Self-consistent inference framework for the gravity model: overcoming limitations of proxy-based analyses

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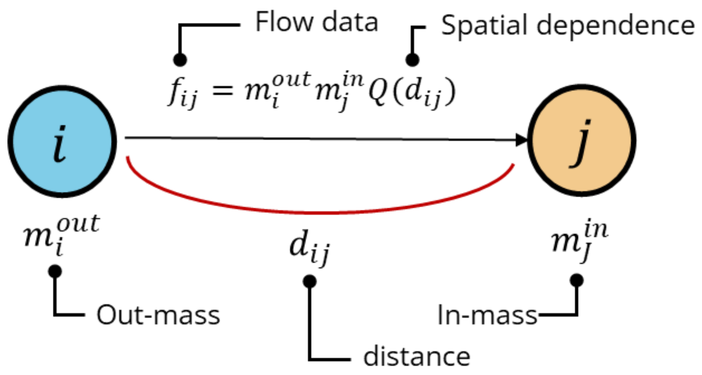
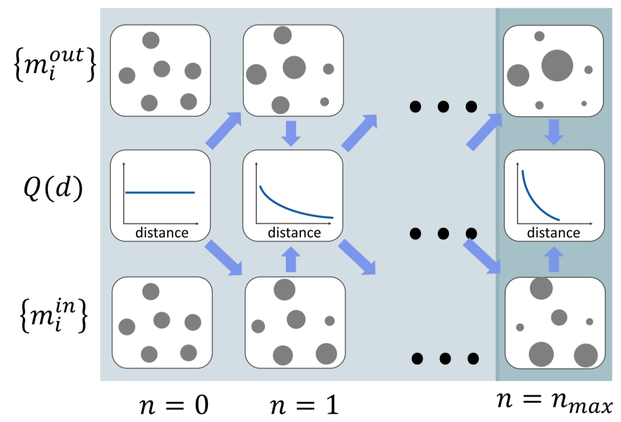
Abstract

The gravity model, inspired by Newton's law of gravity, is a powerful tool to describe interactions in a spatial context, such as trade flows between nations. However, deriving the 'mass' of entities within the system has been a challenge, leading to reliance on external attributes such as GDP as a proxy. In this study, we introduce a new numerical approach that treats 'mass' as a dynamic attribute directly derived from trade flow data. This approach iteratively updates the mass and spatial dependence function in an interdependent manner, finding an optimal representation to describe the system. Notably, it accurately infers the embedding structure of synthetic and real network, providing new insights into the underlying patterns. The results have broad implications for a range of fields, including urban planning, traffic engineering, and epidemic prevention.

