Permeability across a metropolitan area: conceptualizing and operationalizing a macrolevel crime pattern theory

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Received 10 December 2012; in revised form 12 February 2013

Abstract. The intrametropolitan relationship between municipality-level physical environment and crime changes appears to have been overlooked by crime and environment researchers. The current effort focuses on permeability; suggests dynamics whereby permeability affects changing municipality-level crime patterns across a metropolitan area; selects and operationalizes theoretically appropriate permeability indicators; and links permeability to unexpected crime changes. Data are from 355 municipalities in the Philadelphia metropolitan area, and property and violent crime unexpected changes over two change periods are assessed. Three municipality-level indices reflecting internal and boundary permeability are developed that are internally consistent and cross reference in sensible ways with large-scale physical environment features of municipalities. Permeability indicators link as predicted with unexpected violent and property crime changes. This research provides a theoretical and empirical foundation for linking permeability to changing municipality-level crime rates across a metropolitan area.

Keywords: metropolitan crime, permeability, municipality, crime pattern theory, crime

Since the 1820s scholars have noted that both amounts and types of crime vary across space (Eck and Weisburd, 1995; Weisburd et al, 2009). In explaining this variation, many studies have emphasized demographic and social correlates of crime at the neighborhood (Bursik and Grasmick, 1993; Sampson and Groves, 1989; Shaw and McKay, 1942 [1969]), city (Baumer, 2008; Baumer et al, 1998; Pepper, 2008), county (Guerry, 1833; Messner et al, 1999; Quetelet, 1831 [1984]), and state (Harries, 1968) levels. A smaller body of work has considered links between crime and microlevel, built environment features such as streetblocks or small grid squares, and mesolevels, such as communities or neighborhoods (Taylor, 2002; 2005; Taylor and Harrell, 1996). Permeability proves central to this literature and has considerable practical implications for planning and design (Cozens and Love, 2009). Permeability arises from the arrangements of land uses, street and transportation networks, as well as natural and man-made barriers to travel. High permeability facilitates movement among places.

When considering spatiotemporal crime patterns across municipalities within a metropolitan area, however, the crime—permeability relationship appears overlooked. ¶The first and second authors contributed equally and are listed alphabetically.
This occurs even though accessibility, in some ways a metropolitan-level analog of permeability, has been theoretically and empirically important in metropolitan research.\(^{(1)}\)

The units considered here are minor civil divisions (MCDs) also called municipalities. MCDs are within-county administrative units. In general, they are markedly larger than neighborhoods.\(^{(2)}\)

This work extends earlier theory and research by (a) considering how previous community-level work linking crime and permeability might apply to political units existing at higher spatial scales; (b) expanding earlier theorizing to explicitly anticipate links to crime changes; (c) constructing three municipality-level, multi-item indices of permeability; (d) examining the geographical distributions of index scores and how they link to large scale physical features; and (e) testing the relationship between permeability and crime levels. The focus here is on how permeability and crime changes may relate at the MCD level.

**Background**

**Metropolitan areas, crime, and accessibility to transportation**

Considerable scholarship over the past three decades has investigated two features of metropolitan areas: how their structural characteristics link to crime rates, and how accessibility of locations within a metropolitan area shapes structural features of these areas like house prices, and behaviors like commuting. Investigations have examined how metropolitan-level demographic features—for example, inequality, mobility, and racial patterning (Blau and Blau, 1982; Crutchfield et al, 1982; Peterson and Krivo, 2005)—drive metropolitan-level crime rates; or how internal demographic differences within a metropolitan area shape crime levels or patterns within metropolitan areas (Hakim and Rengert, 1981; Rengert and Wasilchick, 1985; Shihadeh and Flynn, 1996; Shihadeh and Ousey, 1996). Some scholars question whether clear crime-prevention implications emerge from these works (Smith, 1988). For recent partial reviews of the structural work see Peterson and Krivo (2010), Pratt and Cullen (2005), or Parker (2008).

The metropolitan feature most closely related conceptually to permeability is either accessibility to jobs and services, or “generalized accessibility” “to all jobs or other

\(^{(1)}\) We retain the term ‘permeability’ in the current work rather than ‘accessibility’ for two reasons. First, it is widely used in the microlevel and mesolevel work on built environment and crime (Cozens and Love, 2009). Second, accessibility “can be defined for personal travel as the ability to reach desired destinations such as jobs, shopping, or recreational opportunities” (Federal Highway Administration, 2011). Third, criminals who commit crime often do not have a crime destination in mind when they are on a trip that will result in a crime being committed (Rengert and Wasilchick, 1985; Wright and Decker, 1997). Therefore, the more general term permeability, which does not imply a destination, seems preferable. An area or boundary that is permeable is simply “open to passage or penetration” (Webster’s New Universal Unabridged Dictionary 2nd edition).

\(^{(2)}\) In rare instances MCDs can be as large as a county (eg, the city of Philadelphia is coterminous with Philadelphia County in Pennsylvania). The United States Census Bureau defines minor civil divisions as “the primary governmental or administrative divisions of a county or county equivalent. MCDs represent many different kinds of legal entities with a wide variety of governmental and/or administrative functions. MCDs are variously designated as American Indian reservations, assessment districts, boroughs, charter townships, election districts, election precincts, gores, grants, locations, magisterial districts, parish governing authority districts, plantations, precincts, purchases, road districts, supervisor’s districts, towns, and townships. In some states, all or some incorporated places are not located in any MCD (independent places) and thus serve as MCDs in their own right. In other states, incorporated places are part of the MCDs in which they are located (dependent places), or the pattern is mixed—some incorporated places are independent of MCDs and others are included within one or more MCDs. Independent cities, which are statistically equivalent to a county, also are treated as a separate MCD equivalent in states containing MCDs” (US Census Bureau, 2011). In Pennsylvania and New Jersey MCDs “also serve as general-purpose local governments that generally can perform the same governmental functions as incorporated places.”
The latter term would include, for example, access to parks and playgrounds, while the former would not. The key idea is that accessibility creates “the potential of opportunities for interaction … it is a measure of the intensity of the possibility of interaction rather than just a measure of the ease of interaction” (page 3105, italics in the original).

**Theoretically connecting permeability and crime: sites, streetblocks, and communities**

Although most microlevel and mesolevel crime theorists agree that permeability links to crime, there is disagreement about whether the connection is positive or negative. Dovey (2000) characterized this as the “enclosure” versus “encounters” debate. Those favoring enclosure argue that high permeability is criminogenic. Those favoring encounters argue that low permeability is criminogenic.

