# When Is a Commute "Reverse"? Measuring Direction in Polycentric Urban labor Markets

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**Abstract**

Reverse commuting has a familiar monocentric meaning: travel from a central residential area toward suburban employment. Yet an origin–destination matrix does not identify a commute as reverse without first specifying the metropolitan hierarchy relative to which its direction is judged. We develop a network-based measure that uses the stationary structure of the full tract-to-tract commuting system to identify counter-directional flows. Under a conventional near-monocentric configuration with predominantly inward commuting, the measure becomes increasingly concordant with the familiar classification of outward trips as reverse; in polycentric systems, it remains operational without requiring a unique center or a predetermined core–periphery boundary. Applying the method to tract-level LODES data for 40 U.S. metropolitan areas from 2002 through 2021, we show that network, distance-based, and local inflow–outflow classifications imply substantially different levels and geographies of reverse commuting. These differences vary systematically with metropolitan employment structure and demonstrate that empirical conclusions about commute direction depend materially on the urban hierarchy embedded in the measurement rule.

**Keywords:** Reverse commuting; commuting networks; polycentric urban regions; employment decentralization; urban labor markets

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# 1. Why Reverse Commuting Needs Rethinking

Reverse commuting has a familiar intuitive meaning: it refers to travel that runs against the dominant metropolitan commute direction, typically understood as movement from a dense central area toward suburban employment locations. This intuition is clear in a stylized monocentric city. When the central business district (CBD) is the dominant employment center, density and employment concentration decline with distance from downtown, and most commuters travel inward, the concepts of "central," "suburban," "outward," and "against the dominant flow" describe nearly the same empirical object. Under those assumptions, defining reverse commuting as movement away from the center is transparent.

The difficulty is that reverse commuting is not observed directly in an origin–destination matrix. It is a classification imposed on observed flows after the researcher specifies the spatial hierarchy relative to which movement is judged conventional or reverse. This makes the concept especially sensitive to assumptions about urban form. Applied spatial research often requires choices about areal units, boundary definitions, distance metrics, and spatial lag structures. In many spatial applications, such choices alter the specification of a broadly stable estimand and can be examined through sensitivity analysis. Reverse commuting is different because the assumed spatial hierarchy partly defines the estimand itself: without a hierarchy, an observed flow has no intrinsic conventional or reverse direction. A core-to-suburb rule therefore maps uniquely onto movement against the dominant metropolitan direction only under restrictive assumptions about urban structure.

Those assumptions are increasingly difficult to maintain. Employment and residential activity have decentralized substantially across metropolitan areas (Brueckner and Fansler, 1983; Brueckner, 2000; Nechyba and Walsh, 2004; Liotta et al., 2022). Contemporary cities often contain multiple employment clusters, dispersed residential development, and complex cross-suburban commuting patterns (Giuliano and Small, 1991; Anas et al., 1998; McMillen, 2003; Duranton and Puga, 2015). Urban activity has also become increasingly consumption-oriented, with employment, amenities, and residential demand jointly shaping metropolitan spatial structure (Glaeser et al., 2001; Glaeser and Gottlieb, 2006). As a result, commuting flows frequently connect residential neighborhoods to suburban office corridors, logistics centers, airports, industrial districts, medical complexes, and mixed-use subcenters rather than to a uniquely dominant urban core.

In such settings, conventional verbal definitions become under-specified. A commute from a dense inner-ring neighborhood to a suburban medical complex may be outward by distance but inward with respect to employment centrality. A suburb-to-suburb trip may appear lateral under a CBD-distance rule but may run against the dominant direction of labor-market connectivity. A flow away from one urban subcenter and toward another may be difficult to classify without first specifying which center defines the relevant hierarchy. The problem is not that conventional definitions of reverse commuting are meaningless; it is that they embed a simplified model of metropolitan structure. Once centrality is multidimensional, the empirical content of "reverse" depends on how the researcher defines the relevant center, the relevant periphery, and the dominant direction of commuting.

This measurement problem matters because reverse commuting is not simply a descriptive curiosity. It has been used to interpret central questions in urban economics, transportation planning, and metropolitan policy: whether employment decentralization reduces or reconfigures spatial mismatch; whether central-city residents can access suburban job growth; whether transit systems remain too strongly oriented around suburb-to-downtown peak flows; and whether the resurgence of central cities reflects employment access, consumption amenities, or both. In policy practice, the concept was institutionalized through the federal Job Access and Reverse Commute program, which funded transportation services intended to connect welfare recipients and low-income workers to employment opportunities.[1]

[1]The standalone Job Access and Reverse Commute program has been repealed, but JARC-type activities remain eligible under the Federal Transit Administration's Urbanized Area Formula Grants and Formula Grants for Rural Areas programs. The program was designed to address transportation barriers faced by low-income workers, including limited access to suburban employment and work schedules poorly served by conventional transit. See `https://www.transit.dot.gov/funding/grants/grant-programs/job-access-and-reverse-commute-program-5316`.

In empirical research, reverse commuting has been used to study welfare-to-work transportation barriers, transit-service gaps, socioeconomic disparity between home and work locations, suburban employment access, and the changing role of central cities as places of residence rather than only places of production (Cervero et al., 2002; Cervero and Tsai, 2003; Aguiléra et al., 2009; Davidson and Ryerson, 2018, 2021; Davidson et al., 2023).

Reverse commuting also has a specific interpretation in the consumer-city literature. In a production-centered account of urban form, central-city residence is valuable largely because it provides access to central-city employment. The consumer-city argument instead emphasizes the value of restaurants, entertainment, cultural variety, social interaction, and other urban amenities (Glaeser et al., 2001). A worker who lives centrally while working in a suburban location provides one observable expression of this mechanism: the residential and consumption value of the central city is sufficient to offset the cost of commuting outward. Commuting direction can therefore help distinguish a city valued principally for proximity to production from one increasingly valued as a place of residence, consumption, and interaction (Glaeser and Gottlieb, 2006; Couture and Handbury, 2020).

