New wine into old wineskins?

Using von Thunen theory to estimate inter-district food flows in Malawi

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Motivation

- Food policy and data problem
  - Any food policy will have positive and negative spillovers (flows) across space and time-necessary for welfare analyses
  - Large literature on international trade using the gravity equation: $\ln X_{od} = A_o(X, \tau) + B_d(X, \tau) + \theta \ln \tau_{od}$
  - For intra-national trade, food flows data across regions not collected for most developing countries
- We know where, when and how much food is produced and consumed within a country
- Research idea: develop a spatially explicit mathematical programming model that estimates food flows given what we know and on the basis of a von Thunen spatial economic theory

This paper

- [Theoretical Contribution]: Links a causal claim of effects of distance (and transport costs) on spatial organization of economic activity by von Thunen to mathematical programming models.
- [Empirical Contribution]: Uses this equivalence to address the following research questions

  1. What proportion of produced volume of food flows across districts within Malawi?
  2. What food policies (particularly reduction in transport costs) based on the knowledge of inter-district comparative advantage and food crop flows can improve economic welfare?

Who was von Thunen?

A German farmer who never occupied an academic position

Thünen at Two Hundred

By PAUL A. SAMUELSON
Massachusetts Institute of Technology

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1983 IS A YEAR of centennials: the death of Karl Marx, the births of Maynard Keynes and Josef Schumpeter. But also, running exactly a century before Schumpeter's life clock (1883–1950) was that of Johann Heinrich von Thünen (1783–1850), the economist who met a payroll and, in recording and analyzing his Junker estate accounts, not only created *marginalism* and *managerial economics*, but also elaborated one of the first models of *general equilibrium* and did so in terms of realistic *econometric* parameters.

Thünen's work of genius is primarily admired by the public at a distance while serving as an occult mine for hundreds of German dissertation writers to sift over and sniff at.

Among geographers and location theorists, Thünen is a founding God. What John Bates Clark did at the end of the nineteenth century in formulating a theory of distributive shares, in terms of the marginal productivities of factors of production, Thünen had already done in the 1842 and 1850 installments to his original 1826 *The Isolated State*. Since J. B. Clark

Figure: Samuelson's essay on Von Thunen in Journal of Economic Literature, 1983

Simplicity and beauty of von Thunen theory

"Imagine a very large town, at the center of a fertile plain which is crossed by no navigable river or canal. Throughout the plain the soil is capable of cultivation and of the same fertility.
Far from the town, the plain turns into an uncultivated wilderness which cuts off all communication between this state and the outside world...

The Problem: What pattern of cultivation will take shape in these conditions?; and how will the farming system of different districts be affected by their distance from The Town?

Result: With increasing distance from The Town, the land will progressively be given up to products cheap to transport in relation to their value. For this reason alone, fairly sharply differentiated concentric rings or belts will form around The Town, each with its own particular staple product"-Thunen (1826)

von Thunen Theory in one figure

Let land rent be: $Rent_i = p_i - R_i(r)$

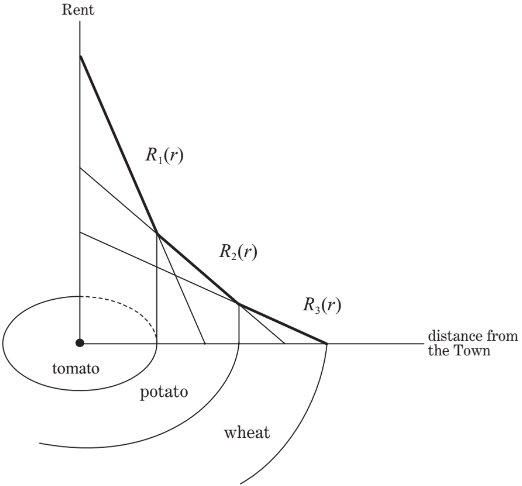


Figure: Land rent profile and thunen rings. Source (Fujita,2010)

Why 200 years old von Thunen Theory?