Adding to the confusion arising from conflicting evidence, theorists have discussed the relationship between permeability and crime at different levels of analysis from the neighborhood/census tract (Bevis and Nutter, 1977; White, 1990), to the streetblock (Appleyard, 1981; Beavon et al, 1994; Hillier, 2004; Jacobs, 1961), to the individual building (Armitage, 2007; Newman, 1972). The relevant dynamics probably depend in part on spatial scale (Taylor, 2010). Broad context differences, such as cities versus suburbs, are also relevant (Cozens, 2008; Cozens and Love, 2009), and also unacknowledged by disagreeing theorists. All this variation deepens conceptual confusion.

The strongest voice advocating encounters was that of the late Jane Jacobs (1961). More recently, Fowler (1987; 1992), Low (2004), Hillier (2004), and Shu and Huang (2003) have joined her. Jacobs (1961) argued that highly permeable street configurations characterized by ‘small streets’ (ie, short streetblocks with frequent intersections), establish a pedestrian-friendly environment; further, a mix of commercial and residential land uses sets the stage for lively streetscapes with residents and nonresidents mixing and interacting. Nonresident street users provide both street interest, (ie, something for residents and people-watchers to observe), and potential watchers and interveners. Residents and small business owners provide informal social control because they manage immediately adjoining public spaces (Hillier, 2004; Jacobs, 1961). Jacobs (1961) described this effect as increased ‘eyes on the street’ and Hillier (2004) called it ‘natural policing’. Attracting both residents and nonresidents outside and onto the streetscape may encourage social interaction and familiarity with other users. The latter, in turn, may strengthen sense of community.

Theorists emphasizing enclosures, the late Oscar Newman (1972) probably the best known among them, highlighted, especially in later versions of the theory (Newman, 1996), changing the physical design of buildings and communities to limit accessibility so only legitimate users gain entry. This should encourage residents and regular users to more actively manage nearby outdoor spaces. Despite significant questions about Newman’s original version of the thesis (Fowler, 1987; Taylor et al, 1980), and complexities surrounding some of the evidence deemed supportive (Donnelly and Majka, 1998; Fowler and Mangione, 1986), the idea of limiting accessibility to places has become a widely practiced if still controversial crime-prevention strategy (Clarke, 2008; Taylor and Harrell, 1996). For example, it is reflected in alley gating schemes (Bowers et al, 2004) and gated communities (Low, 2004).

The broader theoretical foundations of the place management dynamics proposed in the enclosures versus encounters debate at the microlevel and mesolevel is best represented by crime pattern theory (CPT). CPT (Brantingham and Brantingham, 1984; 1991) connects individual motivation and the spatiotemporal aspects of routine activities of individuals to crime events:

“Crime is the product of varying initial conditions under which the decision processes leading to criminal events unfold. The likelihood of a criminal event transpiring depends
on the backcloth, the site, the situation, an individual’s criminal readiness, activity patterns, and the distribution of targets” (Brantingham and Brantingham, 1993; page 265).

Each person has a routine activity space consisting of the set of places which he or she visits on a frequent basis, and the routes taken between those places (Horton and Reynolds, 1971). In this way, people become familiar not only with the places they visit but also with places nearby and along the way to and from their primary destinations. Their activity spaces change whenever they, for example, take a new job. Surrounding their activity spaces are broader awareness spaces reflecting familiar places not visited routinely.

CPT examines how behavior patterns can be used to understand crime site selection (Brantingham and Brantingham, 1991 [1981]). Potential offenders spend most of their time in noncriminal activities (Brantingham and Brantingham, 1993). Thus, they tend to learn about opportunities in their noncriminal-based activity spaces, and make inferences about opportunities in their larger awareness spaces. Places with easy access via transportation systems have an increased likelihood that nonresident potential offenders will know about them.

CPT would seem to favor the enclosure end of the debate. In this frame, permeability and crime patterns connect via the influences of transportation systems and land-use patterns on potential offenders’ awareness of crime opportunities. For example, “[i]n exploring new areas, the potential offender will find it easier to penetrate areas with predictable road networks. Areas with grid street layouts are more predictable than areas with winding roads, cul-de-sacs, or dead ends” (Brantingham and Brantingham, 1991, page 252). In this way the types of streets in an area directly influence the set of opportunities of which offenders are aware.

CPT assumes that criminals and noncriminals alike learn about potential crime opportunities as they go about their routines. Higher permeability means the associated locations will more likely be part of the activity and awareness spaces of more potential offenders. Thus, they would be higher crime locales. So here, too, lower permeability translates to greater expected safety but for different reasons.

**Empirically connecting permeability and crime**

Many studies have examined the relationship between permeability and crime. These investigations have been conducted with a variety of: (1) geographies, (2) indicators to represent permeability, and (3) crime types. They focus on two geographic levels of analysis, micro and meso (Brantingham et al, 1976). This subsection reprises research specifically addressing street features, road networks, and land-use barriers (Cozens and Love, 2009).

By far the greatest numbers of studies on permeability and crime focused on the microlevel of housing units and street segments, concentrating on quantifying attributes of the street network like road type. In this vein, several studies compared cul-de-sacs—streets with one way in or out—with other street types (Armitage, 2007; Beavon et al, 1994; Bevis and Nutter, 1977; Block and Davis, 1996; Hakim et al, 2001; Johnson and Bowers, 2010; Mirrlees-Black et al, 1998; Rengert and Hakim, 1998). Although the research findings are diverse, and the mixed result pattern may arise partly from studies spanning rural versus urban versus suburban contexts (Cozens, 2008), moderate support for the enclosure position emerges from the work. For example, proximity to larger roads seems to increase crime risk (Cromwell et al, 1991).

Closely related to road type are studies quantifying traffic levels (low, moderate, or high) and connectivity. Higher traffic volume is consistently associated with higher crime risk regardless of road type (Armitage, 2007; Rengert and Hakim, 1998). Some studies have indicated, however, a more complex relationship between traffic levels and crime (Rengert and Hakim, 1998). Connectivity captures how many roads link to a particular road or set of roads. More connectivity links to more crime: the more turns onto a street, the higher the
Beyond accessibility for private vehicles, street networks also can increase accessibility by public transportation modes such as buses and trolleys. Bus stops (Bernasco and Block, 2011; Brantingham et al, 1991; Levine and Wachs, 1986a; 1986b; Loukaitou-Sideris, 1999) and light rail and subway transportation stops (Block and Davis, 1996; Brantingham et al, 1991; McCord and Ratcliffe, 2009) link to higher crime. For potential offenders without private vehicles, public transportation expands activity spaces, and thus awareness spaces, beyond comfortable walking or bicycling distances. These facilities also spatially concentrate large numbers of potential targets for some crime types.

Turning to the opposite end of enclosure versus encounters debate, numerous studies relying on space syntax suggest more permeability, less crime (Hillier and Shu, 2000; Jones and Fanek, 1997; Shu and Huang, 2003). Space syntax is used to assign properties to a street within a network based on the street’s level of integration–segregation, and those properties are then related to crime (Hillier, 1999; 2004).