The policy and theoretical importance of reverse commuting makes its measurement consequential. A policy aimed at "reverse commuters" implicitly assumes a model of who those commuters are and where they travel. If the measure identifies the wrong flows, corridors, or neighborhoods, then policy analysis may be organized around a salient but incomplete geography of need. Similarly, if reverse commuting is used as evidence for spatial mismatch, consumer-city dynamics, or metropolitan restructuring, then the classification rule shapes the substantive interpretation of urban change. The goal is therefore not merely to propose another descriptive index, but to provide a theoretically consistent and empirically reproducible way to classify commute direction when the conventional monocentric hierarchy is no longer adequate.

Existing measures typically classify commuting direction using either an exogenously imposed spatial hierarchy or a local flow balance. Distance-based measures define direction relative to a CBD or metropolitan center, while in/out measures classify locations according to whether they primarily send workers elsewhere or receive workers from surrounding areas. These approaches are intuitive and transparent, but they rely on a center-based or locally bilateral view of urban structure. They are therefore less well suited to metropolitan systems in which employment access is mediated through multiple subcenters, corridor-based job clusters, and intermediary neighborhoods (Redfearn, 2007; Giuliano and Dargay, 2012; Manduca, 2021).

This paper treats reverse commuting as a measurement problem and develops a network-based approach for identifying counter-directional commuting in polycentric metropolitan systems. We represent each metropolitan commuting system as a directed weighted network in which neighborhoods are connected through observed residential-to-workplace flows. Each neighborhood's position within that system is summarized by the stationary distribution of a stochastic process defined on the full commuting network. We then compare stationary, network-adjusted flows in reciprocal directions. An observed commute is classified as reverse when its direction is less prevalent than the reciprocal direction after accounting for each tract's systemwide network exposure. Although the resulting comparison is bilateral in form, it is metropolitan in informational content because the stationary weights are jointly determined by the full origin–destination matrix.

The broader contribution is to show that reverse commuting is not a primitive feature of origin–destination data, but a classification that depends on assumptions about metropolitan centrality, peripherality, and prevailing commute direction. The paper makes three specific contributions. First, it provides a theoretically explicit definition that identifies counter-directional movement without requiring a predetermined urban center. Second, it introduces a tractable network-adjusted directional measure that combines reciprocal flow asymmetry with each tract's recursive position in the metropolitan commuting system. Third, it evaluates the measure empirically by showing that network and conventional classifications become more concordant as commuting becomes more strongly CBD-oriented, but imply different levels and geographies of reverse commuting as metropolitan structure decentralizes. Although the empirical application uses U.S. metropolitan data, the underlying measurement problem and network construction apply wherever sufficiently detailed origin–destination flows are available.

## 2. Commuting as a Networked Process

A commute is not conventional or reverse in isolation; it becomes so only relative to a hierarchy of metropolitan places. Conventional measures impose this hierarchy in one of two ways. A CBD-distance rule assumes that centrality declines with distance from a selected center. In this framework, a reverse commute is typically defined as a trip from a designated core—identified, for example, by proximity to the CBD or by a central-city boundary—to a workplace outside that core. The hierarchy is therefore exogenous: places are ordered relative to a predetermined center, and movement outward across the resulting core–periphery boundary is classified as reverse.

An in/out rule instead defines hierarchy using local commuting balance. A tract is treated as workplace-oriented when it receives more inbound commuters than it sends out as resident workers, and as residence-oriented when the reverse is true. A reverse commute is then a trip from a net labor-importing or job-rich tract to a net labor-exporting or residential tract. This hierarchy is local: direction is determined by each tract's own inflow–outflow balance rather than by its position within the metropolitan system.

These measures are useful precisely because they are transparent. Their simplicity, however, comes from treating the relevant metropolitan hierarchy as either exogenous or local. A network approach starts from a different premise: the hierarchy of places is itself embedded in the full system of observed commuting relationships.

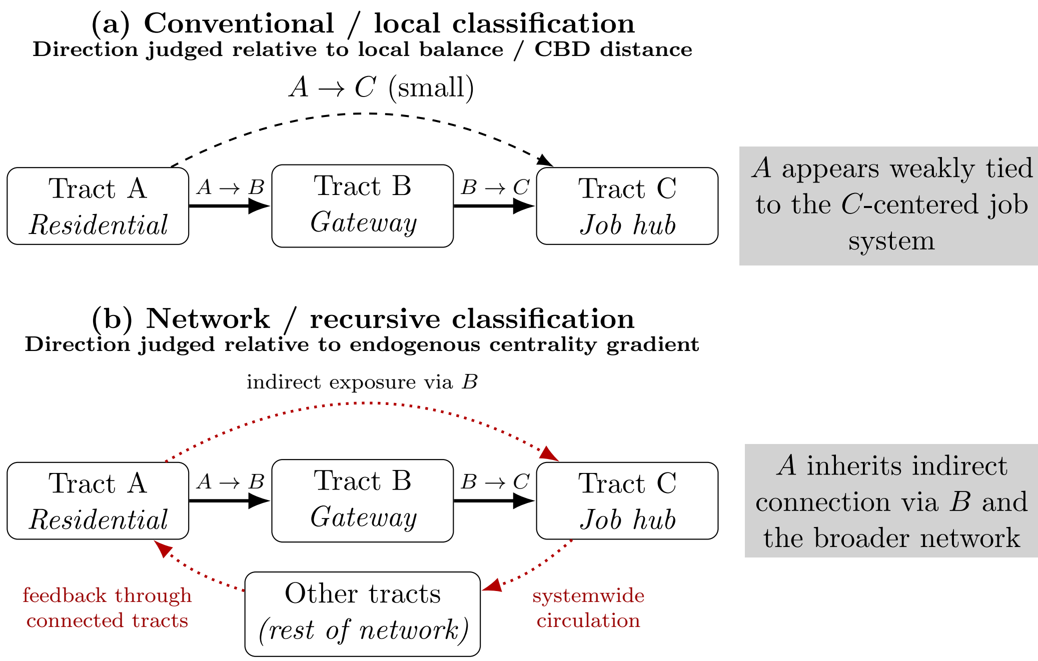
This perspective follows naturally from spatial equilibrium models in which residential locations, workplace locations, amenities, land costs, and commuting frictions are jointly determined (Roback, 1982; Redding and Rossi-Hansberg, 2017). Households choose where to live partly on the basis of housing costs, amenities, and access to employment opportunities, while firms choose locations partly on the basis of productivity, land costs, labor accessibility, and agglomeration advantages. The observed origin–destination matrix is therefore not simply a collection of unrelated bilateral trips. It is a reduced-form representation of how workers, firms, and places are connected across metropolitan space (Couture and Handbury, 2020; Redding, 2023). Two neighborhoods with similar direct inflow or outflow totals may consequently occupy very different positions within the broader labor-market system.

