Article

MODELLING CRIME FLOW BETWEEN NEIGHBOURHOODS IN TERMS OF DISTANCE AND OF INTERVENING OPPORTUNITIES

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Abstract

Using data on solved crimes in The Hague, the Netherlands, we study crime trips between areas where offenders live and where they offend, in order to test the hypothesis that the number of criminal opportunities between two areas ("intervening opportunities") influences the number of crime trips that take place between those areas. The findings are that, contrary to the hypothesis, simple geographical distance between two areas explains the number of crime trips between them better than various measures of intervening opportunities do.

Keywords

intervening opportunities; crime trips; gravitational models

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Introduction

Human spatial interaction has long been investigated through the study of mobility or the movement of people within and between an origin and a destination (Zipf, 1949; Ewing, 1974; Tellier and Sankoff, 1975). Spatial interactions, therefore, encompass a range of movements within geographical space, and have traditionally been studied to gain an understanding of the dynamics behind migration between places, utility of transportation routes and tourism. Although scarcely applied in criminology, spatial interaction has been used as a tool for investigating patterns in the spatial behaviour of offenders – where offenders live, where their offences take place and their journey to crime (Smith, 1976; Rengert, 1981; Kleemans, 1996).

Gravity models for spatial flow

Smith (1976) introduced the idea of using the geography-based *gravity model* in order to link information on where offenders live and where they commit their offences to patterns in offender mobility. The basic gravity model is the most commonly used model for predicting geographical flow and the degree of spatial interaction between two places. Adapted from Newton's Law of Gravity, the basic gravity model predicts the movement of people between two places as a function of the size of each place and the distance between them. The premise behind this theory is, on the one hand, that the larger a place is, the more people tend to be attracted to it, and on the other, that the larger a place is, the more people can be expected to move out of it. Moreover, as a consequence of the principle of least effort, places that are closer together are likely to have a larger movement flow between them than those that are further apart. Hence, in these models, the distance between neighbourhoods is used as a measure of friction or resistance to mobility.

Rational choice theory of spatial interaction

In addition to the fundamental role played by physical distance and "push" and "pull" factors, spatial interaction also involves the cognitive appraisal of other contextual factors. Rational choice theory postulates that all forms of spatial interaction result from a shared process of rational assessments and decision-making based on a cost/benefit analysis of the available options (Clarke and Eck, 2005; Lück *et al.*, 2006). Thus, according to the theory, all decisions related to spatial mobility – for example, choice of travel routes, mode of transport, destination choice – are the result of rational decisions made in order to optimize the chances of achieving set goals (Hechter and Kanazawa, 1997; Bamberg and Schmidt, 1998; Lück *et al.*, 2006). Going hand in hand with rational choice theory is the "homo economicus" – a model of human behaviour from economics – which suggests that humans act to obtain the highest possible level of satisfaction for themselves, given available information about opportunities and constraints (Persky, 1995). These economic theories of human spatial behaviour provide the foundation for Ullman's (1973) theory of the three key determinants of spatial interaction, explicated in the following way by Rodrigue *et al.* (2006):

- *Complementarity*: If location B produces something that location A requires, then an interaction is possible because they have become complementary to one another through the supply/demand relationship that has been established between those two locations. The same applies in the other direction (A to B), which creates a situation of reciprocity.
- *Transferability*: The infrastructure to support transportation (modes and terminals) must be present to support an interaction between B and A. These infrastructures must have a capacity and availability that are compatible with the requirements of such an interaction.
- *Intervening opportunity*: If location C offers the same characteristics (complementarity) as location A and is also closer to location B, an interaction between B and A will not occur and will be replaced by an interaction between B and C (Ullman, 1973).