Mesolevel neighborhood studies have considered internal and boundary permeability. The more major roads in or near an area, the higher the crime (Brantingham and Brantingham, 1975; Greenberg and Rohe, 1984; Greenberg et al, 1982; White, 1990). Studies using global graph-theoretic indicators like the beta index (Bevis and Nutter, 1977) or the gamma index (Grubesic et al, 2008, page 92; Johnson and Bowers, 2010) to capture connectivity sometimes find more permeability, more crime. These studies also have considered permeability at the community boundary: “the openness of traffic to outside the neighborhood” (White, 1990, page 57). More openness links to more crime (Greenberg and Rohe, 1984; Greenberg et al, 1982; White, 1990). Several studies have found that barriers such as rivers, highways, and parks reduce the likelihood that burglars will travel to a neighborhood (Clare et al, 2009; Peeters and Elffers, 2010).

We are not aware of any studies systematically exploring empirical municipality-level connections between permeability and crime, or crime changes. It would probably be unwise to assume that spatial scale does not matter for these connections (Taylor, 2010). Effects may depend on geographic level (Hipp, 2007). What is at stake here is not just the well-known aggregation problem, but different mechanisms operating at different levels (Jepperson and Meyer, 2011). Of primary importance is “measuring structural characteristics at appropriate geographic levels given the hypothesized theoretical mechanisms” (Hipp, 2007, page 674).

**Macrolevel conceptual model of permeability and crime**

On the basis of prior work and theorizing, four content domains for indicators of municipality-level permeability seem most pertinent: internal transportation accessibility, internal barriers to travel, external accessibility to transportation, and external barriers to travel. At the macrolevel (the MCD) relevant classes of features for the four domains would include: transportation network elements facilitating or impeding travel to and within MCDs, and land-use barriers directly interrupting those networks. Higher internal permeability makes it easier for potential offenders to move about once within the MCD. Internal accessibility increases with more high-volume roads, and more public transportation stops. These increase connectivity. Barriers such as large lakes or parks, airports’ and military bases decrease overall internal accessibility of an area because vehicles must travel around them. To cross a river, pedestrians or drivers need a bridge.

Higher external permeability makes it easier for potential offenders to get into and away from an MCD, and thus makes it more likely that populations of nearby offenders will include nearby MCDs within their shared activity and awareness spaces. Relevant indicators consist of natural barriers and variations in man-made features along boundaries such as...
public transport routes and traffic networks. External permeability increases with more road connections across municipal boundaries. Larger roads increase accessibility to a greater degree than residential ones. When on the boundary of an MCD, land features such as rivers, parks, lakes, and military bases represent barriers and decrease external permeability.

To put this in a broader theoretical frame, permeability primarily affects MCD-level crime changes because of impacts on activity patterns of groups of people. Once the number of people residing in or regularly using locations within an MCD, or near an MCD, has been controlled for, MCDs with higher permeability internally or at their boundaries will have more people using or aware of spaces within it. There are shared cognitive and behavioral impacts.

One behavioral impact is more people moving within or through an MCD. The more permeable an MCD, after controlling for its and nearby populations, the busier it is. Therefore, the more likely it is that a group of people will have an MCD, or sections of it, as part of their shared activity space. The corresponding communal cognitive impact is that the shared awareness may either be bolstered by, or may encourage, conversation about these high-permeability MCDs. This makes interpersonal dynamics potentially relevant.

Permeability then plays a role in facilitating people converging within an MCD. If there are two MCDs of identical area and land-use mix, with similar populations and patterns of surrounding populations, individuals are more likely to converge with other individuals, whether that is on sidewalks, roads, bus stops, public transit, or other public or commercial spaces, in the more permeable MCD. Per spatiotemporal unit, the rates at which people converge will vary.

CPT, given the focus on shared activity and awareness spaces, would seem to imply higher crime in MCDs with higher permeability. The theory holds that “[t]he environment be considered and analyzed at a micro-, meso-, or macro-level, or at all levels simultaneously” (Brantingham and Brantingham, 1993, page 286, emphasis in original). Further, unlike some other crime/environment theories which may not be relevant to suburban locations (Cozens, 2008), past work at the microlevel confirms the relevance of CPT dynamics in such locations (Rengert and Wasilchick, 1985).

So a macrolevel version of CPT seems plausible. Such a version would highlight relevant dynamics or processes. It would do so by focusing on change.

“An explanation of how criminal behavior changes as the backcloth varies will produce clear patterns, but such an explanation requires a focus on process, that is, on change itself” (Brantingham and Brantingham, 1993, page 265).

In short, a case can be made for applying CPT to understanding MCD-level spatiotemporal changes in crime patterns. From an ecological vantage, at this higher spatial scale of focus it is important to distinguish ecological continuity from unexpected ecological discontinuity (Hawley, 1950, pages 319–322). If unexpected changes in crime are taking place, (changes not predictable from earlier levels), permeability patterns based on the physical environment features considered here may shape the rates and locations of those changes.

**A macrolevel CPT model for crime changes: relevant dynamics**

Along these lines, a macrolevel CPT model for situations where crime is increasing within or near an MCD can be developed. Three features of the theoretical focus of convenience bear mentioning. The units of interest are municipalities. The outcomes of interest are the ways in which changes in reported crime rates are spatiotemporally patterned. Consequently, adjacency dynamics and how they unfold over time are central. Short-term changes over a year are considered. Since the permeability features of interest (see below) represent elements of the built and natural environment that, in general, have relatively slow change cycles—at least in mature metropolitan areas—these features can be considered relatively static.
Yes, a new set of shops may open up in a locale, but if the locale is sizable, as most of these MCDs are, then the impacts on potential offender dynamics across that municipality and adjoining ones are likely to be negligible.

If the crime increase is taking place within an MCD it could reflect any of the following dynamics: (a) past local offenders have become more active; (b) current local offenders are more numerous or active than past local offenders; (c) past offenders living or working outside the locale are traveling into it more frequently, exploring it more fully, or spending more time there when they travel into it; or (d) new outside-based offenders are traveling into it more frequently, exploring it more fully, or spending more time there when they travel into it. If the crime increase is taking place near a target MCD dynamics (c) and (d) would still be relevant for that target MCD. Of course, changes in crime arising from changes in opportunity structures, prevention programs, or policing also are pertinent. To keep the conceptual frame relatively simple at this juncture, however, these dynamics are not factored in as yet.

If one or more of the above dynamics are in play, how is permeability relevant? When crime is increasing in or near a target MCD, permeability within the target MCD is relevant to dynamics (a) and (b). Permeability at the boundaries of the target MCD becomes increasingly relevant for dynamics (c) and (d). Differences in either the extent or the relevance of shared activity and awareness spaces—differences determined in part by permeability—become more important because offender populations, or offender activity levels, or both, are changing.