The relevant network structure is recursive. A neighborhood's metropolitan position depends not only on the volume of its direct commuting ties, but also on where those ties lead. A mixed-use gateway tract, for example, may not be the largest employment center in a metropolitan area, but it may be closely connected to a major job hub and may link surrounding residential neighborhoods to a broader corridor of economic activity. Likewise, a residential tract may send relatively few commuters directly to the largest employment center while remaining strongly connected to places that are themselves integrated into that center. Local inflows, outflows, or distance from a selected CBD do not fully describe these mediated relationships.

This distinction is especially important in metropolitan areas with multiple employment clusters. Rather than a single dominant center, many cities contain job hubs connected through intermediary neighborhoods, corridor-based development, and mixed-use subcenters (Redfearn, 2007; Giuliano and Dargay, 2012; Manduca, 2021). A neighborhood may therefore be strongly embedded in the metropolitan employment system even when it has weak direct commuting ties to the largest or most traditional center. Conversely, a neighborhood with substantial local inflows may occupy a relatively limited systemwide position if those inflows originate in places that are otherwise weakly connected to the metropolitan network.

Figure 1 illustrates this distinction. Tract $A$ is primarily residential and sends many workers to nearby Tract $B$, a mixed-use gateway. Tract $B$, in turn, has strong commuting ties to Tract $C$, a major employment hub such as an airport zone, medical complex, industrial district, or suburban office corridor. Direct commuting from $A$ to $C$ may be limited. A local flow-balance measure or a distance-from-center rule may therefore treat $A$ as peripheral to the employment system associated with $C$. A network measure can instead recognize that $A$'s metropolitan position is partly mediated through its connection to $B$, whose own position depends on its ties to $C$ and to the rest of the commuting system.

Figure 1: Local and network views of metropolitan commuting structure




**Panel (a)** depicts separate observed commuting flows from $A$ to $B$ and from $B$ to $C$, together with a comparatively weak direct connection from $A$ to $C$. Panel (b) illustrates how $A$'s network position can also depend on the locations to which its directly connected tracts are linked. Dotted arrows do not represent observed journeys or multi-stage commutes; they indicate the recursive propagation of exposure through the synthetic stochastic process. The figure is conceptual and does not identify causal economic support among the tracts.
**Panel (b)** illustrates the network-based view. Even when direct $A \to C$ commuting is limited, $A$ may remain strongly integrated into the metropolitan labor market because it is connected to $C$ through gateway tract $B$ and through circulation involving the rest of the commuting network. In this sense, employment activity at $C$ indirectly supports activity in $B$, which in turn supports residential viability and labor-market access in $A$. Dotted arrows represent indirect network support and recursive propagation of centrality rather than observed tract-to-tract commuter flows. The figure therefore motivates defining commute direction relative to endogenous centrality gradients in the full commuting network, rather than only direct local ties or exogenous spatial anchors.

The figure should not be interpreted as depicting a literal multi-stage journey by a single commuter. The $A \to B$ and $B \to C$ edges represent separate observed origin–destination trips. The recursive process instead asks how frequently a synthetic traveler encounters each tract when successive destinations are drawn from the observed commuting probabilities. This allows the position of $A$ to reflect not only its direct ties, but also the systemwide relationships carried through $B$. Nor does the procedure identify the general-equilibrium effects connecting employment, housing, and local services causally. It summarizes the relational structure that jointly determined residential and workplace choices leave in the observed commuting matrix.

A network approach therefore asks where each neighborhood sits within the full system of commuting relationships. Neighborhoods are not central simply because they receive many commuters, nor peripheral simply because they are far from a CBD. Their position depends on how frequently they are encountered through the recursively connected metropolitan system. The same logic applies to commute direction: a flow becomes conventional or reverse only relative to a hierarchy inferred from the full commuting network. The next section formalizes this hierarchy and defines the counter-directional member of each reciprocal commuting relationship.

## 3. A Network-Based Definition of Reverse Commuting

We define commute direction using the structure of the full metropolitan commuting network. Within a given metropolitan area and year, let $\mathbf{W} \in \mathbb{R}_+^{n \times n}$ denote the origin–destination commuting matrix, where $W_{ij}$ is the number of commuters residing in neighborhood $i$ and working in neighborhood $j$. Row-normalizing $\mathbf{W}$ gives a transition matrix $\mathbf{P}$ with elements

$$P_{ij} = \frac{W_{ij}}{\sum_k W_{ik}}, \tag{1}$$

where $P_{ij}$ is the observed probability that a resident commuter from neighborhood $i$ works in neighborhood $j$. The matrix $\mathbf{P}$ therefore summarizes the destination structure faced by residents of each origin neighborhood.

The key step is to use this transition matrix to summarize each neighborhood's systemwide exposure within the metropolitan commuting network. Let $\boldsymbol{\pi}$ denote the stationary distribution satisfying

$$\boldsymbol{\pi}^\top = \boldsymbol{\pi}^\top \mathbf{P}, \qquad \sum_i \pi_i = 1. \tag{2}$$

The component $\pi_i$ measures the long-run exposure of neighborhood $i$ under the commuting-induced stochastic process. Equivalently, $\boldsymbol{\pi}$ is a left-eigenvector centrality measure for the row-stochastic commuting matrix. A tract receives greater stationary exposure when it is reached with high probability from tracts that themselves carry substantial stationary mass, including through longer circulation and return paths in the commuting network. Technical conditions for existence, uniqueness, and computation are provided in Online Appendix A.

The use of stationary distributions to summarize commuting networks is not itself new. Kane et al. (2024), for example, use a normalized commuting matrix and its stationary distribution to identify prominent mobility loci in New Zealand. Our object is different. Stationary exposure is an input into a directed edge-level comparison rather than the final outcome: we compare reciprocal stationary edge frequencies to identify which observed commute direction is atypical. The contribution is therefore a network-based definition of commute direction rather than a new node-centrality measure.