Stouffer's first approach to intervening opportunities

Stouffer's (1940) theory of intervening opportunities focused on the latter of these requirements for spatial interaction to explain the relationship between residential mobility and geographical distance. In contrast to the gravity model, Stouffer (1940) began with the premise that mobility and distance are not necessarily directly or invariantly related, as is assumed by basic gravity explanations of the flow of movement between two places. Rather, Stouffer (1940) proposed that the direct relationship occurred between mobility and opportunities. Stouffer (1940) presented the theory of intervening opportunities to explain one of the auxiliary processes responsible for the distance (decay) effect in determining the distribution of population movements in space. The theory explains that "the number of persons going a given distance is directly proportional to the number of opportunities at that distance and inversely proportional to the number of intervening opportunities" (Stouffer, 1940). In this way, Stouffer (1940) reveals that one of the crucially neglected concepts in the study of mobility and distance is the ratio of opportunities in the destination to the intervening opportunities available in between. Intervening opportunities can be identified in a variety of ways. In Figure 1, we illustrate "Stouffer's large circle", which is the area circumscribed by a radius equal to the distance between the origin neighbourhood O and a destination neighbourhood D (see Stouffer, 1940).

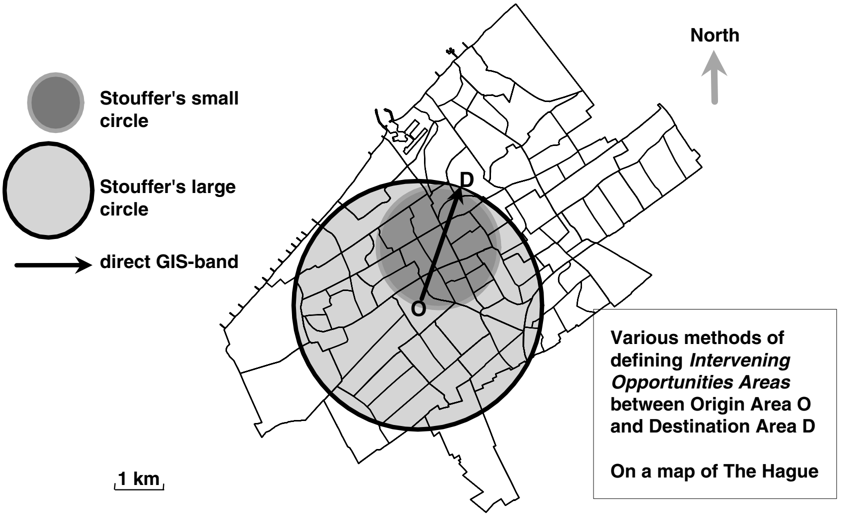

Figure 1 Various operationalizations of intervening opportunities.

Stouffer tested his theory using residential mobility data from Cleveland, defining *opportunity* as "the vacancy occupied, and similar vacancies anywhere in the city which he might have occupied but did not". *Intervening opportunities* was defined as "similar vacancies which are closer to his former residence in [area] X than the dwelling he occupied in [area] Y" (Stouffer, 1940). The results revealed the utility of Stouffer's (1940) theory, indicating that intervening opportunities significantly hinder geographical mobility.

Stouffer's revised approach to intervening opportunities

Stouffer (1960) revised his definition of intervening opportunities to account for the direction of movement and "marked directional drifts", where the uneven distribution of opportunities within the circle might encourage increased movement in one direction from the origin at the expense of another. In the reformulated theory, the distance between the origin and destination is taken as the diameter, rather than the radius, of the opportunity circle, so that only opportunities closer to both the origin and the destination than the distance between the two are included. We have denoted this revised definition as "Stouffer's small circle" in Figure 1.

An obvious generalization seems to be to take an ellipse of given eccentricity, instead of a circle, in Stouffer's definition. We investigated this generalization, but the differences between various ellipses and the Stouffer small circle were, in our empirical examples, negligible. We refrain from giving details.