The macrolevel CPT model does not yet consider changing target populations or movement patterns. How targets should be integrated depends on the specific crime type in question (purse snatch versus burglary versus aggravated assault versus motor vehicle theft), and is left to a later elaboration of the model.

Predictions based on dynamics
If the above proposed dynamics are relevant, then an MCD’s level of internal or boundary permeability could be significant as moderating variables in one or more of the following ways:
(i) If a target MCD’s crime rate is increasing over a period, the rate of that increase could be affected. Higher permeability levels should be associated with faster or greater increases. Internal permeability may be more relevant than boundary permeability.
(ii) If crime rates near a target MCD are high or increasing, the target MCD’s crime rates will either be affected more strongly, or affected sooner, if the target MCD has higher internal or boundary permeability. For target MCDs with these characteristics, adjacency impacts will be stronger and/or faster. Boundary permeability may be more relevant than internal permeability.

An empirical test follows of this generalized, socioecological version of crime pattern theory for understanding the spatiotemporal patterning of crime rate changes at the MCD level across a metropolitan area. Both propositions are examined.

Methodology
Setting
The Philadelphia primary MSA consists of nine counties (New Jersey: Burlington, Camden, Gloucester, and Salem; Pennsylvania: Bucks, Montgomery, Philadelphia, Chester, and Delaware). The city of Philadelphia is coterminous with the county, and is the only MCD in the county. The cities of Chester and Camden are separate MCDs within their named counties. The Delaware River separates the two states in the MSA. The total population in the MSA is around 5 million, about 1.53 million of whom resides in Philadelphia.
Permeability. A variety of publicly available indicators were collected which the researchers agreed represented the four permeability domains (see figure 1). Internally consistent indices were created, tapping three of the domains of interest. In constructing each index, individual variables were z-scored and then averaged. Scores on indices were mapped to verify that they provided geographically differentiated scores.

Crime counts. Total violent crime (homicide, rape, robbery, and aggravated assault) and total property crime exclusive of arson (burglary, theft, theft from auto, larceny) were assembled for 2005–07 at the municipality level.

Unexpected crime changes. To capture unexpected changes in crime counts, 2005 property and violent counts at the MCD level were used to predict 2006 property and violent counts, and residuals retained. The 2005–06 residuals captured unexpected changes in crime counts; shifts that were predictable neither from an MCD’s count the year previous nor from the overall change affecting counts of all MCDs during the period (Bohrnstedt, 1969). For each change period the residuals correlated 0 with beginning of period rates. The same procedure was used to capture 2006–07 unexpected changes. Modeling used a Poisson multilevel model in MLwiN with several features. It was elaborated with a spatial multiple membership model: that is, overdispersion was modeled with unstructured and spatially structured random effects (Congdon, 2006). Initial estimates for parameters were derived from a comparable Poisson multilevel model that did not use full Bayesian procedures. The resulting parameters were then input to an identical multilevel model, except that the latter used full Bayesian MCMC simulations (Browne, 2012a; Browne et al, 2001; Langford et al, 1999). Burn-in chains of at least 5 000 were used and estimation chains of at least 20 000, often 200 000 and higher, were used as needed. Kernel density estimates of resulting parameters were examined, and the number of estimation chains increased as needed. Resulting residuals were roughly normalized.

Figure 1. Conceptual model.

(3) This is a standard option in runmlwin, the Stata interface for MLwiN (Browne, 2012b; Leckie, and Charlton, 2011). Controversy about different assumptions about prior distributions for parameters continues (Browne and Draper, 2006; Raftery, 1995). Inspection of kernel density histograms for estimates of fixed parameters and variances suggested that these starting values resulted in well-behaved distributions of parameters.

(4) The residual distributions for unexpected changes had means of 0, standard deviations between 0.4 and 0.6, normal skewness values (less than |0.6|), and were slightly leptokurtic (kurtosis ~ 4). In short, they were normal distributions with slightly thinner ‘tails’ and slightly taller “peaks” than expected. These unexpected changes, as anticipated, correlated 0 with initial crime levels.
Analytic approach
The permeability indices developed are described and their spatial patterns investigated first. Then permeability links to unexpected crime changes are examined.

To test hypothesis (i), target MCDs’ unexpected crime changes for each period were regressed separately on each permeability indicator. Because some models showed marginally significant spatial autocorrelation of error terms [the $\lambda$ coefficient in GeoDa; see equation (2) in Anselin and Rey, (1991)], spatial error regressions from GeoDa are reported. There were no significant global spatial associations (Moran’s I) among the residuals of these regressions. [Comparable results were obtained with ordinary least squares (OLS) and spatial lag regressions.]

Hypothesis (ii) was tested by thinking about the surround in two ways: the surrounding crime rate at the beginning of the period during which crime in the target MCD is changing unexpectedly, and contemporaneously occurring unexpected crime changes in MCDs surrounding each target MCD. To construct each of these spatially lagged variables, first-order queen continuity was used. Since MCDs around a target MCD sometimes differed substantially in terms of area, GeoDa’s empirical Bayes weighting by area option was used to construct these surrounding rates for each target MCD. So, in short, for each target MCD, for each change period (2005–06, 2006–07), for each crime, there were two surrounding crime rates: one reflecting the nearby corresponding rate at the beginning of the change period, and a second reflecting nearby corresponding unexpected crime changes during the period crime was changing in the target locale.

The next step was to select MCDs which were relevant to hypothesis (ii) and focus on places where ‘crime rates near a target MCD are high or increasing’. To satisfy the ‘high’ condition, MCDs were selected if their surrounding crime rate at the beginning of the period was above the median for that spatially lagged variable. For the next test, to satisfy the ‘increasing’ condition, MCDs were selected if their surrounding unexpected changes in crime were above the median for that spatially lagged variable. Finally, given the smaller $n$ of MCDs ($n = 177$) in these tests of hypothesis (ii), permeability indicators were used in dummy form ($1 =$ impermeable, $0 =$ permeable) capturing a boundary impermeability or internal barrier score above the median. For internal accessibility, $1 =$ permeable (high accessibility), $0 =$ impermeable (low accessibility). One-tailed tests were conducted because it was expected that higher impermeability would always be associated with less of an unexpected crime increase. An OLS equation was then run for each outcome–predictor combination, while also controlling for MCD area. Given multiple outcomes and multiple equations for each outcome, $\alpha$ levels were Bonferroni-adjusted downward (adjusted $\alpha \sim 0.004$). The generalized model being tested expects that, if a target MCD is surrounded by other MCDs where unexpected crime rate increases are higher, crime rates in the target MCDs will increase more if accessibility of the target MCD is higher.