A useful interpretation is provided by a taxi analogy. Imagine a fixed fleet of taxis circulating through the metropolitan labor market. After dropping a commuter at a workplace tract, each taxi immediately picks up a new commuter residing in that tract and travels to that commuter's workplace, with destinations drawn according to the observed probabilities in $\mathbf{P}$. Over many transitions, taxis spend more time in tracts that are repeatedly encountered through the full commuting system. The stationary distribution $\boldsymbol{\pi}$ records this long-run exposure.

The analogy is not intended as a behavioral model of individual commuters or as a claim that workers make successive multi-stage journeys. The stationary process is a reduced-form device for summarizing the relational position of each tract within an origin–destination matrix generated by residential and workplace choices (Redding and Rossi-Hansberg, 2017). Its purpose is to infer a metropolitan hierarchy from observed commuting relationships without choosing a CBD or imposing a spatial ordering in advance.

We then define commute direction by comparing stationary edge frequencies in reciprocal directions. Let

$$F_{ij} = \pi_i P_{ij} \tag{3}$$

denote the long-run frequency with which the induced process traverses the directed edge from neighborhood $i$ to neighborhood $j$. For each reciprocal tract pair, define the network-adjusted directional ratio

$$R_{ij} = \frac{F_{ij}}{F_{ji}} = \frac{\pi_i P_{ij}}{\pi_j P_{ji}}. \tag{4}$$

Although this comparison is bilateral in form, it is metropolitan in informational content: the stationary weights $\pi_i$ and $\pi_j$ are jointly determined by the full origin–destination network. Equivalently,

$$\log R_{ij} = \log\left(\frac{P_{ij}}{P_{ji}}\right) + \log\left(\frac{\pi_i}{\pi_j}\right), \tag{5}$$

so the classification combines reciprocal directional asymmetry with each tract's systemwide network exposure.

For reciprocal positive flows, $R_{ji} = R_{ij}^{-1}$. Except in the directionally balanced case $R_{ij} = 1$, exactly one member of the reciprocal pair is therefore identified as counter-directional. An observed $i \to j$ commute is classified as reverse when

$$R_{ij} < 1, \tag{6}$$

meaning that its stationary network-adjusted frequency is lower than that of the reciprocal $j \to i$ direction. The measure therefore identifies the less prevalent direction of a commuting relationship after adjusting for the different positions of its endpoints in the metropolitan network.[2]

The network rule recovers the conventional interpretation under a natural near-monocentric configuration.[3] In the canonical monocentric setting, employment is concentrated at a dominant CBD and workers residing outside the core ordinarily commute inward (Alonso, 1964; Muth, 1961; Mills, 1967). Strictly interpreted, that benchmark contains no outward employment trips to classify. Once a limited amount of employment decentralization is admitted, however, a core-to-periphery trip becomes an unusual outward movement within an otherwise inward-oriented commuting system.

Let $i$ denote the more central location and $j$ the more peripheral location. A sufficient condition for the observed outward commute $i \to j$ to be classified as reverse is

$$\pi_i P_{ij} < \pi_j P_{ji}, \tag{7}$$

or equivalently,

$$\frac{P_{ji}}{P_{ij}} > \frac{\pi_i}{\pi_j}. \tag{8}$$

The right-hand side adjusts for the greater systemwide exposure of the central location. The condition therefore requires the ordinary inward direction to be sufficiently more prevalent that the outward movement remains atypical even after accounting for the core's larger network position. This is the natural empirical analogue of conventional reverse commuting: centrality is concentrated near the core, prevailing movement is inward, and relatively unusual outward trips are classified as reverse.

The same criterion remains well-defined when metropolitan structure ceases to be radial. Unlike a distance-to-CBD rule, the network measure does not require a single center

[2]Online Appendix A provides computational details. When $P_{ji} = 0$, the observed $i \to j$ direction has no reciprocal observed flow and is not classified as reverse.

[3]The classic Alonso–Muth–Mills model does not express commuting patterns using the transition probabilities defined here. Its stronger spatial premise is that employment is concentrated at the CBD and that residential workers outside the core commute radially inward. Mills 1967, for example, allows some suburban workers to be employed locally while assuming that the remaining workers commute to the CBD. The relevant empirical special case is therefore a near-monocentric perturbation in which some employment has decentralized but the prevailing commute direction remains inward.

to be selected in advance. Unlike an in/out rule, it does not evaluate each tract using only its own local commuting balance. Direction is instead inferred from reciprocal flows after each endpoint has been positioned within the full metropolitan network. The measure consequently becomes more concordant with the conventional interpretation when a dominant inward-oriented hierarchy is present, while remaining operational in systems organized around multiple employment centers, cross-suburban corridors, or other non-radial structures.

The resulting measure remains tractable because it requires only standard origin–destination commuting matrices. It can therefore be implemented consistently across metropolitan areas and over time as employment geography evolves. The next section compares its classifications with those produced by distance-based and local inflow–outflow rules.

# 4. Empirical Application

## 4.1. Data and metropolitan sample

We use tract-level origin–destination flows from the U.S. Census Bureau's Longitudinal Employer–Household Dynamics Origin–Destination Employment Statistics (LODES) for a geographically diverse sample of 40 U.S. metropolitan statistical areas observed annually from 2002 through 2021. The sample spans metropolitan areas that vary in size, region, and urban form and is intended to evaluate the measure across heterogeneous urban systems rather than to provide a probability sample of all U.S. cities. We use the LODES OD Main files for all jobs and worker segments and retain commutes for which both the residence and workplace tract lie within the metropolitan area. Tracts are represented using 2020 Census geography.

For each MSA–year, census tracts form the network nodes and commuter counts form directed residential-to-workplace edges. Intratract flows contribute to the transition matrix and stationary distribution, while reverse-commuting classifications are defined over observed off-diagonal tract-to-tract flows. We remove tracts with no outbound commuting mass, restrict the network to its largest closed strongly connected component, and add a small lazy self-loop to ensure aperiodic convergence. Unless otherwise noted, metropolitan reverse-commuting shares are commuter-weighted and represent the share of commuters traveling on origin–destination pairs classified as reverse under a given method. The analysis is descriptive rather than causal: its purpose is to examine how the measured prevalence and geography of reverse commuting change when direction is defined relative to alternative metropolitan hierarchies.