- Claim of causality between spatial organization and distance under his assumptions
- Evidence of Thunen predictions in Madagascar (Jacoby and Minten, 2009.JDE), DRC (Minten and Kyle,1999) and Nepal (Jacoby, 2000.Economic Journal; Fafchamps and Shilpi,2003.Journal of Development Studies)
- For example, Jacoby and Minten, 2009.JDE find
  - Least remote households: 87% of crop sales by weight are either fruits, vegetables, or tubers
  - Most remote households: 95% of crop sales by weight are high value per kilogram dry grains (mainly rice, maize, and beans)

Von Thunen →Sector Programming Models

- Sector mathematical programming models (McCarl and Spreen,1980) are regional models-rich in data and structure
- But lack a spatial economic theory. This paper argues the theory should be spatial economic theory of Von Thunen
- Not really a new idea though
  - Notable suggestions in using von Thunen and math programming include Stevens (1968).Papers in regional science association, Hartwick(1972).Southern Economic Journal, Samuelson(1983).JEL
  - None of these suggest spatial math programmming with rich structure on production
  - None apply the suggestion to data

Von Thunen $\rightarrow$Sector Programming Models

Table: Relaxing von Thunen assumptions

Assumption	**von Thunen**	**Sector math programming**
1) Soil fertility	Uniform	Vary by region
2) Market center	Single	Multiple markets
3) Unit transportation cost	Uniform	May vary by crop
4) Production costs	Uniform	Vary by region/crops
5) Demand	Infinitely elastic	Empirical estimates

Model Setup

- Computation: Implemented in GAMS (General Algebraic Modeling System)
- Geography: 27 regions/districts, 4 of which are city districts Appendix
- Homogeneous commodities/products: 6 food crops (Maize, Rice, Groundnuts, Beans, Potatoes, Cassava)
- Policy model with decentralized farmer and consumer decisions
- Static, perfectly competitive, partial equilibrium

Model setup

- Sets
  - Regions/districts:Ω_G, Multiple products/food crops:Ω_Y, Multiple variable inputs:Ω_{ZV} and Production activities/crop area:Ω_{XG}
- Endogenous Variables
  - Quantity demanded of product i in district g:Y_{gi}
  - Quantity supplied of variable input k in district g: Z_{gk}
  - Level of production activity j (area of land under crop j) in district g: X_{gj}
  - Quantity of product i shipped from district g to district h: TY_{ghi}
  - Quantity of product k shipped from district g to district h: TZ_{ghk}
- Linear output demand: $P_{gi} = a_{gi} + b_{gi} Y_{gi}$
- Linear input supply : $R_{gk} = c_{gk} + d_{gk} Z_{gk}$

Model

- Exogenous variables/parameters
  - Output of product i per unit of production activity j in district g: e_{gij}
  - Requirement of variable input k per unit of production activity j in district g: v_{gkj}
  - Unit transport costs for outputs and inputs: ty_{ghi} & tz_{ghk}
- **Objective function**: Maximize net quasi-welfare

$$
\begin{aligned}
&\sum_{g\in\Omega_G}\sum_{y\in\Omega_Y}[a_{gi}Y_{gi}+0.5b_{gi}Y_{gi}^2]-\sum_{g\in\Omega_G}\sum_{k\in\Omega_{ZV}}[c_{gi}Z_{gi}+0.5d_{gi}Z_{gi}^2] \\
&-\sum_{g\in\Omega_G}\sum_{h\in\Omega_G,h\neq g}\sum_{i\in\Omega_Y} ty_{ghi}TY_{ghi}-\sum_{g\in\Omega_G}\sum_{h\in\Omega_G,h\neq g}\sum_{k\in\Omega_{ZV}} tz_{ghk}TZ_{ghk}
\end{aligned}
\tag{1}
$$

Model

Subject to:

- Food product balance:

$$Y_{gi} - \sum_{j \in \Omega_{XG}} e_{gij} X_{gj} + \sum_{g \in \Omega_G, h \neq g} TY_{ghi} - \sum_{g \in \Omega_G, h \neq g} TY_{hgi} \leq 0, \quad \forall g \in \Omega_G, i \in \Omega_Y \tag{2}$$