Results
Internal barriers index
Six characteristics reflecting land use, transportation networks, street pattern, and highway and rail barriers (see table 1 for items; table 2 for descriptive statistics) contributed to this index. A higher score indicated lower permeability: more internal barriers to circulation of vehicular and/or foot traffic, and less connectivity across locations within the MCD.

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(5) The representation of permeability indicators using dummy variables meant that, due to collinearity among the measures, it was not possible to enter all the permeability indicators into the same model. Because only half of the MCDs were analyzed, it was not possible to conduct spatial error or spatially lagged regression models.
Almost all of the items correlated positively with one another. Monotonic correlations (Kendall $\tau-c$) ranged from 0.00 to 0.69. Cronbach’s $\alpha$ for the index (\texttt{barrint}) based on the average of the $z$-scored items was an acceptable 0.76. The distribution of scores on the index was relatively normal except for two positive outliers. Philadelphia had an extremely high index score (8.77). This is not surprising given its large area (142.7 square miles). Washington Township, Burlington County (NJ) has the second highest index score (2.65). It is the second largest MCD in terms of area (102 square miles) and has only two state routes running through it. Further, much of it is covered by the Wharton State Forest.

\textbf{Figure 2.} Internal barriers index scores map.
A quintile map of scores on the internal barrier index shows many of the largest MCDs score in the top quintile, presenting the least permeability to internal circulation (figure 2). These include Philadelphia, several New Jersey MCDs in the easternmost segment of the MSA, and a string of MCDs north of Philadelphia in Bucks County, and west and south of Philadelphia spanning Montgomery, Delaware, and Chester counties. Also, many of the smallest area MCDs score in the lowest or next to lowest quintiles, presenting the fewest barriers to internal circulation. These include, in addition to separate boroughs and other small MCDs nested within larger MCDs, a string of small MCDs stretching south and east of the city of Camden, NJ, along US Route 30; and a cluster of small MCDs on the Pennsylvania side, back from the Delaware River, stretching south of Philadelphia down toward the city of Chester. We also explored whether normalizing the scores by areas would provide more information to explain the observed spatial patterning and it did not.

Underscoring the independence of index scores from municipality size, however, are numerous key features of the geographical distribution. For example, many of the larger MCDs in the eastern portions of New Jersey have very high internal barrier scores. But so do average-size MCDs along interstate highway 76 in Pennsylvania and Southwest of Philadelphia. A cluster of MCDs in the extreme western New Jersey portion of the MSA, along the Delaware River in the western-most segments of Gloucester and Salem counties, have more interior barriers than MCDs immediately to the north, east, and south. Sparse road networks and undeveloped land in the less permeable cluster of MCDs help explain the difference.

Table 1. Characteristics representing internal barriers (barrint).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
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<tbody>
<tr>
<td>Connectivity γ index (gconng_n) (reversed)</td>
<td>γ is a global connectivity index that “evaluates the ratio of existing arcs in a network to the maximum number of arcs possible” and thus represents relative connectivity (Grubesic et al, 2008, page 92). We reversed it so that as the γ index approaches a value of 1 the internal MCD road network is less connected: $\gamma = \left(\frac{e}{\frac{1}{2}v(v-1)}\right) \times 100$, where $e$ is the number of edges or streets, and $v$ is the number of vertices or intersections in the street network.</td>
</tr>
<tr>
<td>Square miles of minor civil division (MCD) containing barrier land uses (tbarrsqm)</td>
<td>Represents the total square miles in the MCD containing land uses that create barriers to vehicular and/or pedestrian traffic, including water, public parks, military bases, cemeteries, and airports.</td>
</tr>
<tr>
<td>Total miles of passenger rail line (prlmil)</td>
<td>The measure includes all above ground rail lines associated with the Philadelphia subways and trolleys, SEPTA, PATCO, and NJ Transit regional rail systems, and Amtrak.</td>
</tr>
<tr>
<td>Total miles of limited access highway (lahrdmil)</td>
<td>Total miles of limited-access highways.</td>
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<tr>
<td>Total miles of cul de sac segments in the street network (cdsmil)</td>
<td>Cul-de-sacs were selected using FCC code A61. A length variable was created that accounted for both the ‘stick’ and the ‘lollipop’ of the cul de sac.</td>
</tr>
<tr>
<td>Total miles of dead end segments in the street network (dendmil)</td>
<td>Total miles of streets that are dead ends.</td>
</tr>
</tbody>
</table>
Three of the predictors gauging internal accessibility to transportation routes (busstp, ramps, railsub) were used to create an index (subustra) capturing internal permeability as reflected in both public and private transportation via highway ramps, bus stops, and train/subway/rail stops (table 3 for variables; table 4 for descriptive statistics). Cronbach’s $\gamma$ for the index (subustra) based on the average of the $z$-scored items was an acceptable 0.65. A higher score indicated higher permeability: more access ramps to highways, as well as more bus, subway, and train stops.

The index values are quintile mapped in figure 3 and produce a more globally clustered pattern than the internal permeability measure based on barriers. High internal accessibility to transportation areas are centered on Philadelphia and its adjacent MCDs. Strings of high-permeability MCDs radiate outward from Philadelphia to the northeast, west, southwest, south, and southeast. Most of these MCDs have major highways running through them and are well served by both bus and regional rail train lines. The high degree of spatial association

**Table 2.** Descriptive statistics for variables in internal barriers index (barrint).

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Standard deviation</th>
<th>Mean</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>gconng_n</td>
<td>355</td>
<td>−61.90</td>
<td>−0.01</td>
<td>3.72</td>
<td>−1.62</td>
<td>−0.79</td>
</tr>
<tr>
<td>tbarrsqm</td>
<td>355</td>
<td>0</td>
<td>77.03</td>
<td>4.98</td>
<td>1.09</td>
<td>0.13</td>
</tr>
<tr>
<td>prlmil</td>
<td>355</td>
<td>0</td>
<td>168.34</td>
<td>9.04</td>
<td>1.15</td>
<td>0.00</td>
</tr>
<tr>
<td>lahrdmil</td>
<td>355</td>
<td>0</td>
<td>87.88</td>
<td>6.82</td>
<td>2.86</td>
<td>0.00</td>
</tr>
<tr>
<td>c.dslmil</td>
<td>355</td>
<td>0</td>
<td>27.75</td>
<td>2.76</td>
<td>1.32</td>
<td>0.33</td>
</tr>
<tr>
<td>dendmil</td>
<td>355</td>
<td>0</td>
<td>64.68</td>
<td>7.43</td>
<td>7.04</td>
<td>4.80</td>
</tr>
</tbody>
</table>

Note. Units = minor civil divisions in Philadelphia primary Metropolitan Statistical Area.