We compare the network classification with two conventional measures constructed on the same retained tract network. The in/out rule classifies a tract as job-rich when the number of commuters working there exceeds the number of employed residents commuting from it. A trip from a job-rich origin to a non-job-rich destination is then classified as reverse.

The distance rule follows approaches that order metropolitan locations relative to a selected center (Christopher et al., 1995; Berube and Forman, 2002) and studies that describe reverse commuting as central-city-to-suburban or central-city-to-outskirts travel (Glaeser et al., 2001; Aguiléra et al., 2009). We use the centroid of the 2020 Census place polygon corresponding to each MSA's principal city as a transparent proxy for the metropolitan center. We calculate projected distance from each retained tract centroid to this point and define the closest quintile of tracts as the metropolitan core. A commute from a core tract to a non-core tract is classified as reverse. The quintile threshold provides a common and reproducible benchmark; it is not intended to imply that every metropolitan core occupies exactly one-fifth of its tract geography.

The two comparison rules therefore impose different hierarchies. The in/out rule derives direction from each tract's local employment balance, while the distance rule orders tracts relative to an exogenous center. The network measure instead compares reciprocal flows after positioning both endpoints within the full metropolitan commuting system.

### 4.2. Construct validity in center-oriented metropolitan systems

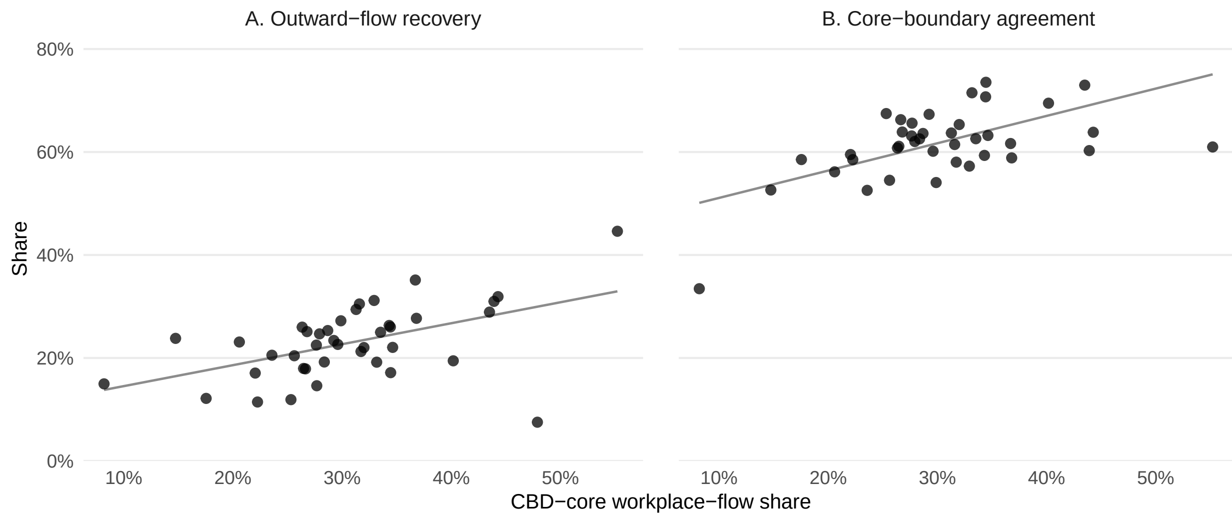
The near-monocentric special case implies that the network and distance classifications should become more concordant where commuting remains strongly oriented toward the conventional metropolitan center. We measure this orientation using the share of observed intertract commuter flows terminating in the closest-to-center tract quintile defined above. A larger value indicates that workplace commuting remains more concentrated near the principal-city center and that the metropolitan system more closely approximates the conventional monocentric benchmark. A smaller value indicates greater employment decentralization, although it does not by itself distinguish a polycentric system from diffuse, corridor-based, or otherwise non-centralized development.

For each metropolitan area, we pool the relevant commuter-count numerators and denominators over 2002–2021 to construct one commuter-weighted observation. We examine two outcomes. Outward-flow recovery is the commuter-weighted share of core-to-periphery trips—all of which the distance rule classifies as reverse—that are also classified as reverse by the network measure. Core-boundary agreement is the commuter-weighted share of all trips crossing the core boundary for which the two methods assign the same direction.

Both measures of concordance increase with center orientation. A 10-percentage-point increase in the share of intertract commuters working in the closest-to-center tract quintile is associated with a 4.1-percentage-point increase in outward-flow recovery (heteroskedasticity-robust standard error = 1.76) and a 5.3-percentage-point increase in agreement on core-boundary direction (standard error = 1.97). Center orientation explains approximately 26 percent and 37 percent of the cross-metropolitan variation in the two outcomes, respectively.

These relationships indicate increasing concordance rather than complete equivalence. Even in strongly center-oriented systems, the network measure remains more selective than the distance rule because it requires an outward trip to be atypical relative to its reciprocal network-adjusted flow, not merely to cross an imposed boundary in the outward direction. The results therefore support the intended special-case behaviour while preserving a sub-

Figure 2: Construct validity across metropolitan forms




Each point represents one MSA, constructed by pooling commuter counts over 2002–2021. The horizontal axis reports the share of observed intertract flows terminating in the closest-to-center tract quintile. Panel A reports the commuter-weighted share of core-to-periphery trips also classified as reverse by the network measure. Panel B reports agreement between the network and distance classifications among all flows crossing the core boundary. Grey lines are unweighted ordinary least squares fits across the 40 MSAs.