Gravity model

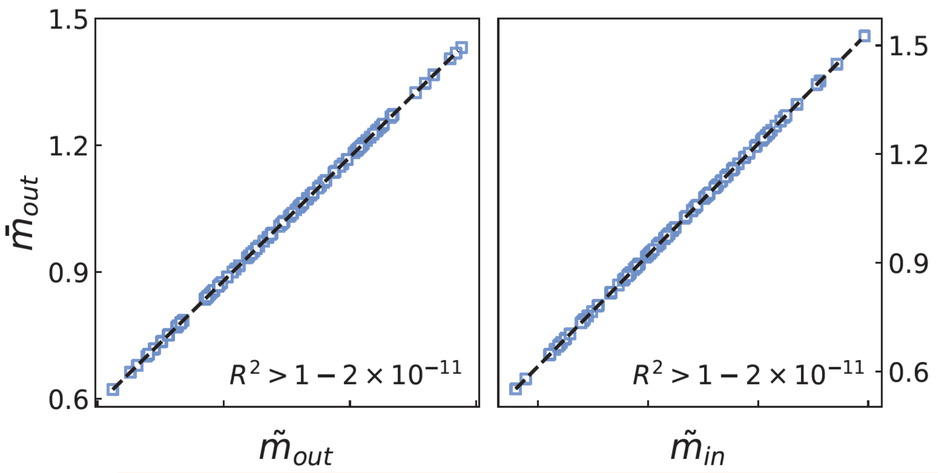


Inference algorithm

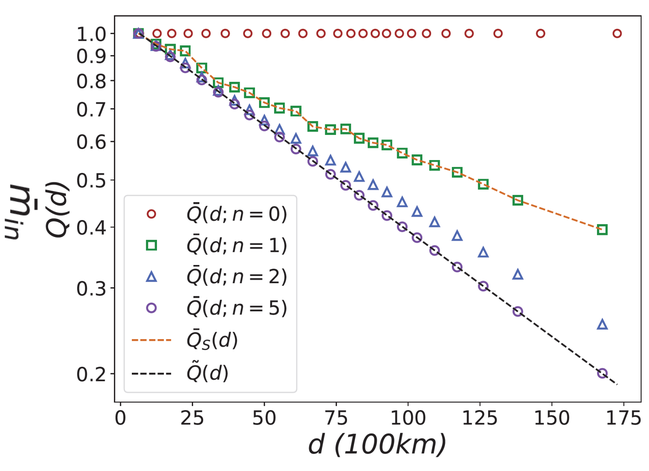


- Theoretical formulation to explain flow data (trade, transport, ...)
- Each flow can be explained by masses and spatial dependence (=Q(d))
- Self-consistent way of inferring masses and Q(d) from flow data
- Iteratively updating each other until reach the steady state

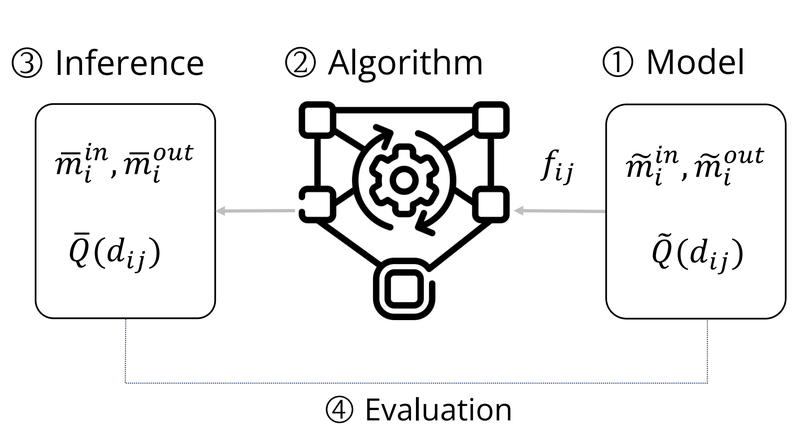
Inference of masses



Inference of Q(d)