- Input balance:

$$\sum_{j \in \Omega_{XG}} v_{gkj} X_{gj} - Z_{gk} + \sum_{g \in \Omega_G, h \neq g} TZ_{ghk} - \sum_{g \in \Omega_G, h \neq g} TZ_{hgk} \leq 0, \quad \forall g \in \Omega_G, k \in \Omega_{ZV} \tag{3}$$

- Non-negativity requirement:

$$Y_{gi}, X_{gj}, Z_{gk}, TY_{ghi}, TY_{ghk} \geq 0; \forall g \in \Omega_G; i \in \Omega_Y, j \in \Omega_X, k \in \Omega_Z; h \in \Omega_G, h \neq g \tag{4}$$

Analytical: Impact of Transport Costs on Trade Flows

Fom Kuhn-Tucker-Karush conditions:

$$\frac{\partial L}{\partial TY_{ghi}} = -ty_{ghi} + \lambda_{hi} - \lambda_{gi} \leq 0; \quad \forall g \in \Omega_G, h \in \Omega_G, h \neq g, i \in \Omega_Y \tag{5}$$

$$\sum_{g \in \Omega_G} \sum_{h \in \Omega_G, h \neq g} \sum_{i \in \Omega_Y} \frac{\partial L}{\partial TY_{ghi}} TY_{ghi} = 0 \tag{6}$$

$$TY_{ghi} \geq 0; \forall g \in \Omega_G, h \in \Omega_G, h \neq g, i \in \Omega_Y \tag{7}$$

- Result: Transport costs equal price differences across districts for positive trade flows

Data and Model Inputs

- Regional Demand [a_{gi}, b_{gi}]
  - Elasticities by urban or rural
  - District level prices
  - Consumption per person per day
  - Population for each district

Appendix2

- Supply [c_{gi}, d_{gi}, e_{gij}, v_{gkj}]
  - Crop land mix for 10 years
  - Crop budgets: Yields, Prices, Input-Output Coefficients
- Trade costs[$ty_{ghi} = tz_{ghk}$]
  - Iceberg transport costs per ton per km and distance across district centroids

Baseline Results

- Maize flows
  - 16% of production
  - A trade survey in 2010 reported maize sales of about 12% of production
- Rice flows
  - 83% of production
- Groundnuts and beans flows
  - 85% and 91% of production
- Potatoes and cassava flows: 0

Baseline Results

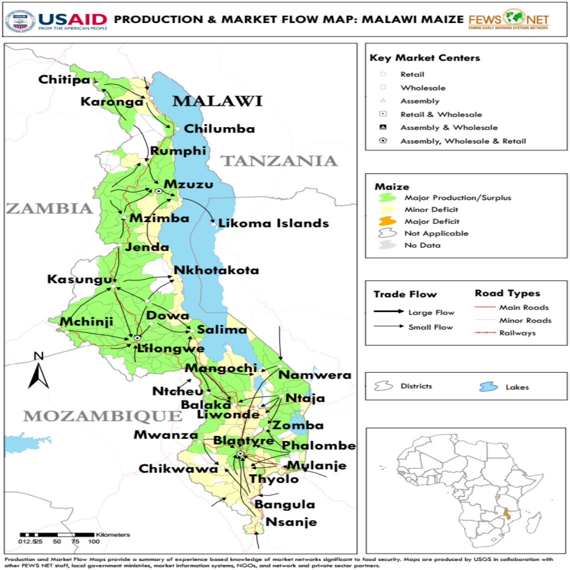


Figure: Trade flow map. Source: FEWSNET

Baseline Results

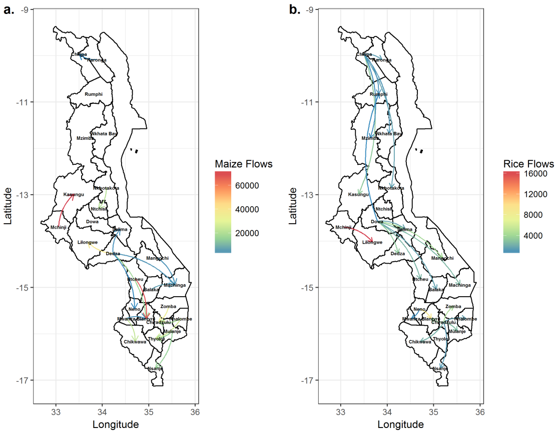


Figure: Baseline cereals flows (MTs)