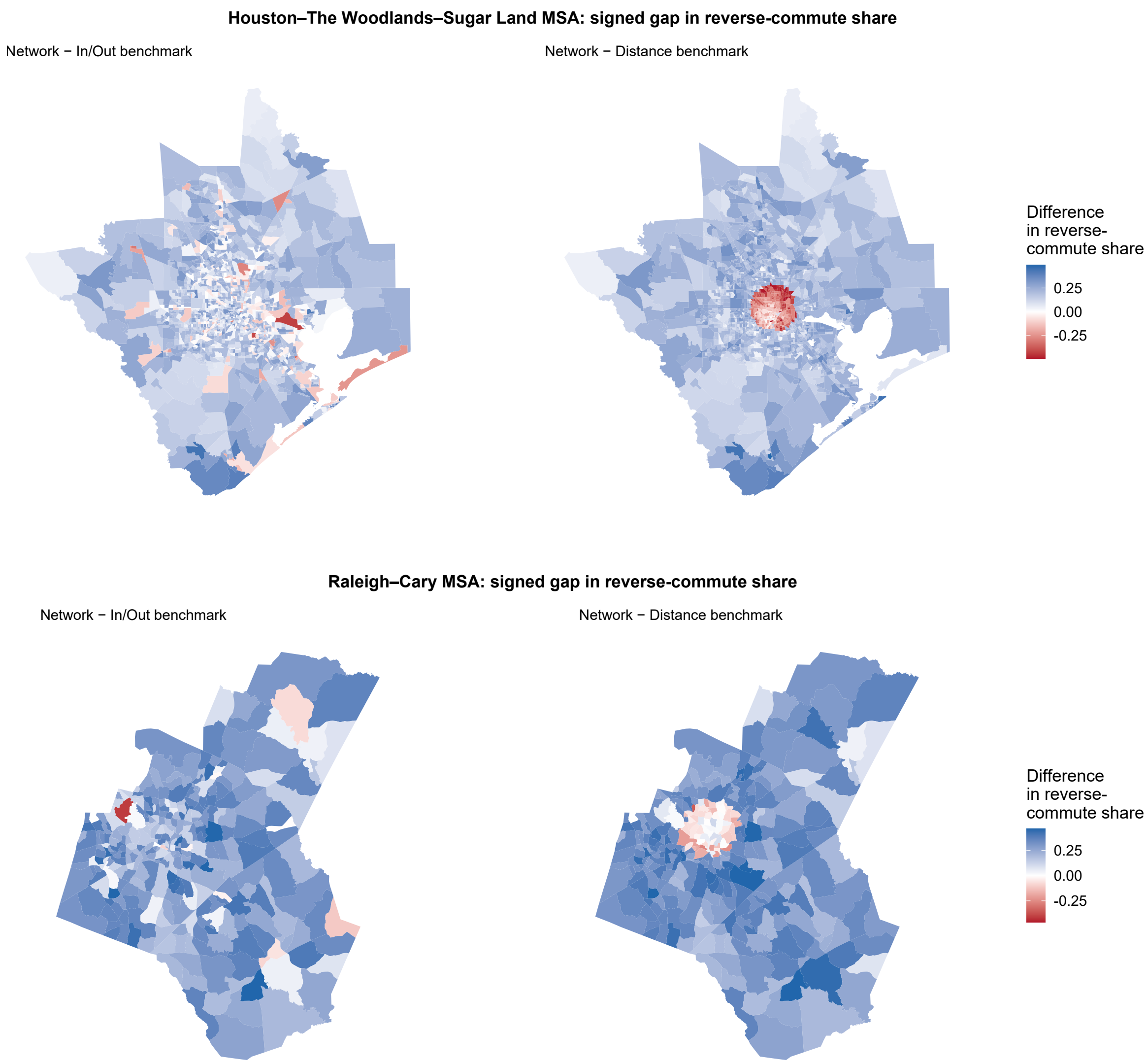
stantive distinction between geographic outwardness and directional atypicality.

### 4.3. Spatial patterns of classification disagreement

Figure 3 uses Houston and Raleigh to illustrate two distinct spatial forms of measurement disagreement observed in the metropolitan sample. The cases are not intended to be statistically representative. Rather, they show that alternative classification rules can disagree in different ways across urban space.

In Houston, disagreement is spatially heterogeneous. Relative to the distance rule, the network measure classifies a smaller reverse-commuting share in many tracts near the conventional core but a larger share across much of the outer metropolitan area; disagreement with the in/out rule is more locally mixed. Raleigh displays a more uniformly positive network-minus-benchmark gap outside its central cluster. The contrast shows that definitional disagreement is not merely an aggregate difference in measured prevalence. Depending on metropolitan structure, it can alter either particular local classifications or the broader

Figure 3: Tract-level disagreement between reverse-commuting measures in selected metropolitan areas.




Each panel maps the signed tract-level difference in estimated reverse-commute share between the network measure and two alternative measures: an in/out centrality benchmark (left column) and a distance-to-CBD benchmark (right column). The maps report results for 2019. For tract $i$, the plotted quantity is $\Delta_i = \widehat{s}_i^{\text{Network}} - \widehat{s}_i^{m}$, where $m \in \{\text{In/Out}, \text{Distance}\}$ and $\widehat{s}_i$ denotes the share of commuters residing in tract $i$ whose workplace tract is classified as reverse under a given method. Positive values indicate tracts where the alternative measure classifies a smaller share of commuters as reverse than the network measure, while negative values indicate tracts where it classifies a larger share. The upper panels report results for Houston and the lower panels report results for Raleigh.

inferred geography of reverse commuting across the urban region.