**Table 3.** Variables in internal accessibility index (subustra).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total bus stops</td>
<td>Counted the number of points in a minor civil division where buses stopped.</td>
</tr>
<tr>
<td>(busstp)</td>
<td>(ramps) Ramps were defined as access points where vehicles could gain entry</td>
</tr>
<tr>
<td>Total ramps</td>
<td>to a limited-access highway.</td>
</tr>
<tr>
<td>(ramps)</td>
<td>(lrailsub) The number of commuter rail and subway stops was counted based</td>
</tr>
<tr>
<td>Total light rail</td>
<td>on data from the Southeastern Pennsylvania Transportation Authority (SEPTA),</td>
</tr>
<tr>
<td>and subway</td>
<td>and the New Jersey Transit systems.</td>
</tr>
<tr>
<td>stops (lrailsub)</td>
<td>a Count was natural logged after adding 1 in the index.</td>
</tr>
</tbody>
</table>

**Table 4.** Descriptive statistics for variables in internal accessibility index (subustra).

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Standard deviation</th>
<th>Mean</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>busstp</td>
<td>354</td>
<td>0.00</td>
<td>9.04</td>
<td>1.74</td>
<td>1.98</td>
<td>2.07</td>
</tr>
<tr>
<td>ramps</td>
<td>354</td>
<td>0.00</td>
<td>4.11</td>
<td>0.65</td>
<td>0.39</td>
<td>0.00</td>
</tr>
<tr>
<td>lrailsub</td>
<td>354</td>
<td>0.00</td>
<td>5.18</td>
<td>0.52</td>
<td>0.22</td>
<td>0.00</td>
</tr>
</tbody>
</table>

between adjacent counties most likely stems from the linear nature of public and private transportation systems. MCD’s that share a border are also likely to share a transportation system.

**Figure 3.** Internal accessibility index scores map.
External Boundary Impermeability

A single index (extbarr) that averaged the z-scores of three predictors representing overall boundary impermeability of MCDs generated a Cronbach’s $\gamma$ of 0.53. This value reflects a marginally acceptable level of internal consistency. One item captured boundary miles of land uses or natural features creating barriers to vehicle or pedestrian traffic including airports, parks, cemeteries, military installations, and rivers (bluper). Boundary-crossing residential and collector roads (reversed) also contributed to the index (resperrv and colperrv). These ease passage into or out of an MCD. A higher score indicated more external barriers to circulation of vehicular and/or foot traffic moving across an MCD boundary (see table 5 for variables and table 6 for descriptive statistics).

Table 5. Characteristics representing external impermeability (extbarr).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of perimeter miles made up of relatively impermeable land uses, or water (bluper).</td>
<td>All the miles of each minor civil division’s (MCD’s) perimeter associated either with a water boundary, or with military installations, airports, cemeteries, and parks not easily crossed on foot or in a vehicle are included. The perimeter miles associated with each land use, or with water, were added up, then divided by total perimeter miles, then multiplied by 100 to reflect the percentage of the perimeter linked to one of these land uses, or water.</td>
</tr>
<tr>
<td>The number of residential road crossings, per perimeter mile, reversed (resperrv).</td>
<td>The total number of times a residential street crossed an MCD’s boundary divided by the MCD’s total perimeter miles. (Reversed in index.)</td>
</tr>
<tr>
<td>The number of collector road crossings per perimeter mile, reversed (colperrv).</td>
<td>The total number of times a collector road crossed an MCD’s boundary divided by the MCD’s total perimeter miles. Collector roads are major transportation arteries. (Reversed in index.)</td>
</tr>
</tbody>
</table>

Table 6. Descriptive statistics for variables in the external impermeability index (extbarr).

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Standard deviation</th>
<th>Mean</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>bluper</td>
<td>355</td>
<td>0.00</td>
<td>88.34</td>
<td>17.90</td>
<td>14.28</td>
<td>6.48</td>
</tr>
<tr>
<td>resperrv</td>
<td>355</td>
<td>−11.28</td>
<td>−0.07</td>
<td>2.09</td>
<td>−3.35</td>
<td>−2.89</td>
</tr>
<tr>
<td>colperrv</td>
<td>355</td>
<td>−3.50</td>
<td>0.00</td>
<td>0.51</td>
<td>−0.74</td>
<td>−0.66</td>
</tr>
</tbody>
</table>

Scores are again mapped by quintiles in figure 4. There are three clusters of low-scoring (permeable) MCDs located (a) just northwest of Philadelphia largely in Montgomery County, (b) southwest of Philadelphia (see inset map in figure 4), and (c) stretching south and east of the city of Camden in New Jersey along US Route 30. Each of these clusters ‘makes sense’ when cross-referenced against geographic features. MCDs in areas (a) and (b) are generally densely settled and older with extensive residential collector and arterial road networks. MCDs in (b) and (c) are similarly densely settled with dense road networks, but are much smaller in size.

Clusters of adjoining MCDs with high-scoring (impermeable) perimeters appear in (d) eastern Burlington County (NJ); (e) south of Philadelphia along the Delaware River on the New Jersey side; and (f) around the Valley Forge/Skippack park complexes in Montgomery/ Chester counties. Again, cross-referencing with geographic features suggests these scores are sensible. For (d), large state forests and military bases are relevant. For (e) the Delaware River
and numerous smaller waterways feeding into it are relevant. For (f), park land uses are relevant.

**Hypothesis 1:** Target MCDs with increasing crime rates will be associated with higher permeability.

Four outcomes were assessed: unexpected property crime changes 2005–06 and 2006–07, and violent crime changes for the same two periods. Assessing changes over two periods allows estimation of the robustness of results across different change periods.
For each outcome, for each permeability indicator, a maximum-likelihood spatial error regression was run that also included the size of the MCD in square miles. Separate models for each permeability indicator provide an initial estimate of the gross contribution of each indicator. All of these models were repeated using spatially lagged regressions, yielding identical patterns of significance.

Results appear in table 7. Across all four outcomes and all three permeability factors, after controlling for MCD area, eleven of the twelve permeability impacts were in the predicted direction, far more than would be expected by chance ($p < 0.005$ by one-tailed sign test).

