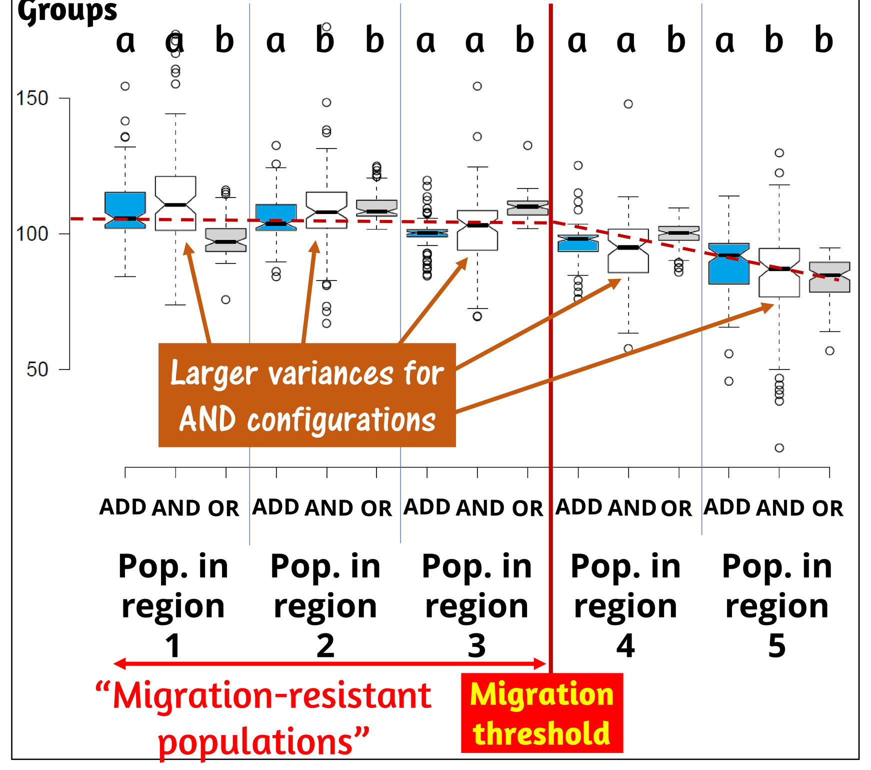
4 Analysis

Uncertainty analysis (UA) solves how uncertainty in inputs translate into uncertainty in outputs. In our model, inputs have uniform distributions around expected ranges. Then, we perform Monte-Carlo analysis.

We explore three cases of ADD+ADD, AND+AND, and OR+OR:

Each configuration has different migration patterns. Even in one configuration, multiple patterns may exist, building multimodality to the distribution. Besides, if a population is too spread, it needs to be controlled by a policy.