Stouffer (1960) tested the relative predictive power of the original model, a distance-based model and the redefined intervening opportunities model, in predicting the flow of migrants from St Louis to Los Angeles, St Louis to Denver and St Louis to New York. The results showed that the original intervening opportunities model and the distance model were both outdone by the reformulated intervening opportunities model in predicting migration flow to and from St Louis (Stouffer, 1960). To test the generality of these findings, Stouffer (1960) repeated the study, this time examining reverse migratory flow *to* St Louis rather than *from* it. These results showed that both the original and the reformulated intervening opportunities models predicted migration accurately, while the distance model failed for a second time (Stouffer, 1960). The other innovation of Stouffer's (1960) reformulation was the introduction of the "competing migrants" concept, which is based on the idea that the migratory flow from origin i into destination j is restricted by competition for opportunities in j. The fusion of the intervening opportunities-competing migrants concepts into a single model was tested more extensively on migration data from 16 US cities with a population over 500,000 to and from Los Angeles, Denver, Chicago and New York between 1935 and 1940. The explanatory power of Stouffer's intervening opportunities-competing migrants model was superior to that of the distance model, explaining 98% of variance in the data (with a 15% error of estimate), while the distance model explained 93% (with a 23% error). The explanatory value and standard error of the models reveal that Stouffer's (1960) model also provided a better fit for the data than the distance model.

Various replications of Stouffer's (1960) study have been undertaken, with many showing strong empirical support for his models. Galle and Taeuber (1966) replicated Stouffer's second study using migration data from the 1960s' census for US metropolitan areas with populations of 250,000 and over. Once again, Stouffer's (1960) intervening opportunities-competing migrants model proved to be very powerful, explaining 95% of the variance in the 1960s' migration data, and approximately 98% of the variance in the 1940s' migration data (Galle and Taeuber, 1966). Both the measures of intervening opportunities and competing migrants made independent and roughly equal contributions to the predictive power of the model (Galle and Taeuber, 1966). Thus, the Galle and Taeuber (1966) replication showed that Stouffer's (1960) intervening opportunities-competing migrants model is a better predictor of migratory flow than the simple distance model (which explained 89% of the variance in the 1960s' migration data, and 93% in the 1940s' migration data). Wadycki (1975) also found results that provided compelling support for Stouffer's (1960) theory, although he reported that Stouffer's original intervening opportunities model not only generated better results than the 1960 reformulation but also had stronger theoretical support (Wadycki, 1975; see also Galle and Taeuber, 1966).

Stouffer's approach applied to crime flow

The above studies provide compelling evidence of the empirical superiority of Stouffer's intervening opportunities model over the simple distance model in predicting the geographical mobility of resident populations (Galle and Taeuber, 1966). But what about the effectiveness of the model in predicting the geographical mobility of the offender population? Smith (1976) followed through on Stouffer's (1940) suggestion that the model may be applied to explain patterns in criminal mobility. Smith's (1976) results showed no evidence to support Stouffer's theory of intervening opportunities, and instead revealed that models including a distance measure were more successful in predicting crime flow.

The current study

The current study will build on Smith's (1976) study by using Stouffer's intervening opportunities theory to investigate whether they affect crime flow between offender home neighbourhoods and the neighbourhoods where their offences are committed. The aim of the current study is to tease out the relative effects of distance and intervening opportunities on crime flow. If we consider a set of crime trips as a set of events being produced by *motivated* offenders, looking for a target, it becomes less likely that a large origin–destination flow will occur, if, between origin and destination, a wealth of other opportunities exist that present themselves to the offender. Of course, a completely informed *homo economicus* would not be vulnerable to the seduction of a nice but suboptimal opportunity. However, following Elffers (2004), we may suppose that quite some potential perpetrators have incomplete information on where optimal opportunities may be: they simply roam around, and decide to take an opportunity if it is promising enough, not aware or not caring for the fact that possibly a better opportunity is available a bit further down the road. Such sequential decision makers ought to fit in well in an intervening opportunity model. Gravitational models are multiplicative, and in order to be able to use standard additive linear regression programs, we apply log transformations to the relevant variables. We model the (logarithm of the) crime flow between an origin neighbourhood O and a destination neighbourhood D as being dependent on a standard gravitational model, having the (log) number of criminal trips starting in neighbourhood O (with whatever destination) as the "push factor", the (log) number of criminal trips with destination D (from whatever origin) as the "pull factor" and, as geography factors, first the distance between origin and neighbourhood area, secondly the number of intervening opportunities, to be defined more precisely presently. Notice that inflow is presented here as a proxy to the pull factor "attraction", outflow as a proxy to the push factor "production", which in itself are the analogues of the two size variates in the general gravity model.