**Table 7.** Regression results for target minor civil division (MCD) crime change and permeability.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Permeability factor</th>
<th>$b$</th>
<th>Standard error</th>
<th>$z$</th>
<th>$p &lt;$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Property crime change, 2005–06</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External impermeability</td>
<td>−0.015</td>
<td>0.035</td>
<td>&lt;</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Internal barriers</td>
<td>−0.055</td>
<td>0.050</td>
<td>−1.101</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Internal accessibility</td>
<td>0.024</td>
<td>0.029</td>
<td>&lt;</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Property crime change, 2006–07</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External impermeability</td>
<td>−0.022</td>
<td>0.035</td>
<td>&lt;</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Internal barriers</td>
<td>0.071</td>
<td>0.050</td>
<td>1.428</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Internal accessibility</td>
<td>0.160</td>
<td>0.028</td>
<td>5.713</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td><strong>Violent crime change, 2005–06</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External impermeability</td>
<td>−0.097</td>
<td>0.048</td>
<td>−2.004</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Internal barriers</td>
<td>−0.126</td>
<td>0.070</td>
<td>−1.792</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Internal accessibility</td>
<td>0.097</td>
<td>0.041</td>
<td>2.379</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td><strong>Violent crime change, 2006–07</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External impermeability</td>
<td>−0.072</td>
<td>0.049</td>
<td>−1.462</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Internal barriers</td>
<td>−0.118</td>
<td>0.072</td>
<td>−1.641</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Internal accessibility</td>
<td>0.096</td>
<td>0.042</td>
<td>2.300</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>

Note: $N = 355$ MCDs in Philadelphia primary metropolitan area. Outcomes = standardized, unexpected crime count changes from Markov chain Monte Carlo multilevel model allowing for spatially clustered errors. Results from 12 different maximum-likelihood spatial error regressions (Bonferroni-adjusted $\alpha$ level = 0.0041); each regression contained a constant, a permeability indicator, MCD area (square miles), and a spatial error parameter ($\lambda$). Results shown only for permeability indicator. $P$-levels for one-tailed hypothesis tests, ns = not significant. A higher score indicated a higher unexpected crime increase. Unexpected crime changes correlate 0 with beginning of the period crime counts. Residuals from each of these models exhibited no significant spatial autocorrelation. The identical pattern of significance was obtained using spatial lag regression models. Less permeability is indicated by: higher external impermeability; higher internal barriers; and lower internal accessibility. See text for details of index construction.

Controlling for multiple tests, spatial error, and MCD size, unexpected property crime increases from 2006 to 2007 were higher in MCDs where there was greater access to public transportation ($b = 0.16, p < 0.001$). Four other results for violent crime changes were significant at the conventional $\alpha$ level ($p < 0.05$) but not the Bonferroni-adjusted $\alpha$ level. Unexpected violent crime changes 2005–2006 were higher in MCDs with higher internal accessibility ($b = 0.097, p < 0.01$), or weaker internal barriers ($b = -0.13, p < 0.05$), or weaker boundary impermeability ($b = -0.10, p < 0.05$). Finally, 2006–07 unexpected violent crime changes were higher in MCDs with more accessible public transportation networks ($b = 0.096, p < 0.05$). Controlling for MCD size and multiple tests, more accessible internal public transportation networks were associated with stronger property crime increases.
for one change period (2006–07; \( b = 0.16, \ p < 0.01 \)). There were suggestions that: more accessible public transportation linked to stronger violent crime increases as well for both change periods, and external and internal impermeability linked to violent crime changes in one change period.

These results provide partial support for the first hypothesis from the generalized, ecological permeability model. Results appear to depend on the type of crime change, the period of the crime change, and the permeability indicator. Support for the expected connection is clearest when examining the impacts on internal access to public transport and 2006–07 unexpected property crime changes; places with more access increased faster on this crime, controlling for the size of the locale.

**Hypothesis 2:** If crime rates are high or increasing in MCDs adjacent to the target MCD, the impact on the target MCD’s crime rates will vary based on the permeability of the target MCD.

Coefficients for the first set of analyses focusing on higher initial crime rates surrounding each MCD appear in table 8. Again, eleven of the twelve coefficients were in the expected direction (\( p < 0.005 \) with one-tailed sign test). Two specific impacts were significant at the adjusted \( \alpha \) level. Among MCDs surrounded by higher initial property crime rates, higher unexpected property crime changes from 2006 to 2007 appeared in MCDs with more accessible internal public transportation networks (\( b = 0.29, \ p < 0.001 \)). The unexpected crime change difference, between locales in the top versus bottom half of internal accessibility scores for 2006–07.

Table 8. Regression results for surrounding minor civil division (MCD) crime change and permeability.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Permeability factor</th>
<th>( b )</th>
<th>Standard error</th>
<th>( t )</th>
<th>( p &lt; )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Property crime change, 2005–06</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External impermeability</td>
<td>−0.095</td>
<td>0.069</td>
<td>−1.37</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Internal barriers</td>
<td>−0.025</td>
<td>0.072</td>
<td>&lt;1</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Internal accessibility</td>
<td>0.134</td>
<td>0.064</td>
<td>2.11</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td><strong>Property crime change, 2006–07</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External impermeability</td>
<td>−0.180</td>
<td>0.071</td>
<td>−2.55</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Internal barriers</td>
<td>0.028</td>
<td>0.074</td>
<td>&lt;1</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Internal accessibility</td>
<td>0.293</td>
<td>0.062</td>
<td>4.7</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td><strong>Violent crime change, 2005–06</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External impermeability</td>
<td>−0.284</td>
<td>0.106</td>
<td>−2.69</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>Internal barriers</td>
<td>−0.174</td>
<td>0.113</td>
<td>−1.54</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Internal accessibility</td>
<td>0.208</td>
<td>0.099</td>
<td>2.09</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td><strong>Violent crime change, 2006–07</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External impermeability</td>
<td>−0.140</td>
<td>0.103</td>
<td>−1.35</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Internal barriers</td>
<td>−0.167</td>
<td>0.106</td>
<td>−1.58</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Internal accessibility</td>
<td>0.222</td>
<td>0.096</td>
<td>2.32</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>

Note: \( N = 177 \) MCDs in Philadelphia primary metropolitan area. Only MCDs with a surrounding initial crime level above the median were included. Outcomes = standardized, unexpected crime count changes from Markov chain Monte Carlo multilevel model allowing for spatially clustered errors. Results from 12 different ordinary least squares regression models. Bonferroni-adjusted \( \alpha \) level = 0.0041. Each regression contained a constant, a permeability indicator, and MCD area (square miles). Results shown only for permeability indicator. \( p \) levels for one-tailed hypothesis tests. ns = not significant. A higher score indicated a higher unexpected crime increase. Unexpected crime changes correlate 0 with beginning of the period crime counts. Less permeability is indicated by: higher external impermeability; higher internal barriers; and lower internal accessibility. See text for details of index construction.
all MCDs, was 68.7% of a standard deviation (0.293/0.427) on the crime change. Further, among the MCDs with more violent initial surrounds, lower unexpected violent crime changes from 2005 to 2006 appeared in MCDs whose boundaries were less permeable ($b = -0.284, p < 0.004$). The MCDs with more impermeable perimeters scored almost half a standard deviation lower ($-0.284/0.608 = -0.467$) on later unexpected violent crime increases.

Four other results were suggestive. The first result noted above for internal public transportation networks and property crime changes appeared but more weakly for the first year of property crime changes ($b = 0.13, p < 0.05$). The second result noted above for boundary impermeability appeared but more weakly for 2006–07 property crime changes ($b = -0.18, p < 0.01$). Finally, two results suggested that internal public transportation networks might link to higher violent crime changes for 2005–06 ($b = 0.21, p < 0.05$) and 2006–07 ($b = 0.22, p < 0.01$).