- Calibrated maize flows consistent with expert opinion and FEWSNET figure, not consistent for rice

Baseline Results

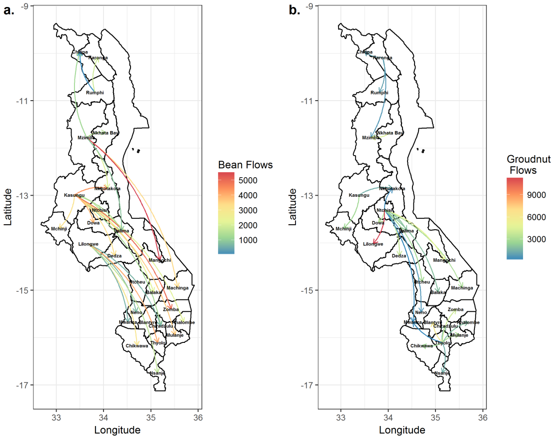


Figure: Baseline legumes flows (MTs)

Policy experiments

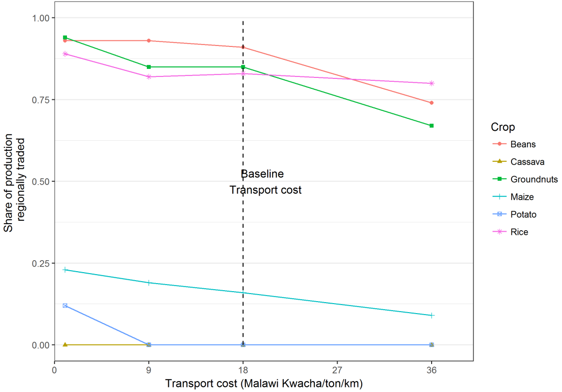


Figure: Share of production traded across districts

Notes:Baseline transport cost= 0.0252 USD

Policy implications

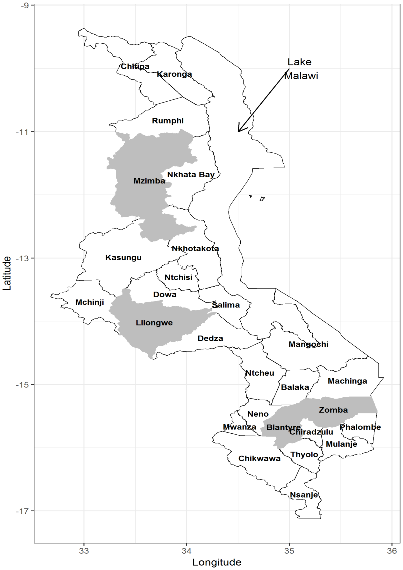
- Small, non linear and crop specific transport cost effects on trade flows
    - Venables and Limao (2000) estimate 50% reduction in international trade for a doubling of transport costs
    - Subsistence and intra-district trade not captured by the model may be important
- Focus should be on rural-urban infrastructural investments
- Introduce a Commodity Flow Survey
    - Can be a component of the Integrated Household Survey-Living Standards Measurement Survey (IHS-LSMS) conducted by National Statistical Office and World Bank

Conclusion

- Some limitations and validity concerns
  - Water availability and nutrition modules needed to reflect biophysical reality
- Paper deals with trade flows as outcome. What about gains to this trade?
- Add imports and exports
- Future plans: Use gridded/raster data for production, population, night lights, consumption and terrain.

Appendix

Map



Appendix

Elasticities

Table: Expenditure and Marshallian elasticities. Source: Ecker and Qaim (2011)

Crop	Expenditure elasticities		Own-price elasticities	
	Rural	Urban	Rural	Urban
Maize	0.948	0.628	-0.877	-0.722
Rice	0.892	0.904	-0.816	-0.959
Cassava	-0.665	0.076	0.618	-1.152
Potatoes	0.712	1.004	-0.770	-1.248
Beans	1.365	0.197	-0.952	0.415
Groundnuts	0.744	0.413	-0.821	-0.013