Outputs of different letters (a, b) are statistically different at α=5%



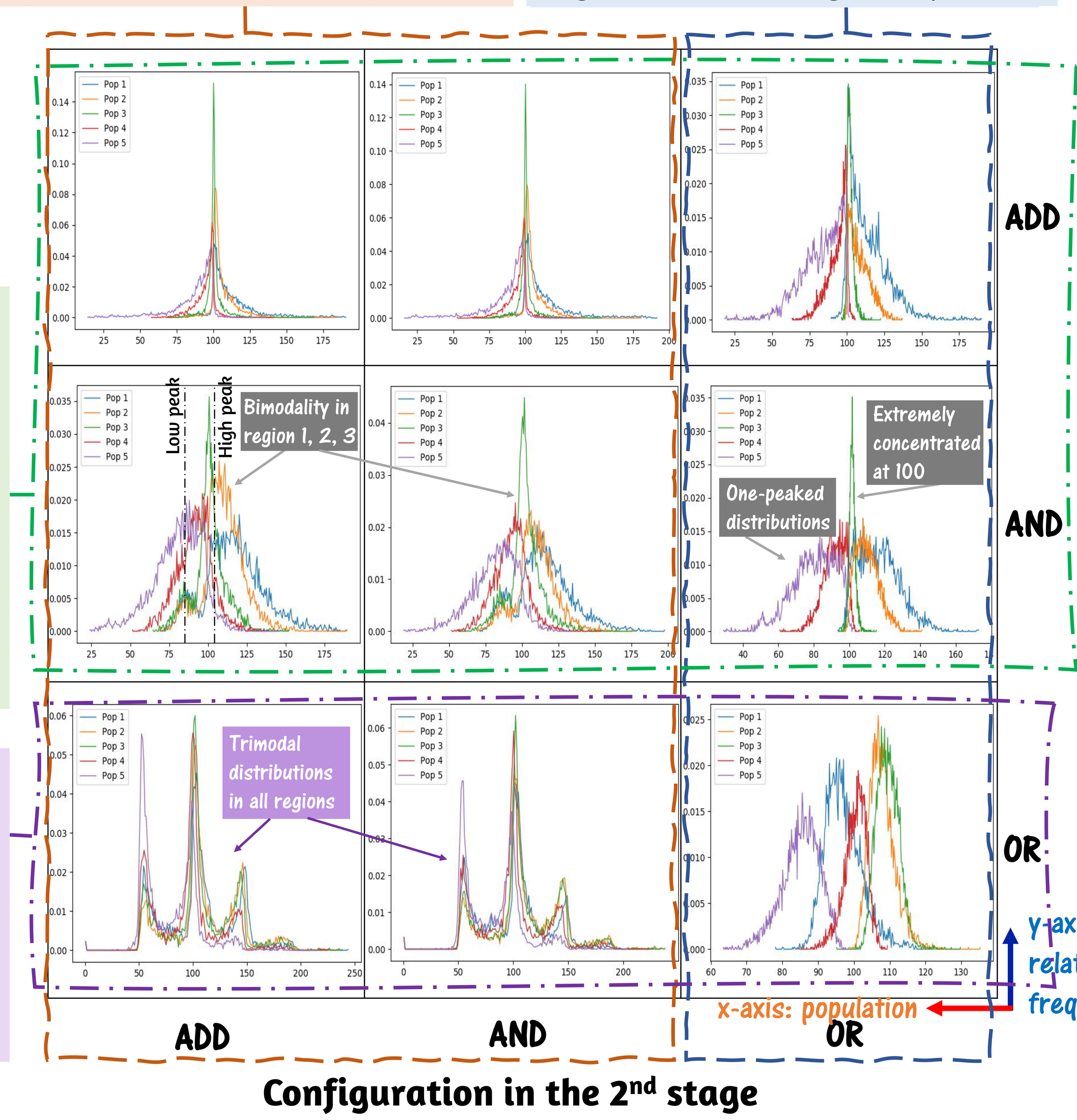
Largely, 5 regions are split into 2 super-regions. ADD+ADD and OR+OR configurations are always significantly different.

Now, ADD and AND configurations of the 1st stage are less similar compared to the those of the 2nd stage (red box). AND+ADD and AND+AND display bimodality which may indicate that multiple migration patterns lie even in a single configuration

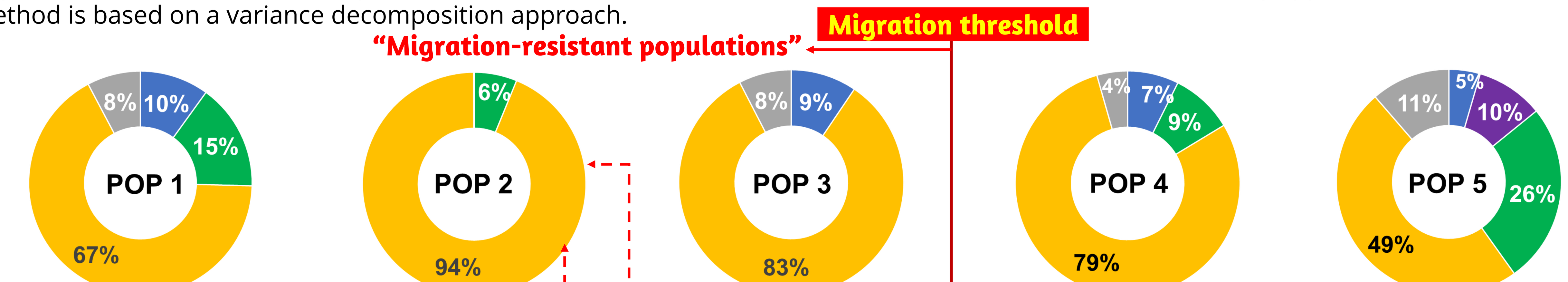
OR configuration of 1st stage even shows trimodality of populations, producing more complex patterns. Still in this case, OR-OR configuration is distinct from other two configurations.

