Interconnected Tracks and Tech: Analyzing the Impact of Transport and Technology Networks on Labor Market Integration in the Yangtze River Delta, China

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Abstract:
Applying a panel model to data for the Yangtze River Delta for 2014-2021, we analyze the different impacts of transport and technology networks on labor market integration. We then abstract these different connections as a two-layer multiplex network and explore their (potential) interplays. Our analysis reveals a positive correlation between transport networks and labor market integration, contrasting with a U-shaped effect observed in technology networks. We also observe evidence for a nuanced interplay between cities interconnected through these transport and technology networks. Specifically: 1) cities' overall connections in the multiplex networks have a U-shaped effect on labor market integration, and 2) the interdependencies between cities (across different network layers) contribute to an increased integration level of labor markets.

Keywords: transport networks; technology networks; labor market integration; network externalities; wage convergence; China

1. Introduction

Cities are increasingly understood as both overlapping agglomeration economies and sets of interconnected nodes in networks (Amin & Thrift, 1992; Bathelt et al., 2004). City networks are inherently multiplex: they comprise multifunctional, multidirectional, and multiscalar flows (Burger et al., 2014). Given this multiplexity, city networks depend on the lens through which they are manifested or abstracted (Zhang et al., 2020). Simply put, cities are not only connected by physical infrastructure such as transport connections (Tranos, 2011), but also by functional relationships such as knowledge transfers (Dai et al., 2023). Among these myriad linkages, transport and technology networks have been particularly relevant in examining regional integration – both physical and functional aspects (see examples in Cao et al., 2018 on transport and knowledge networks) – as they are argued to be major conduits for this regional integration process.

Despite the relevance of transport and technology networks for understanding cities'

regional integration, their relationship with labor market integration (LMI) has, to the best of our knowledge, not yet been explicitly broached. LMI, defined here as the free movement of labor, less restricted access to labor markets, and wage convergence (Zhao et al., 2017), is hypothesized to be closely related to the networks through city 'network externalities'. Specifically, transport networks are argued to enhance labor mobility and extend access to a larger labor pool for job 'matching' (Johansson et al., 2002). In addition, the hypothesized LMI impact of technology networks can be understood through 'learning', where knowledge diffusion (largely) affects skilled labor movement and wage inequalities. As a result, cities' transport and technology connections may contribute to enhanced labor mobility and increased LMI.

Focusing on the different *types* of network connections and LMI also requires an examination of the interactions within multiplex networks. As cities become increasingly interconnected through different networks, the benefits become more than additive – the whole may become more than the sum of its parts (cf. Meijers, 2005, p. 765). This multiplex observation can be captured through *multilayer* networks, where each type of flow is recognized as a layer of network (Wang et al., 2023). Such representation can help to deal with the multifaceted relationship - both tangible and often intangible - between multiplex networks and LMI dynamics.

Despite growing attention to the hypothesized links between multiplex networks and LMI, a robust conceptual framework and detailed empirical corroboration examining the relationships have been lacking. Against this backdrop, our study aims to answer *three* related research questions:

1) How do cities' transport networks affect LMI?
2) How do cities' technology networks affect LMI?
3) What are the combined/ interactive impacts of transport and technology networks on the LMI of cities?

To address these questions, we examine the relationship between transport/technology networks and LMI in the YRD from 2014 to 2021. In so doing, we aim to contribute to the growing research on multiplex networks and regional integration dynamics. More specifically, we exclusively focus on these networks for their often-argued role in representing physical and knowledge-based interactions. Our study extends the state-of-art in *four* main ways: 1) our analysis presents, for the first time, a theoretical framework that systematically links transport/ technology networks and LMI through the lens of networks externalities; 2) we empirically investigate the purported impact of these networks on LMI across space *and* time in China's megacity-region; 3) we construct a two-layer multiplex network to explore the (potential) combined/interactive network effects on LMI; and 4) we conceptually enrich this literature by borrowing ideas of the 'synergy' effects to investigate the interplays (if any) between transport and technology networks on LMI.

2. Research Methodology

2.1 Data

In our investigation of multiplex networks and LMI, we have used *two* different types of datasets for the period 2014-2021.

2.1.1 Intercity network connections

Transport networks are represented by railway frequencies (sourced from the *Shengming* train timetable), serving as tangible conduits for capturing the movement of people and goods at the regional scale (Zhang et al., 2020). Technology networks are depicted through patent transfer data from Incopat Global Patent Database, embodying the intangible exchange of knowledge and ideas (Dai et al., 2023).

