

CORVINUS UNIVERSITY OF BUDAPEST

THESIS BOOKLET

**Understanding Internal Migration Through a Network
Perspective**

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I. Research background

The main argument of this dissertation is simple: internal migration happens through a path-dependent network of flows, which has its own internal mechanisms, and every factor affecting migration is embedded in this flow structure. This notion is as old as migration research itself, but wide-spread contemporary models of internal migration do not account for it. They rely on modelling independent units, and independent dyads (bi-lateral flows), without a systematic framework. I argue that the application of new network science methods to empirical analysis can account for this simple and old notion, achieving systematic quantitative models of internal migration flow systems.

The traces of network thinking were present since the very origin of migration research, in the groundbreaking works of Ernst Ravenstein, who built his model of internal migration in the United Kingdom on a system of currents between locations (Ravenstein 1885, 1889). His laws describe an interdependent system, in which each locality is influenced by other localities, and this influence itself is the core of explanation. His work aimed to explain relations, not the properties of individual places. Ravenstein's laws can easily be translated to a network model: localities are nodes, where agents reside, and the movement of agents produces the emergent macro-level structure of migration streams. Surprisingly, this systematic aspect of his work mostly disappeared during the 20th century – while some of his laws, one by one, laid the foundation for gravity thinking, the step-migration model, or ideas around migratory potential and counter-currents, the empirical tradition treated the individual locality, and later the individual dyad, as the base unit of analysis. Even today, more than a century later, migration researchers still return to Ravenstein as a kind of analytic null model (Rees and Lomax 2019, Macedo et al. 2020), but the systemic reading of his work remains rare.

During the last century, only one large-scale migration theory emerged as both an extension and a critique of Ravenstein: the migration transition hypothesis developed by Zelinsky 1971. According to this model, migration patterns are directly influenced by the developmental stage of a society. Ravenstein described the era of the second industrial revolution, when centralization and urbanization moved migrants upwards the urban

hierarchy. Zelinsky predicts that in post-industrial societies, a highly elaborated lattice of major and minor metropolises will define migration.

While the origins and macro-theories of migration all treat internal migration as a systematic social process, the theories that turned into the mainstream framework for applied quantitative research generally lack systematic elements. Push-pull theory, in its Lee 1966 formulation, is usually cited as the canonical foundation of migration modelling, but contemporary use of it usually reduces it to a simple plus-minus calculus of factors at origin and destination. This misses that Lee also explicitly embedded the push-pull calculus in migration streams. The systematic element disappeared from widely cited comprehensive reviews of the area (Greenwood 1975, 1985, 1997, Lucas 1997, Cushing and Poot 2003, Molloy et al. 2011, Etzo 2008), where the push-pull calculus refers to migration-enhancing or reducing qualities of individual units. I call this approach the individual unit approach. Gravity models, on the other hand, work on dyads. The formalization from Zipf 1946 and Stewart 1948, and the tradition following them treats every dyad independently, without accounting for the fact that flows in the same system affect each other. I call this the individual dyad approach.

Individual unit and dyad explanations do not answer two seminal questions of migration research: which specific destinations will experience migration inflow, and what mechanisms will direct migration exactly to those locations. As de Haas puts it, although the truism holds that economic and other opportunity differentials generally play a major role in migration, this alone cannot explain the actual, patterned and geographically clustered morphology of migration (de Haas 2010). Push-pull and gravity models work on the aggregate, and omit important detail. This is why after decades of aggregate-level research, a logical step forward is to understand the patterns and determinants of directions - which can naturally be operationalized as migration flow networks.

Before flow networks can serve as a heuristic, the mechanisms that build and sustain them have to be addressed - the task of system theories of migration. The tradition originates in migration system theory (Mabogunje 1970) and cumulative causation theory (Massey 1990, Massey et al. 1993): through information feedbacks and network connections between migrants

and origin populations, each act of migration reduces costs of future movement; and as the number of connections reaches a threshold, migration becomes self-perpetuating (Palloni et al. 2001, Massey 1990). De Haas synthesises these ideas and shows migration systems can also collapse through inherent saturation dynamics (de Haas 2010, 2021). System theories almost always work on international migration, but their central mechanisms – path dependency, feedback, cumulative causation – are just as relevant for internal migration; only their context is different.

Internal migration is also analysed by urban studies. Central place theory (Christaller 1933, Lösch 1940) dominated urban research for decades, but became insufficient as urban development itself started to behave differently. New empirical accounts – employment subcenters (Giuliano and Small 1991), city network cooperation (Camagni and Salone 1993), the space of flows (Castells 2020), the polycentric urban region (Kloosterman and Musterd 2001) – describe a shift from hierarchies to networks, from centrality to nodality (Batten 1995, Meijers 2007). Polycentric development itself splits into a morphological and a functional interpretation (Burger and Meijers 2012), the latter defined on flow networks. This dissertation works inside the functional polycentricity tradition.