### 4.4. Cross-metropolitan comparisons

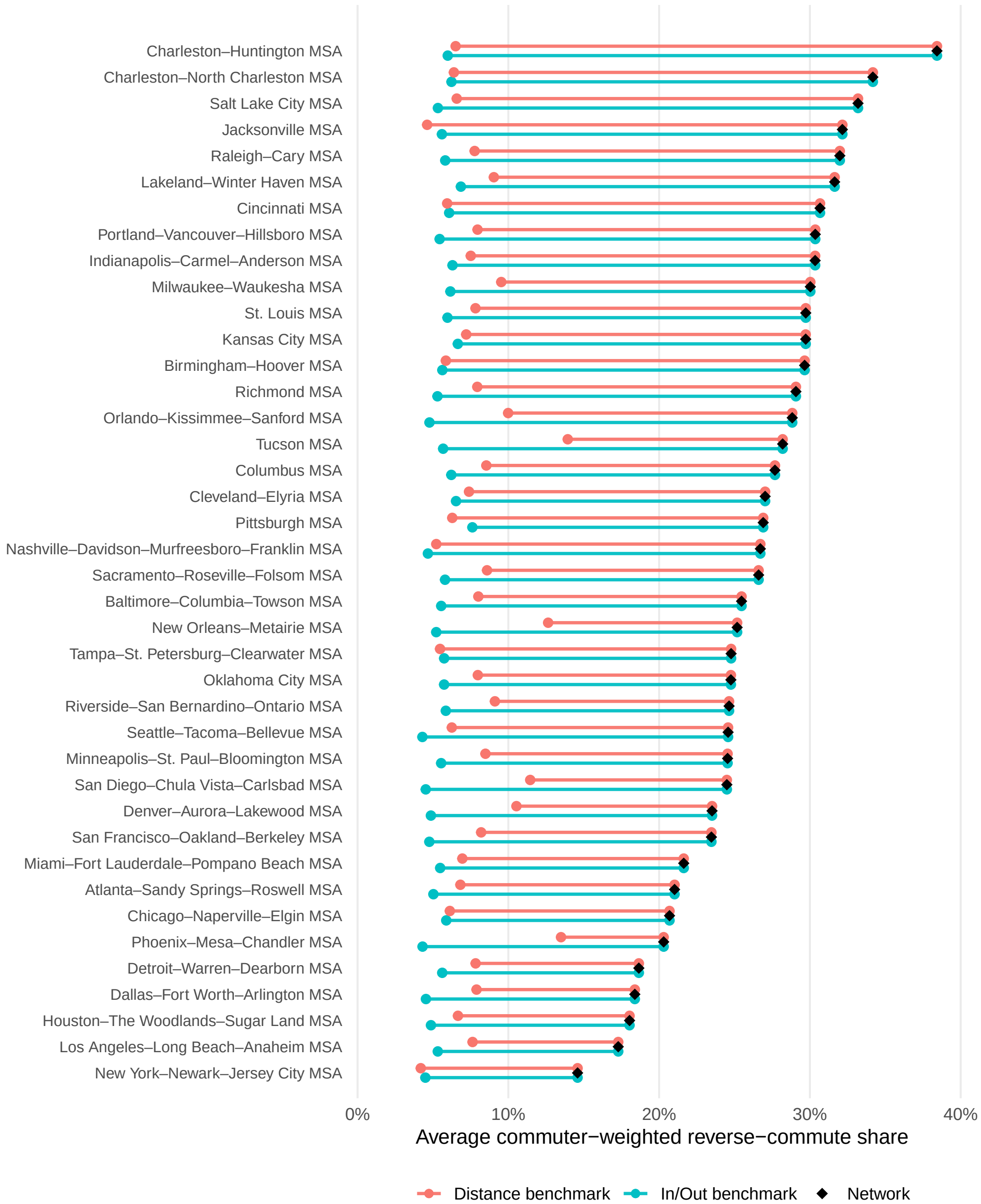
The disagreement between network-based and conventional classifications is not unique to the mapped examples. Figure 4 summarizes average commuter-weighted reverse-commuting shares across the 40 metropolitan areas in the analysis sample over the 2002–2021 period. In most metropolitan areas, the in/out and distance-based benchmarks produce lower reverse-commuting shares than the network framework, although the magnitude of the gap varies substantially across urban systems. This cross-metropolitan variation suggests that benchmark disagreement is not simply an artifact of a single city or year. Rather, it reflects broader differences in how metropolitan commuting systems are spatially organized.

Online Appendix C reports corresponding MSA-level time series, showing that network reverse-commuting shares and classification gaps also vary within metropolitan areas over time.

To examine whether variation in the resulting measures is systematically related to changing metropolitan characteristics, Table 1 reports descriptive MSA–year regressions for 2009–2021. Column (1) examines the commuter-weighted reverse-commuting share implied by the network measure. Columns (2) and (3) examine the network-minus-in/out and network-minus-distance classification gaps. Positive values in these columns indicate that the conventional measure classifies a smaller commuter share as reverse. All specifications include MSA and year fixed effects and use standard errors clustered by MSA. The coefficients therefore describe within-metropolitan covariation over time rather than cross-sectional differences across cities.

The clearest pattern is the relationship between metropolitan employment dispersion and network-classified reverse commuting. Employment entropy—constructed from the distribution of workplace activity across tracts—is positively associated with the network reverse-commuting share. As workplace activity becomes less concentrated across metropolitan

Figure 4: Reverse-commuting shares across metropolitan areas under alternative classification methods.




The figure compares metropolitan-level average commuter-weighted reverse-commuting shares generated by the network-based framework to those obtained using distance-to-CBD and in/out centrality benchmarks across 40 U.S. metropolitan statistical areas (MSAs). For each MSA–year, the reverse-commuting share is computed as the commuter-weighted share of off-diagonal tract-to-tract flows classified as reverse under each method. The plotted value for each MSA is the simple arithmetic mean of its 20 annual commuter-weighted shares from 2002 through 2021. Black diamonds denote the average reverse-commuting share implied by the network measure, while colored endpoints indicate the corresponding average shares generated by the alternative classification methods. Horizontal segments connect each benchmark measure to the network estimate within the same metropolitan area, with longer segments indicating larger disagreement between conventional and network-based classifications. Metropolitan areas are ordered according to the network-based average reverse-commuting share.

Table 1: Descriptive correlates of reverse-commuting shares and benchmark disagreement

| Dependent Variables: | Network reverse share | Network–in/out gap | Network–distance gap |
|---|---|---|---|
| Model: | (1) | (2) | (3) |
| *Variables* | | | |
| Employment entropy, 10 p.p. | 0.0226*** | -0.0075* | 0.0143 |
| | (0.0069) | (0.0042) | (0.0124) |
| Log population | 0.0003 | -0.0160 | -0.0242 |
| | (0.0200) | (0.0199) | (0.0360) |
| Log median household income | 0.0850*** | 0.0770*** | 0.0961** |
| | (0.0266) | (0.0255) | (0.0464) |
| Unemployment rate | -0.0001 | -0.0003 | $4.1 \times 10^{-5}$ |
| | (0.0004) | (0.0004) | (0.0009) |
| Average commute time | -0.0008 | -0.0003 | -0.0002 |
| | (0.0010) | (0.0010) | (0.0017) |
| Vehicle access | 0.0011 | 0.0016 | 0.0031 |
| | (0.0016) | (0.0017) | (0.0028) |
| Bachelor's+ share | -0.0015 | -0.0022** | -0.0012 |
| | (0.0010) | (0.0008) | (0.0021) |
| Housing price index change | $2.73 \times 10^{-5}$ | $-9.36 \times 10^{-6}$ | 0.0003** |
| | $(9 \times 10^{-5})$ | $(8.17 \times 10^{-5})$ | (0.0001) |
| New construction permits per 1,000 | 0.0007* | 0.0010*** | 0.0011 |
| | (0.0004) | (0.0003) | (0.0007) |
| Amenity establishments per 1,000 | -0.0003 | -0.0010 | -0.0028 |
| | (0.0031) | (0.0026) | (0.0072) |
| Amenity employment share | -0.0004 | $-8.29 \times 10^{-5}$ | -0.0008 |
| | (0.0008) | (0.0007) | (0.0014) |
| Professional services share | 0.0003 | 0.0006 | 0.0010 |
| | (0.0010) | (0.0008) | (0.0016) |
| *Fixed-effects* | | | |
| Year | Yes | Yes | Yes |
| CBSA | Yes | Yes | Yes |
| *Fit statistics* | | | |
| Observations | 520 | 520 | 520 |
| $R^2$ | 0.99276 | 0.99212 | 0.98756 |
| Within $R^2$ | 0.23729 | 0.17615 | 0.18322 |