We constructed undirected 26-by-26 matrices for each year, where nodes represent 26 cities in the YRD, and edges indicate the number of railway connections/patent transfers between cities. Our multiplex network, $G^{[M]} = (V^{[M]}, E^{[M]})$, comprises *two* interrelated layers: E_1 and E_2 symbolize transport and technology network connections, respectively, with a common node set $V^{[M]}$ (across both layers) representing cities within the YRD.

2.1.2 Socio-economic data

The average wage data of each city is used for measuring the labor price convergence (Prado et al., 2021) as its analysis indicates the extent to which the labor market is moving towards integration. Other socio-economic data of cities, such as GDP and population, are sourced from the China Statistical Yearbook.

2.2 Analytical strategy

2.2.1 Operationalizing variables

(1) Dependent variable

LMI is used as the dependent variable in our analysis. Following previous studies (Prado et al., 2021), we calculated relative wage differences to assess variations in labor prices and the level of LMI.

(2) Independent variables

To quantify the independent variables of transport and technology networks, we calculate the normalized degree centrality for each network to capture the direct linkages incident upon that city. For multiplex networks, we use aggregated degree centrality, an extension of degree centrality for multilayer analysis (Basaras et al., 2017). We also introduce a so-called node interdependence to capture the potential interdependencies of cities in networks (Hu et al., 2020).

(3) Control variables

We include a set of control variables that are identified as factors potentially affecting LMI, such as the economic size, total population and tertiary output value (Zhao et al,

2017).

2.2.2 Methods

Our analysis centers on a two-way fixed-effect model (i.e., individual and time fixed) to investigate the impact of multiplex networks on LMI. The generalized model is as follows:

$$LMI_{it} = \delta + \alpha NC_{it} + \beta X_{it} + \gamma_i + \delta_i + \varepsilon_{it} \quad (1)$$

where LMI_{it} is the labor market integration, NC_{it} represents network connections, X_{it} denotes control variables, γ_i is the time-fixed effect, δ_i is the individual fixed effect, and ε_{it} is the random error term. As the inclusion of network-derived variables may risk violating core assumptions of regression analysis, we adopt a bootstrapping approach (at 5000 replications) for more robust estimations.

3. Results

Turning attention to empirical results, we commence with a discussion of the impact of transport and technology network on LMI. We found that transport networks positively influence LMI, indicating that an increased transport network connectivity is associated with a higher degree of LMI, aligning with the findings of Hu et al. (2020). In contrast, technology network shows a somewhat complex relationship with LMI: a 'U'-shaped relationship, with an initial negative effect, followed by a positive effect in the latter phase, aligning with the findings of Chu et al. (2021).

Extending our analysis to multiplex networks and LMI, we observed an interesting and somewhat surprising point: the combine effects of two networks on LMI are 'U'-shaped. This could be explained by the (potential) 'dominant' role of one type of connection in this multiplex network. Put differently, technology networks may play a more pivotal role in affecting LMI, as they are argued to be less spatially constrained and particular relevant to labor market performance.

Moving to the interplays between transport and technology network, we observed the high correlation and node interdependence. Cities connected by dense transport connections allows people to travel with their intangible knowledge, while technology connections are likely to increase face-to-face interactions and tangible travel. In addition, we found a significant positive correlation between node interdependence and LMI. This suggests that increased interdependencies in transport and technology networks could collectively promote labor mobility, reduce wage differences and increase levels of LMI, echoing the rise of regional synergies (cf. Meijers, 2005, p. 766).

4. Discussion and Conclusion

In summary, this study *theoretically* links transport and technology networks to LMI

through the lens of network externalities and synergies. *Empirically*, it juxtaposes the impacts of transport and technology networks on LMI – both individually and collectively - within China's megacity-regions. Our main findings are that:

(1) A city's transport network is positively related to its level of LMI with the region; while technology network exhibits a 'U'-shaped effect on LMI.
(2) The combined effect of cities connected in transport and technology networks on LMI is 'U'-shaped.
(3) The interdependencies of cities in both networks have been found to translate into a higher level of LMI.

Our findings highlight the explanatory potential of city networks, either infrastructure or knowledge-based connections. They are both crucial for the regional integration agenda. This underscores the need to consider multiplexity in networks. In addition, rather than simply quantifying network externalities and synergies, we focus on the benefits arising from the interconnection/interdependencies of cities, and how cities could potentially internalize these benefits to promote LMI.