The application of network science to internal migration is a young tradition. Recent works map internal migration systems with centralities, community detection, and other network statistics; the number of studies dedicated to migration networks tripled through the last decade (Pitoski et al. 2021). Some studies add network effects to gravity-type regressions, others move to explicit generative network models. ERGMs (Holland and Leinhardt 1981) and their valued extensions (Krivitsky 2012) enable statistical inference on network mechanisms, and have been applied to different scales of migration (Windzio 2018). The theoretical usefulness of descriptive network statistics should not be taken as granted, but generative network models allow us to test what mechanisms generate observed flow patterns.

All three articles of this dissertation work with Hungarian data. Hungary is special from internal migration and housing standpoints. Budapest is an extraordinarily dominant city compared to its country: the metropolitan area is more than nine times larger than the second one, placing Hungary

13th in the global OECD ranking, with only African, Asian, and Latin American countries in the first 12 (OECD 2020). The suburbanization after the regime change was defined by market and private actors, not central planning (Sýkora and Bouzarovski 2012, Stanilov 2007, Hirt 2012), producing spontaneous, uneven settlement patterns (Timár and Váradi 2001, Kok and Kovács 1999, Kovács et al. 2019). Infrastructure followed rather than preceded suburban population growth in the Budapest agglomeration – making classic pull-factor thinking hard to apply. The Budapest agglomeration has moved from monocentricity toward polycentricity, with functions redistributing between existing centres (Szabó et al. 2014). The Hungarian housing system is also exceptional in many sense: the give-away privatisation of the 1990s and pre-existing homeownership patterns pushed the share of owner-occupied housing above 90% (Hegedüs and Tosics 1996, Kovács and Kohl 2025). Homeownership generally reduces migration (Mulder 2006), and the effect of housing structure on the direction of internal migration flows in Eastern Europe is still understudied (Bloze 2009).

A formally theorized unification of all these network threads is still missing, and an article-based dissertation cannot deliver it. But the three articles that make up this thesis aim to be examples of research that is theoretically founded on interdependence-based classical theory, and empirically enriched by state of the art network science methods. As de Haas puts it, migration studies have experienced theoretical regression rather than progress (de Haas 2010). I hope these articles can offer small, incremental steps in the opposite direction, using different methodological innovations to work on the overarching research question:

How do interdependent flow structures shape the spatial patterning of internal migration in Hungary – and what can network methods reveal about this structure that unit-based and dyadic models cannot?

The three articles address this question on three different spatial scales – national inter-settlement, inter-district under a house price shock, and intra-metropolitan - each with a different network method and each returning a different piece of the answer.

Article 1

The first article, *Rural-urban flows determine internal migration structure across scales*, published in *Cities* in 2025 with László Lőrincz, addresses the national, inter-settlement scale. It asks what elements of the flow structure connect the different scales of an internal migration network, and whether population size and geographic distance in themselves are enough to model cross-scale connections.

The mapping of inter-urban networks with network science methods is in the focus of many urban researchers. Different inter-urban networks have been modelled: transportation, telecommunication, corporate, online social (Krings et al. 2009, Lengyel et al. 2015). For internal migration, inter-urban network models proved useful in delineating source and sink regions (Wang et al. 2019), identifying temporally coherent subgroups (Zhang et al. 2020), and dissecting polycentric structures (Liu et al. 2016). But this literature mostly focuses on networks of larger cities: in the meta-analysis of Li and Neal 2024 samples vary between 9 and 1575 cities, while Hungary alone contains more than 3000 settlements. Focusing only on large cities is problematic: rural-urban delineation is not straightforward (Tacoli 1998), rural-rural, urban-urban, rural-urban, and urban-rural flows are interdependent (Selod and Shilpi 2021), and small towns have a vital role in reducing rural dependency on large cities (Najarsadeghi and Dorostkar 2022). Distinguishing network effects is particularly important in understudied Central- and Eastern European geographies, where internal migration is usually understood only through centralization. Only Pitoski et al. 2021b and 2021c offer systematic network approaches for nearby countries, but do not identify system-defining mechanisms.

Article 2

The second article, *Internal migration flow network reorganization during a house price shock in a capital city*, addresses the inter-district scale on a short timescale, and asks whether an abrupt house price boom in a dominant capital city triggers immediate reorganization of the migration flow network, or whether hub-centered patterns persist despite substantial affordability deterioration.