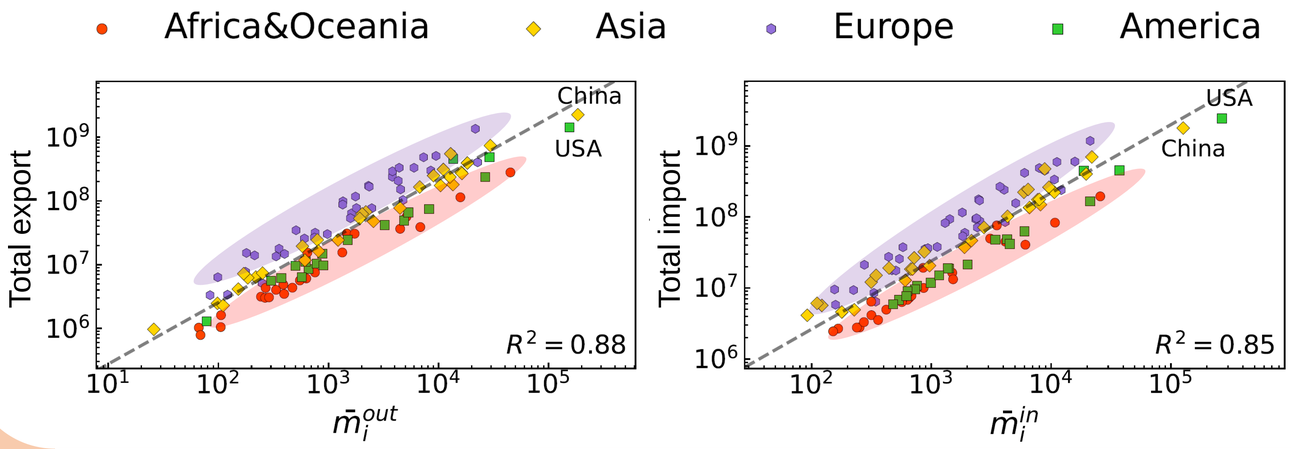


Validation scheme

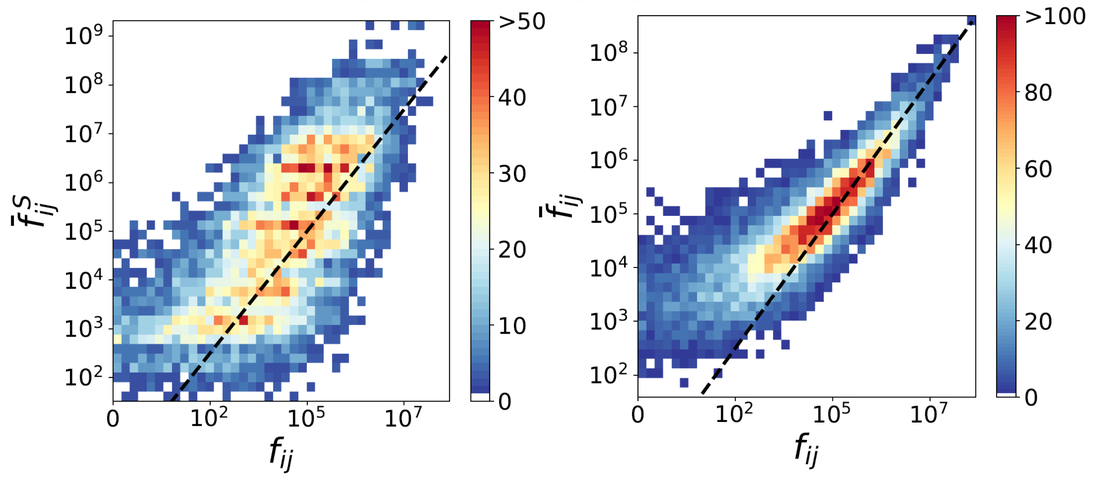


- High level of consistency with ground truth data
- Previous strength-based model fails to find the answer
- Inferring the quantities of synthetic model network
- Comparison between inferred quantities and ground truth

Mass distribution of International trade network



Data reconstruction

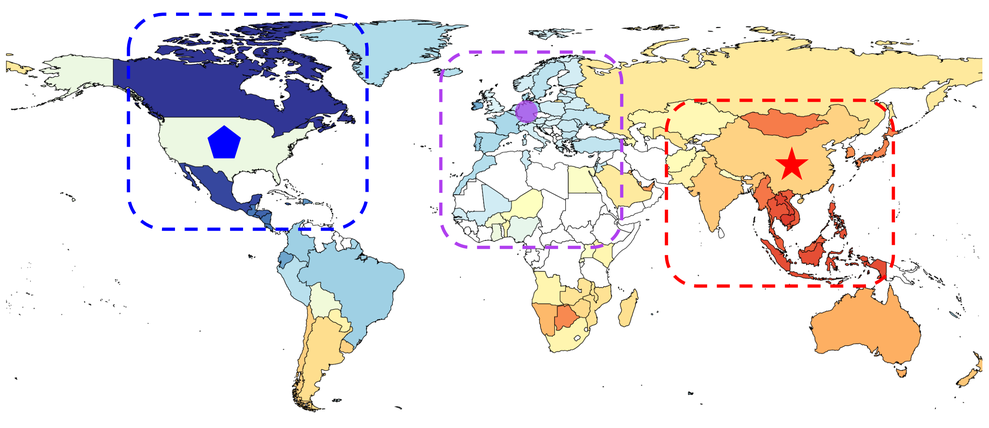


- Application to the international trade network
- European countries achieve higher export & import with respect to their masses
- Comparison between inferred $(\bar{f}_{ij})$and real (f_{ij}) flow
- Higher performance than strength-based model

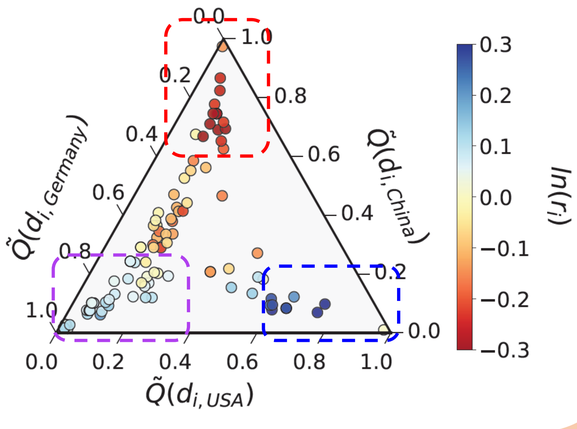
Conclusion

- Self-consistent inference algorithm of gravity model
- Successfully found the ground truth of synthetic network
- Comparative analysis on the masses, export and import reveals the economic surrounding of each country
- International trade network shows continent-dependent characteristics of economic landscape
- Economic landscape of world trade is highly affected by three major powers

Economic landscape of international trade



Trade balance Index



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- r_i = Trade Balance Index (High: Export-Favorable, Low: Import-Favorable)
- Economic landscape of each country is affected by its nearest major power