This table reports descriptive associations between metropolitan characteristics and reverse-commuting outcomes using an annual balanced panel of 40 U.S. metropolitan statistical areas (MSAs) observed between 2009–2021. Column (1) examines the commuter-weighted reverse-commuting share implied by the network benchmark. Columns (2) and (3) examine benchmark gaps, defined as the network reverse-commuting share minus the reverse-commuting share implied by the corresponding alternative classification. The network benchmark classifies commute direction using tract-to-tract Longitudinal Employer–Household Dynamics Origin–Destination Employment Statistics (LODES) commuting flows. Employment entropy is constructed from tract-level workplace distributions within each metropolitan area as $H_m = -\frac{\sum_i s_{im} \ln(s_{im})}{\ln(N_m)}$, where $s_{im}$ denotes tract $i$'s share of metropolitan workplace activity and $N_m$ denotes the number of workplace tracts in metropolitan area $m$. Population, commuting characteristics, vehicle access, educational attainment, unemployment rates, and demographic measures are obtained from the American Community Survey (ACS). Median household income is obtained from ACS Table B19013. Professional-services employment shares, amenity employment shares, and amenity-establishment measures are derived from QCEW data. Housing price changes are constructed using Federal Housing Finance Agency (FHFA) metropolitan house price indexes, and residential development activity is measured using Census Building Permit Survey (BPS) data on newly authorized housing units. All specifications include metropolitan and year fixed effects. Standard errors are clustered at the CBSA level.

tracts, a larger share of commuters travels in directions classified as atypical by the recursively structured network measure. This result is consistent with the paper's central argument that commute direction becomes less adequately summarized by a single center–periphery hierarchy as employment disperses. Household income, residential development, and the remaining metropolitan covariates exhibit some additional associations, but these are less directly tied to the paper's measurement argument and are treated as ancillary. All estimates are descriptive: they document systematic covariation within metropolitan areas rather than the causal determinants of commuting structure.

## 5. Why the Measurement Choice Matters

The empirical patterns above point to a broader conceptual issue: commuting direction is not only a geographic fact, but also a measurement choice. A commute can appear conventional or reverse depending on whether metropolitan space is understood as a fixed center–periphery system, a collection of local inflow–outflow balances, or a relational network of labor-market connections. This distinction is especially important in polycentric regions, where employment access may be mediated through corridors, subcenters, and intermediary neighborhoods rather than through a single dominant downtown.

The network framework therefore reframes centrality and peripherality as relational positions within metropolitan labor-market systems. A neighborhood is not central simply because it is near a CBD or because it receives many direct inflows. It is central when it is repeatedly encountered through chains of commuting relationships. This perspective connects older concerns about spatial mismatch and employment suburbanization to newer questions about consumer-city dynamics, remote work, and the changing geography of metropolitan labor markets (Glaeser et al., 2001; Glaeser and Gottlieb, 2006; Aguiléra et al., 2009; Grengs, 2010; Monte et al., 2026). In each case, the relevant empirical question is not only whether workers move toward or away from downtown, but how employment access is organized across the full metropolitan commuting network.

These measurement choices matter because different literatures attach different substantive interpretations to reverse commuting. In the spatial-mismatch and transportation-equity literature, reverse commuting often indexes the ability of central-city or low-income residents to reach decentralized employment opportunities. In the consumer-city literature, it helps reveal whether central cities are valued as residential and consumption locations even when employment opportunities decentralize. In transportation planning, it identifies corridors and service patterns that may be poorly served by conventional radial transit networks. A measure of reverse commuting therefore does more than label flows; it shapes conclusions about job access, urban resurgence, metropolitan equity, and the changing economic role of central places.

## 6. Conclusion

This paper develops a network-based definition of reverse commuting for metropolitan systems that need not conform to a single core–periphery hierarchy. The measure compares reciprocal stationary edge frequencies after accounting for the systemwide exposure of their origin and destination tracts. Under a conventional inward-oriented configuration, the rule identifies relatively unusual outward trips as reverse; outside that setting, it remains operational without requiring a predetermined downtown or one-dimensional spatial ordering.

The empirical application shows both continuity and divergence between the network and conventional definitions. Network and distance classifications become systematically more concordant as workplace commuting becomes more strongly oriented toward the CBD, supporting the measure's intended behaviour in near-monocentric systems. Nevertheless, the methods continue to imply different reverse-commuting shares and different tract-level geographies across the 40 metropolitan areas. Employment dispersion is also positively associated with network-classified reverse commuting. Together, these findings show that the hierarchy embedded in a classification rule affects both the measured prevalence and spatial interpretation of reverse commuting.

The goal is not to discard distance-based or local-balance measures. Those rules remain transparent, easy to implement, and closely connected to long-standing theories of monocentric urban form. They are most informative when the hierarchy they impose provides a reasonable description of the metropolitan labor market. As employment decentralization, hybrid work, suburban growth, and changing residential preferences produce more complex commuting systems, however, researchers also need measures that infer prevailing direction from the observed structure of metropolitan flows. More generally, the analysis shows that reverse commuting is not simply a geographic label: it is a theoretically consequential classification whose empirical meaning depends on the urban hierarchy used to define it.

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