Housing and internal migration have a long established bi-directional relationship (Mulder 2006). The most-studied mechanism is the lock-in effect (Quigley 2002): mobility-reducing frictions from down-payment and

equity constraints (Stein 1995, Chan 2001), intensified during bust periods (Henley 1998, Ferreira et al. 2010). But the well-documented lock-in only refers to migration propensity, not direction. Modelling price change effects shows destination price growth acts as a deterrent, and stronger than the origin push – an asymmetry documented in Germany (Stawarz et al. 2021), the USA (Olney and Thompson 2024), and Australia (Siriban et al. 2025). Most of this literature relies on gravity-type or bilateral flow models, treating dyads as independent – omitting the systematic, interdependent nature of inter-urban flow structure. Testing the effect of housing prices on flow structure with methods that model edge dependence explicitly is still rare. Hungary during the 2010s is an exceptional case for the question. The country experienced a severe housing price shock: between 2014 and 2024, Hungarian nominal house prices grew by over 300%, the highest in the EU, with the boom originating in and most intensely concentrated in Budapest (European Commission 2025). Internal migration also peaked during this decade (Bálint and Obádovics 2021).

Article 3

The third article, *Social connections and links to communities drive intra-metropolitan migration when housing is scarce*, addresses the intra-metropolitan scale, and asks whether social ties, and especially ties to densely knit communities direct migration flows where housing supply cannot act as a pre-emptive pull factor. The article asks three nested questions: whether past social ties between settlements affect future migration between them, whether ties to densely connected local networks matter more, and whether the effect of ties intensifies when destination housing is scarce.

Push-pull theories struggle to explain the patterned, geographically clustered morphology of migration linking particular origins to particular destinations (de Haas 2010). Social networks emerged as complementary explanation. Local social networks in the USA reduce inter-metropolitan migration more than wage or housing cost differentials (Michaelides 2011). Büchel et al. 2020 for Switzerland show that the share of contacts in destinations increases the probability of moving there; Blumenstock et al. 2025 shows for Rwanda that migrants prefer destinations where their networks are interconnected (support capital) over destinations where

networks are extensive (information capital). But most studies treat network effects as unconditional main effects.

Networks likely matter more where formal resources are scarcer: they function as a third source of welfare when market income and institutional support fall short (Hill et al. 2021, Dawkins 2006). I theorize that the effect of social connections on migration has special weight in scarcity of the material requirements of mobility – especially housing. The Budapest agglomeration area (BAA) is an ideal context for testing this hypothesis. The article combines administrative migration records with iWiW online social network data (Hungary's pre-Facebook network, over 3 million users at its 2009 peak, Wachs et al. 2019), using past network structure (2000-2009) to model future migration (2010-2019). For each user, clique-like groups of 5+ friends in destinations are identified, giving both quantity and density measures.

II. Methods

Article 1: multi-scale community detection with a radiation-model null

- Data: 3177 Hungarian municipalities (including the 23 districts of Budapest); permanent residential migration records from HCSO for 2015-2019, aggregated over 5 years; weighted and directed network.
- Multi-scale community detection: map equation with Infomap (Rosvall and Bergstrom 2008), a flow-based method that treats directed and weighted networks naturally. Markov time scaling (Kheirkhahzadeh et al. 2016) is used as a resolution parameter to overcome the field-of-view limit, offering a multi-focal lens from local cliques to polycentric regions.
- Analytic null: the radiation model (Simini et al. 2012), which predicts directed flows from populations and inter-settlement distances alone. The same 3177 nodes are used to generate a synthetic network for comparison.
- Analysis: comparison of simple network statistics (degree distributions, dominant flows, mixing patterns), plus map equation run on both networks to identify where multi-scale community structures diverge.

Article 2: count-ERGMs for the inter-district flow network

- Data: 174 LAU1 districts + Budapest as one; migration flows from HCSO; house prices from National Tax and Customs Administration transaction contracts; principal-component indices of amenity and economic activity from HCSO T-Star.
- Three time periods: 2010-2012, 2013-2015, 2016-2018, chosen to bracket distinct house price dynamics.
- Method: Poisson-reference count-ERGM (Krivitsky 2012), extending classical ERGMs (Holland and Leinhardt 1981) beyond binary ties.
- Network mechanisms (following Huang and Butts 2023): mutuality for reciprocity, and sender/receiver activity variance to capture heterogeneity of node activity and dependence between dyads.
- Two model families: (i) cross-sectional specifications for each period, with and without network mechanisms, to see how push-pull estimates shift once network dependencies are accounted for; (ii) a Period-3 specification with Period-2 flows as an edge covariate - a lagged-flow, change-effect design.
- Estimation: MCMLE with Poisson reference; convergence and degeneracy checked through step-length trajectories, GOF diagnostics against observed statistics, and robustness to alternative MCMC configurations.

