A Bayesian network approach to food security modeling in Brazil

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Abbreviated abstract: In the context of policies for complex systems, it is difficult for decision-makers to account for all the variables within the system. The usual approach to relate factors and outcomes is based on regression models that do not allow cause-effect inference. Our proposal is based on Bayesian networks that can capture non-linearities and complex cause-effect relationships. The outcome of this project is a probabilistic decision tool that integrates the main factors influencing food insecurity in Brazil.

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Food security

"**Food security exists when all people**, at all times, have physical, social and economic **access to sufficient, safe, and nutritious food** which meets their dietary needs and food preferences **for an active and healthy life**" (FAO, 2001).

Food insecurity can result in an increased risk of:

- × Death or illness from stunting
- × Weak responses to infections
- × Diabetes
- × Cardiovascular diseases
- × Some Cancers;
- × Mental ill health

Brazil's scenario:

- ↓ Politico-economic crisis (2014)
- ↓ Public spending cuts
- ↓ Demobilization of public policies
- ↓ Acceleration of increased hunger and food insecurity
- ↓ COVID-19 pandemics (2020)

! Food security is a **complex system involving many variables** and therefore **planning initiatives becomes an challenging task**.

$ It is essential to **optimize the allocation of available resources** due to the **reduced government budget**.

→ **Public policy evaluation** is an **immediate action**.

» Timeline of household food security surveys in Brazil:

PNAD/IBGE	2004
PNAD/IBGE	2009
PNAD/IBGE	2013
POF/IBGE	2018
VIGISAN/PENSSAN	2020

? Food insecurity classification:
No › Mild › Moderate › Severe

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Bayesian networks

A Bayesian network (Pearl, 1988) is a **directed acyclic graph (DAG)** G that encodes probabilistic relationships between the elements of a R.V. $\boldsymbol{X} = (X_1, \dots, X_p)'$ through:

$$p(\mathbf{x} \mid \boldsymbol{\Theta}, G) = \Pi_{i=1}^{p} p(X_i \mid \boldsymbol{\Theta}_i, \boldsymbol{\Pi}_i, G),$$

with $(X_i \perp X_j) \mid \boldsymbol{\Theta}_i, \boldsymbol{\Pi}_i, \quad X_j \notin \boldsymbol{\Pi}_i, \quad (i,j) = 1, \dots, p.$

(i) BNs are represented by two sets:
- *G*: conditional independence assertions
- *Π*: local conditional distributions

(ii) BNs learning is performed in two steps:
- **Structure**: Learning ς from the data or expert knowledge
- **Parameter**: Learning local distribution parameters given learned *G*

(iii) BNs have attractive attributes:
- **Causality**: Structure can infer causal relationships
- **Scalability**: Parallel computing for large tasks

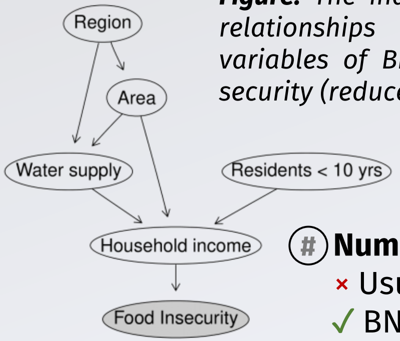

Figure: *The independence relationships between variables of Brazil's food security (reduced) system.*

(#) **Number of parameters:**
- × Usual joint model: 1279
- ✓ BN model: 82

✓ BNs alleviate the **curse of dimensionality**

→ The **discrete dynamic Bayesian networks** is the framework knitting the components of Brazil's food security system.

\+ **This new approach combines:** **discrete BNs** (Heckerman et al., 1995) with time evolution parameters (e.g. $\Theta_t \rightarrow \Theta_{t+1}$) via a **time-varying Dirichlet process** (Fonseca and Ferreira, 2017).

Preliminary results

Scenario simulation/Policy evaluation

Table: *Simulated scenarios based on illustrative policies.*

Policy	% of food-secure households (CI 95%)	
	2019	2020
P1: ‘do nothing’	60.8 (60.8;60.9)	45.8 (45.7;45.8)
P2: Decrease housing costs by 50% (all households)	62.1 (62.1;62.2)	47.1 (47.1;47.2)
P3: Income transfer program (R$ 600 for all households)	63.6 (63.5;63.6)	48.6 (48.6;48.7)

Groups comparison

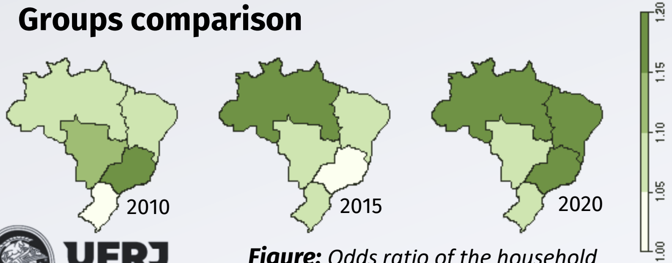

Figure: *Odds ratio of the household food security in the presence and absence of water supply.*

From **2004 to 2013**, there was a **progressive decrease in food insecurity**, especially in its most severe form.

In the simulated scenarios, the **increase in income** would imply 2-3% of households (~ 4.3 to 6.2 mi people) **not exposed to food insecurity** during the COVID-19 pandemic.

Water insecurity is associated with food insecurity, especially in rural areas.

Households without water supply have always been **more exposed to food insecurity** in all regions. The pandemic maximized this exposure.

After **economic crisis**, this **progress was reversed**. With the **outbreak of the pandemic**, the **reduction in FS** was even more **intense and abrupt**.

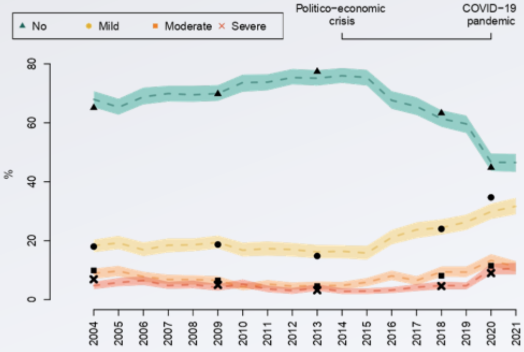

Figure: *Estimated percentual path of food-secure households in Brazil, 2004 to 2021. The dots represent the empirical percentual.*

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