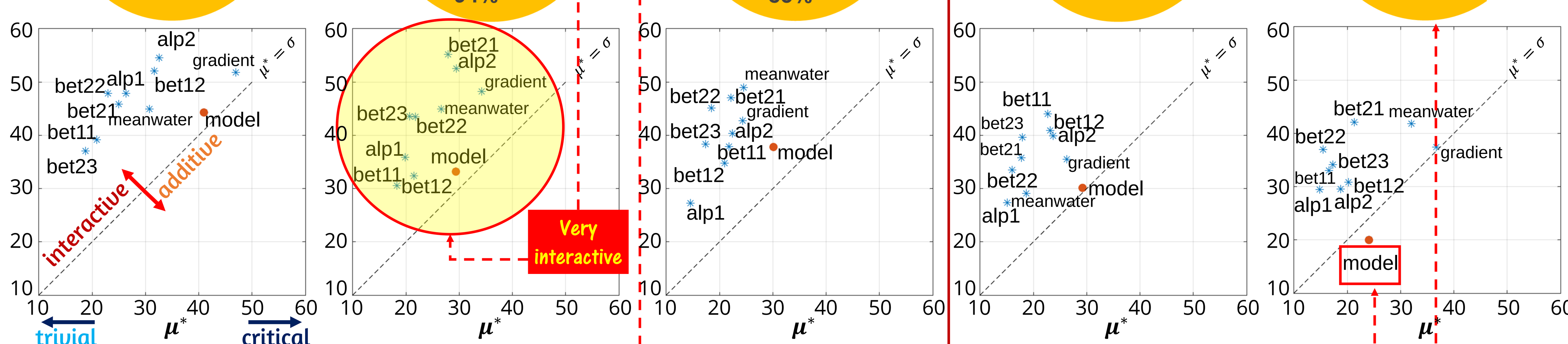
ADD and AND configurations of the 2nd stage have similar migration patterns.

However, OR configuration of the 2nd stage has different migration patterns.



Global sensitivity analysis (GSA) is a powerful tool to identify influential input factors controlling the system outputs of interest (equity, population fluxes, etc.). Here, we present two GSA methods: Morris and Sobol. Morris method takes a screening approach, whereas Sobol method is based on a variance decomposition approach.





- model: Factor configuration
- meanwater: Average water availability
- gradient: How equally water is distributed
- Interactions (high order effects)
- Others

A direct effect of configuration is very insignificant to the migration process. A change of it does not directly shift a migration pattern in region 2.