Some potential implications are worth exploring. Increased transport linkages and knowledge flows endow cities with benefits related to increased labor mobility, particularly in megacity-regions. Moreover, externalities may broadly emerge in different networks, the benefits of which can manifest themselves through 'sharing,' 'learning,' and 'matching'. As such, policy focus should extend to enhancing the interconnection of a city/region in a wide variety of networks (Burger & Meijers, 2016).

Future research can address some limitations of our study. First, our choice of rail connections and patent transfer are less-than-perfect proxies as they represent only specific aspects of regional networks. It is therefore important to stress that a 'city network' is a theoretical abstraction: it is a representation of a complex and multilayered reality at best (Derudder, 2021). Second, our theoretical framework of 'network externalities' might oversimplify certain aspects. Future inquiries should explore different theoretical lenses for a more holistic understanding of urban networks. Third, our analysis focused on intra-regional connections in China's megacity-region; future studies could consider the (additional) effects of inter-regional connections in other regions and generalize research findings through a place-based perspective.

References

Amin, A., & Thrift, N. (1992). Neo-Marshallian nodes in global networks. *International Journal of Urban and Regional Research*, *16*(4), 571-587.

Basaras, P., Iosifidis, G., Katsaros, D., & Tassiulas, L. (2017). Identifying influential spreaders in complex multilayer networks: A centrality perspective. *IEEE Transactions on Network*

Science and Engineering, *6*(1), 31-45.

Bathelt, H., Malmberg, A., & Maskell, P. (2004). Clusters and knowledge: local buzz, global pipelines and the process of knowledge creation. *Progress in Human Geography*, *28*(1), 31-56.

Burger, M. J., Van Der Knaap, B., & Wall, R. S. (2014). Polycentricity and the multiplexity of urban networks. *European Planning Studies*, *22*(4), 816-840.

Cao, Z., Derudder, B., & Peng, Z. (2018). Comparing the physical, functional and knowledge integration of the Yangtze River Delta city-region through the lens of inter-city networks. *Cities*, *82*, 119-126.

Chu, A. C., Furukawa, Y., Mallick, S., Peretto, P., & Wang, X. (2021). Dynamic effects of patent policy on innovation and inequality in a Schumpeterian economy. *Economic Theory*, *71*, 1429-1465.

Dai, L., Derudder, B., Cao, Z., & Ji, Y. (2023). Examining the evolving structures of intercity knowledge networks: the case of scientific collaboration in China. *International Journal of Urban Sciences*, *27*(3), 371-389.

Derudder, B. (2021). Bipartite network projections of multi-locational corporations: Realising the potential. *Geographical Analysis*, *53*(2), 383-393.

Hu, Y., Deng, T., & Zhang, J. (2020). Can commuting facilitation relieve spatial misallocation of labor?. *Habitat International*, *106*, 102136.

Johansson, B., Klaesson, J., & Olsson, M. (2002). Time distances and labor market integration. *Papers in Regional Science*, *81*(3), 305-327.

Meijers, E. (2005). Polycentric urban regions and the quest for synergy: Is a network of cities more than the sum of the parts?. *Urban Studies*, *42*(4), 765-781.

Prado, S., Lundh, C., Collin, K., & Enflo, K. (2021). Labour and the 'law of one price': Regional wage convergence of farm workers in Sweden, 1757–1980. *Scandinavian Economic History Review*, *69*(1), 41-62.

Tongjing, W., Meijers, E., & Wang, H. (2023). The multiplex relations between cities: A lexicon-based approach to detect urban systems. Regional Studies, *57*(8), 1592–1604.

Tranos, E. (2011). The topology and the emerging urban geographies of the Internet backbone and aviation networks in Europe: a comparative study. *Environment and Planning A*, *43*(2), 378-392.

Zhang, W., Derudder, B., Wang, J., & Witlox, F. (2020). An analysis of the determinants of the multiplex urban networks in the Yangtze River Delta. *Tijdschrift Voor Economische En Sociale Geografie*, *111*(2), 117-133.

Zhao, J. L., Zhang, X. B., & Song, J. P. (2017). Measurement and Determinants of Labor Market Integration in Jing-Jin-Ji Region. *Economic Geography*, *37*(5), 94-100.