Turning to the second set of analyses where MCDs were selected because their contemporaneous surrounding crime increases placed them in the top half of MCDs (results not shown), one significant result was obtained. Among MCDs whose surrounding property crime rates were increasing the most during the period 2005–06, those MCDs with more accessible internal public transportation networks were likely to experience stronger property crime increases ($b = 0.207, p < 0.001$). Three other results were suggestive. Higher external impermeability linked to weaker increases for property crime in 2005–06 ($b = -0.11, p < 0.05$), and weaker violent crime increases for the same change period ($b = -0.17, p < 0.05$). Finally, weaker violent crime increases in 2005–06 were seen among MCDs with stronger internal barriers to circulation ($b = -0.21, p < 0.05$).

Discussion

The current work proposed a conceptual framework for understanding how MCD-level crime changes, across a metropolitan area, might link to land use, transportation, and street network geographic features. Earlier microlevel and mesolevel work suggested attending to features of locales that make a location more permeable. A key distinction in this earlier work was maintained here: between conditions describing the ease with which travel could be undertaken within a locale (internal MCD permeability), and the ease of crossing the perimeters of locales (boundary MCD permeability). The proposal has implications for deepening our understanding of how crime patterns shift across a metro region and appears to fill a gap in current scholarship.

More broadly, the current work built on earlier research in two ways: by considering macrolevel physical environment features related to the earlier work; and by considering the relevance of the conceptual foundations undergirding earlier work. One of those foundations, CPT, was elaborated to suggest relevant dynamics for understanding changing spatiotemporal crime patterns across a metropolitan area. The framework suggested how these travel influences could shape crime changes, or the impact of crime-relevant structural changes. That framework guided the selection of relevant geographic features. Indices for internal barriers, internal accessibility, and boundary impermeability with strong to moderate internal consistency were constructed. All provided strong geographic differentiation across the metropolitan area and cross-referenced to specific physical features in sensible ways.

Consistent with the first hypothesis, internal accessibility proved important. Higher internal accessibility via transportation networks was associated with greater unexpected increases in crime. The relationship was only statistically significant at the adjusted alpha level for 2006–07 property crime changes.

Consistent with the second hypothesis, among MCDs with more dangerous surrounding conditions, for 2006–07, target MCDs’ corresponding property crime rates were more likely to increase if public transportation within the MCD was more accessible. This result surfaced,
regardless of whether surrounding danger was defined in terms of high initial surrounding crime levels or contemporaneously increasing crime levels.

Further, turning to violent crime, for one change period (2005–06), higher boundary impermeability protected target MCDs from the more dangerous surround if the focus was on initial surrounding crime conditions rather than changing surrounding crime conditions. Thus, external impermeability appeared to exercise some moderating influence if initially high crime rather than simultaneously increasing crime was considered in the surround.

Our results were consistent with the macrolevel crime pattern theoretical frame proposed. Internal accessibility via personal or public transportation was a key attribute for predicting target MCD crime change. Internal accessibility also was important for altering how high crime levels or crime increases in neighboring MCDs might affect a target MCD. Finally, boundary impermeability appeared in some instances to moderate how much a target MCD was affected by its dangerous neighbors.

Although the current work has broken new theoretical and empirical ground, it has limitations. Most importantly, this is a case study because it is limited to one metropolitan area. Collecting data for MCDs in a large number of metropolitan areas so that regional patterns can be examined would be worthwhile. Although geographic data are more readily available than ever, it is still a large undertaking to identify sources especially for metropolitan areas that cross state boundaries. There are significant differentials in data availability. In particular, certain types of information (for example, public transportation routes) are often quite difficult to obtain in GIS-usable formats.

A second weakness of the current study is the inability to examine changes in internal or boundary permeability and how those might affect overall MCD permeability. Infrastructural changes such as adding new roads or bridges or developing airports or military bases do not happen often, especially in mature metropolitan areas. In the South or Southwest, however, substantial metropolitan growth can occur quickly. Such contexts may be better suited for researchers hoping to understand impacts of changing permeability at the MCD and metropolitan levels.

A third limitation is that this work has considered the overall rather than the net impact of each of these physical environment features, given the lack of any prior work with these indicators and crime, at this geographic level. Future work can isolate net impacts and relative importance of various features.

A fourth limitation is that results did not prove robust across the two change periods examined. This may be because annual crime changes at this level, for this MSA, exhibit spatiotemporal interaction (Taylor et al, 2012).

Offsetting these study limitations, however, are potential study strengths. We have focused on one of the six largest metropolitan areas in the US. Further, we have carefully selected potential macrolevel permeability indicators based on close attention to earlier microlevel and mesolevel work. Resulting indices successfully discriminated between MCDs. We succeeded in constructing indices with at least moderate internal consistency. Even more compelling, index scores cross-referenced clearly and sensibly with large-scale natural and man-made features of MCDs. We established that the permeability measures linked to both violent and property crime changes. Finally, conceptualization paid close attention to spatial scaling concerns and suggested dynamics relevant to groups of offenders (Hipp, 2007; Taylor, 2010).

Beyond the points already noted, additional important conceptual and operational issues are yet to be addressed. To take just one example: how is the relationship of permeability to crime changes conditioned on opportunity, differentials or changes? Future studies might include measures of opportunities such as ambient population estimates of the number of
people in an MCD during the day in contrast to the residential population (Andresen, 2006; 2007). This would capture the presence of nonresident potential offenders and targets.

In sum, this paper provided a theoretical foundation for understanding the roles of municipality level permeability indicators in shaping short-term crime changes. It described how key ideas from crime pattern theory could be adapted to consider socioecological dynamics relevant to groups of potential offenders. It successfully identified a small number of indicators for internal permeability, boundary permeability, and internal accessibility, creating indices of each. Each index differentiated MCDs across the metropolitan area, and presented meaningful clusters of similarly scoring MCDs. Exploring how permeability is related to municipality-level crime rates while including other characteristics of the built and social environment using multivariate modeling is an important next step. Such investigations will be critical to understanding instances where municipalities with similar socioeconomic characteristics but different permeability levels experience different crime changes. These explorations could have broad applicability for urban planners and public policy makers as well as law enforcement officials.

Acknowledgements. This work as supported by grant 2009-IJ-CX-0026 from the National Institute of Justice (RBT, PI; ERG, DE co-PIs). Opinions are solely the authors and reflect neither the opinions nor the official policies of the National Institute of Justice or the Department of Justice. The authors appreciate helpful comments on earlier versions from the late editor, several anonymous reviewers, John Hipp, George Rengert, and Ron Davis.

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