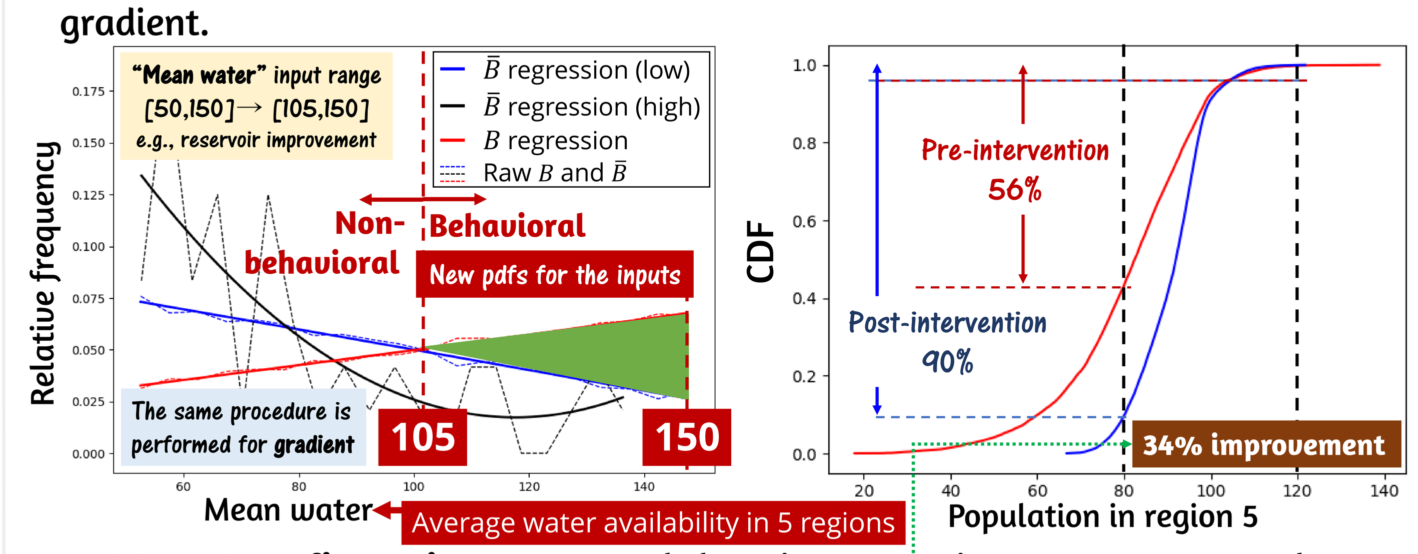
A factor configuration is an important factor to the migration patterns in five regions. It is a very interactive input and sometimes has almost zero direct effects as in region 2.

Configuration is less interactive but not highly critical compared to other regions. Inputs have high direct effects relative to other regions and thus interactions take a smaller portion.

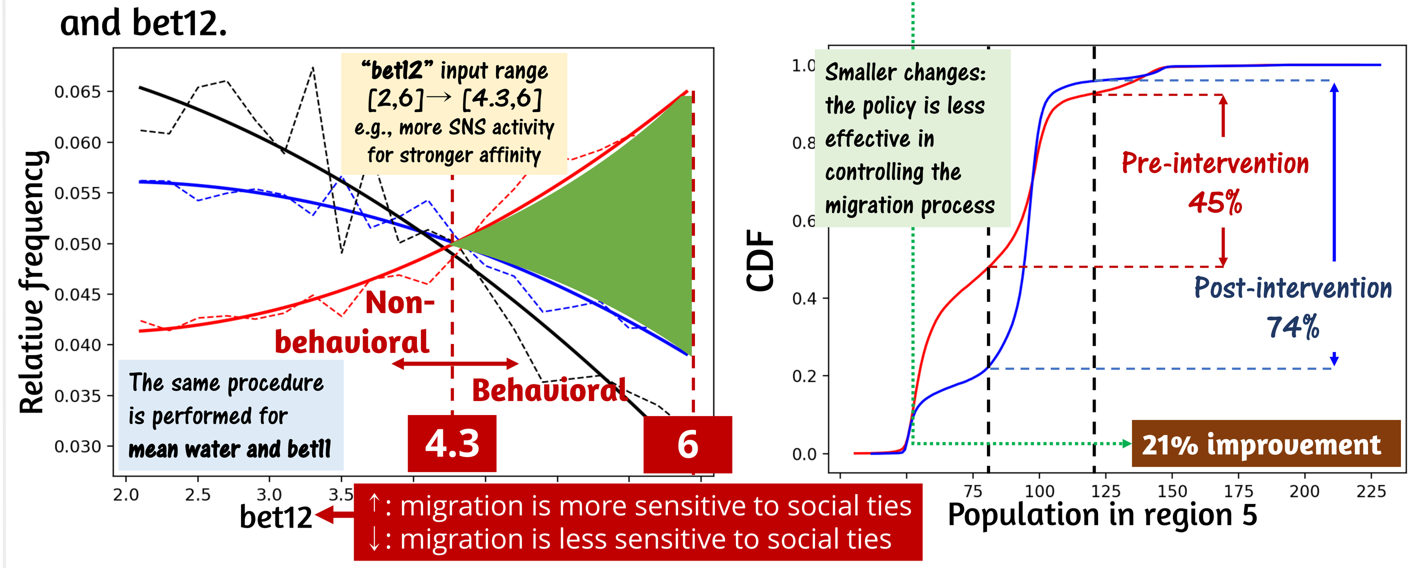
Monte-Carlo Filtering (MCF) is a decision analysis method that controls a certain range of inputs like a policy and evaluate the change by the control. First, you select a threshold *t* to divide the inputs into behavioral (> *t*) and non-behavioral (< *t*) subsets. Using Kolmogorov-Smirnov test at 5%, you redefine a new input distribution with a behavioral subset to get a desired results.