Although Stouffer proposed the concept of competing migrants as useful in his mobility models, we do not see a direct analogue of that concept within a crime flow model. The resulting model is now:

$$\text{Ln}(\#crime\,trips_{OD}) = \beta_0 + \beta_1 \ln(inflow_D) + \beta_2 \ln(outflow_O) + \beta_3 \ln(distance_{OD})_2 + \beta_4 \ (\#IntOppIndicator_{OD}) + \varepsilon$$

Data

The flow of criminal traffic is analysed for all 94 neighbourhoods in the city of The Hague, the Netherlands. The Hague is a city with a population of about 440,000. The city is situated at the North Sea coast, and its current boundaries include the former coastal villages of Scheveningen, Loosduinen and Kijkduin. The city comprises 94 neighbourhoods, the boundaries being defined by the The Hague municipality on the basis of historical and infrastructural characteristics. Five neighbourhoods are almost or completely non-residential (industrial areas, parks, dune area). These five cannot be crime trip origins, but are included in the analysis as potential destinations. On average, the other 89 neighbourhoods have a surface of 0.65 square kilometres, a population of 4,950 residents living in 2,350 houses and apartments.

We analyse crime flow between origin neighbourhood and destination neighbourhood for all combinations of the 94 neighbourhoods, including those cases where the origin (O) and destination (D) are identical neighbourhoods. The number of crime trips between each O–D-pair is the dependent variable in our analysis.

Data, obtained from the The Hague regional police force, pertain to solved crimes in the time period 1996–2004. We needed solved crimes in order to obtain information on the neighbourhood in which the offender lives, as well as an address of the *locus delicti*. Crimes for which both locations were unknown, and for which the perpetrator did not live in the city of The Hague, are omitted. The resulting 62,871 crimes will be considered to have generated crime trips from the neighbourhood where the arrested suspect lives, to the destination neighbourhood where the crime is committed. Crimes were aggregated over both origin and destination, resulting in $94^2 = 8{,}836$ origin–destination combinations.

As explanatory variables we used:

(a) *outflow*$_O$ = the total number of solved crimes being committed by perpetrators living in O, irrespective of in which destination area they have been committed (*concentration of offenders at origin*)
(b) *inflow*$_D$ = the total number of solved crimes being committed in destination area$_D$, irrespective of their origin (*overall criminal attraction at destination*)
(c) the *distance*$_{OD}$ between origin and destination (using the distance between centroids of the areas concerned. If origin and destination happen to be the same neighbourhood, we use the Ghosh (1951) approximation for the average distance between two points in the same neighbourhood).
(d) the number of intervening opportunities, for which we used three different operationalizations. All operationalizations use a two-step procedure. The first step defines the *set of all areas counting as* "*in between O and D*". The second step determines the *number of intervening opportunities* as the sum of all opportunities available in that set. The three variants of intervening opportunities used specify different ways in which the set of neighbourhoods counting as "in between *O* and *D*" is constructed. The three variants are:

    (d1) The first approach specifies the set as all neighbourhoods that have a centroid within the *Stouffer small circle* based on the centroids of *O* and *D*, and counts all opportunities in that set, $IO_{OD}^{(1)}$
    (d2) The second operationalization specifies the set of all neighbourhoods that have centroids within the *Stouffer large circle* based on the centroids of *O* and *D*, and counts all opportunities in that set. $IO_{OD}^{(2)}$
    (d3) The third operationalization chooses the set of all neighbourhoods that are intersected by the line OD, and counts all opportunities in that set, $IO_{OD}^{(3)}$.

In all three cases, the origin neighbourhood *O* is considered to be in between *O* and *D*, hence in the relevant set, but the destination neighbourhood (if different from *O*), is considered as not in that set.

While the Stouffer-based sets are easily determined analytically, given the coordinates of all centroids, the case of the line between *O* and *D* has to be determined for each *O* and *D* using a GIS-program. We call this method, therefore, the "direct GIS-band" method.

Finally, we have chosen what to consider as "an opportunity". We count as number of opportunities in an area the *total number of (solved) crimes* that took place in that neighbourhood, as a proxy for the "real" number of opportunities.