Article 3: log-log gravity regression with online social network data

- Data: settlements of the Budapest agglomeration area (official HCSO delimitation); HCSO migration records aggregated over 2010-2019; iWiW friendship ties (2000-2009 window); HCSO housing and PCA-based amenity/economic/educational indices.
- Design: past network structure → future migration, to address reverse causality (Blumenstock et al. 2025).
- Network measures: for each user with non-home friends, ego-network statistics per destination settlement, and clique-like groups of 5+ interconnected friends. Aggregated at settlement-pair level to give (a) count of online connections and (b) mean density of destination cliques.
- Regression: log-log gravity, allowing elasticity interpretation.

III. Scientific results of the dissertation

Results of Article 1 – Rural-urban flows determine internal migration structure across scales

- The observed migration network is much denser than the radiation-predicted network (244,314 vs. 70,093 edges; mean total degree 153.8 vs. 44.1) and disperses migration across many weaker connections (mean edge weight 6.1 vs. 38.5).
- Node degree scales super-linearly with node strength across the urban hierarchy in the observed network, while the radiation model predicts near-linearity.
- Both networks reproduce inflow mixing across the urban hierarchy, but only the observed network shows outflow mixing: villages typically send population to nearby larger towns and cities. The radiation model fails to predict this rural-urban outflow pattern.
- Multi-scale community detection reveals a distinct hierarchical structure. At low Markov time (0.2-0.8) dense local cliques form around agglomeration centres; around 1.0-1.1 urban agglomeration zones emerge as coherent modules; above 1.5 Budapest's module absorbs all others.
- The structure is strongly hierarchical - once a settlement joins a centre's module, it stays there across higher scales - without the algorithm imposing hierarchy. The radiation network does not reproduce this.
- Some villages and smaller towns retain a centre role in their communities across resolution levels that some administratively ranked regional centres do not. Population and administrative rank alone cannot predict the maximal scale at which a settlement acts as a flow centre.
- Overall: migration is structured by a hierarchical but interconnected system in which small settlements cluster into local communities that connect through their ties to centres. Population and distance alone cannot account for this structure, especially around mid-sized towns.

Results of Article 2 – Internal migration flow network reorganization during a house price shock in a capital city

- Between 2010-2018, the ratio between Budapest and the country in house prices grew from 2.76 to 4.09 (+48%); income-per-capita ratio fell from 2.97 to 1.69 (–43%); affordability (price/income) deteriorated by 162%. Other push-pull factors changed only modestly.
- The migration network expanded rather than reorganized: edges grew 27%, total migration 38%, density from 0.167 to 0.212. Budapest's share of flows declined only marginally.
- Triangles with Budapest as middleman multiplied (+30%), but direct flow shares in these triangles stayed low (5-6%). The system added connections around the expensive hub without bypassing it.
- After controlling for network mechanisms in count-ERGMs, several push-pull estimates lose or gain significance, demonstrating that individual-unit and individual-dyad approaches produce misleading estimates when network dependencies are omitted.
- House price effects run counter to a simple affordability hypothesis in all periods and specifications: origin prices have significant negative effects (expensive districts retain population), destination prices significant positive effects (expensive districts attract), even after economic and amenity controls.
- Urban hierarchy effects differentiate only after controlling for network mechanisms: hierarchy operates through, but is not reducible to, network position. In Period 3, regional centres and other towns show enhanced retention, and non-regional-centre towns enhanced attraction, that were absent earlier.
- Network mechanisms are consistent across all models: mutuality is always positive and significant; receiver activity variance is positive and significant, showing influential attractor districts beyond what economic and amenity factors predict.
- Overall: hub-centred patterns persist despite substantial affordability deterioration. Structural differentiation happens in the middle of the urban hierarchy, where descriptive statistics do not reveal it, but ERGM controls do.

Results of Article 3 – Social connections and links to communities drive intra-metropolitan migration when housing is scarce

- In the BAA, population growth outpaced housing stock growth in all three periods studied, with the gap intensifying, confirming a spontaneous suburbanization context where housing supply cannot act as a pre-emptive pull factor.
- The number of clique-like communities scales linearly with total connections, but mean density varies substantially across settlement pairs with similar connection counts: density captures a structural property distinct from network size.
- Pure gravity models explain 35.4% of variance in log migration; adding social connection measures raises R^2 to 37.9%; adding housing and urbanization further raises it to 41.6%.
- At median values in full-interaction models, a 1% increase in online connections is associated with a 2.30-2.55% increase in migration; a 1% increase in known friend clique density with roughly 1.77% increase. Both effects are stable across specifications.
- The connections - density interaction is consistently positive and significant (1.62-1.73): connection quantity and quality reinforce each other.
- Housing-connections interactions and the density-origin-housing interaction are consistently negative and significant.
- Overall: social ties direct intra-metropolitan migration flows even after controlling for gravity, housing, and urbanization. Destination-side friend clique density matters beyond mere connection counts, and network effects intensify where housing scarcity is greatest, supporting the theoretical claim that social networks function as informal infrastructure compensating for inadequate housing supply.

IV. Main references

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