Goal: to have 20% variation from the initial population in region 5. That is, population in region 5 is in the range of [80, 120]

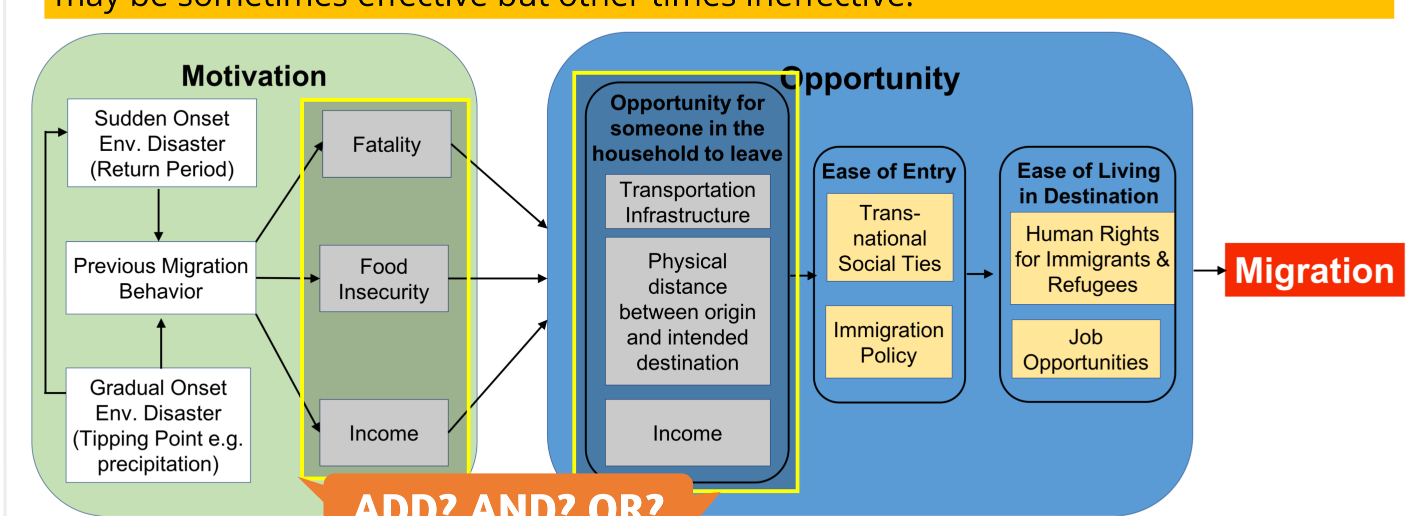
In AND-AND configuration, *we control two important inputs: mean water and gradient.*



In OR-AND configuration, *we control three important inputs: mean water, bet11, and bet12.*



As each configuration has different important inputs and migration patterns, a policymaker should establish different policies according to the configuration. A policy may be sometimes effective but other times ineffective.



Ultimately, this study provides an insight to the real-world migration problem. Migration goes through a complex decision-making process. We must provide a well-established illustration of how factors are combined.

To Summariz3

Migration patterns greatly change depending on how social and natural factors are incorporated.
"Resistant to migration" model configuration is important and interactive, but its importance decreases beyond the threshold.
A policy must be established based on how multiple factors are combined to maximize its effect which may differ in each configuration due to an interactive nature of the migration.

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