The number of intervening opportunities as defined here is clearly associated with the distance between origin and destination neighbourhood: the farther away a neighbourhood is, the more neighbourhoods there are in between, hence the more opportunities to be expected.

Results

A linear regression on the logarithm of the total number of crime trips using a standard gravitational model with log(inflow), log(outflow) and log(distance) resulted in 62% of the variance explained. All three regressors have highly significant ($\alpha = 0.001$) and substantial contributions to make:

Table 1 demonstrates that our data display a standard distance decay picture, and we will now investigate what difference it makes whether we add or substitute intervening opportunity measures. Before adding such measures, it was checked whether the various intervening opportunity operationalizations do differ at all, by computing product–moment correlation coefficients. All indicators have high, but not excessive correlations; both Stouffer variables are more alike to each other than to the direct GIS-band. Scattergrams show indeed that there is not a clear linear correlation between indicators, and we decided to use all of them in the analysis (Table 2).

The next step is ascertaining what part of the distance effect may be attributed to intervening opportunities, and what part remains to be ascribed to other effects of distance. In the regression models below, we first estimate the effects of attraction and production, and then add the IO-variable, followed by distance. Then we change the order in which distance and intervening opportunities are included in the model in order to study the difference in additional variance explained (Table 3).

As expected, the gravitational "push"–"pull" model explains a considerable amount of variance: 51%. When we add the number of intervening opportunities, that variable explains an extra 5–8% of variance, dependent on what definition we use. The inclusion in the model of the variable that represents the distance between neighbourhoods reveals that this explains again an extra 3–6% of the variance in the dependent variable. This shows that, although distance and intervening opportunities are correlated, distance has something

Table 1 Standard gravitational model

Multiple regression of ln(crime flow) on:	*Standardized β*
ln(outflow)	0.59
ln(inflow)	0.32
ln(distance)	−0.34

n=8,836 pairs of neighbourhoods.
R^2=0.62.

Table 2 Association between IO measures

Product–moment correlation coefficients between variables			
$IO^{(1)}$ (Stouffer's small circle)	1		
$IO^{(2)}$ (Stouffer large circle)	0.84	1	
$IO^{(3)}$ (direct GIS-band)	0.78	0.66	1

n=8,836 pairs of neighbourhoods.

Table 3 Variance explained by intervening opportunities

Multiple regression of ln (crime flow) on:	*Intervening opportunities defined by method 1: $IO^{(1)}$ Stouffer small*		*Intervening opportunities defined by method 2: $IO^{(2)}$ Stouffer large*		*Intervening opportunities defined by method 3: $IO^{(3)}$ direct GIS band*	
Order of incorporating distance and IO regressors	*First IO, then distance*	*First distance, then IO*	*First IO, then distance*	*First distance, then IO*	*First IO, then distance*	*First distance, then IO*
R^2 ln(inflow) , ln(outflow)	0.51	0.51	0.51	0.51	0.51	0.51
$\Delta(R^2)$ add: Int Opp	**0.07**		**0.08**		**0.05**	
$\Delta(R^2)$ add: ln(distance)	0.04	0.11	0.03	0.11	0.06	0.11
$\Delta(R^2)$ add: Int Opp		**0.00**		**0.00**		**0.00**
Total R^2	0.62	0.62	0.62	0.62	0.62	0.62

n=8,836 pairs of neighbourhoods, total crime.

extra to contribute, independent of intervening opportunities. However, proceeding in a different order, first forcing distance in the model, and then adding intervening opportunities afterwards, the results emerged differently. In fact, distance alone is, for all three operationalizations of intervening opportunities, able to encapsulate *all* common influence of distance and opportunities. Intervening opportunities have nothing more to contribute when distance is already in the model. Moreover, the differences between various definitions of intervening opportunities are rather small.

We have also estimated slight variations of the model and data, such as leaving out O–D-pairs with very few crime trips, leaving out the O–O-pairs or using property crime data only. While of course parameters estimated change, the overall structure remains identical: distance is accounting for more than opportunities do, while opportunities cannot explain extra variance after incorporating distance into the model.

Discussion

Using various operationalizations of intervening opportunities, in the Stouffer tradition, we have unravelled the role of distance and opportunities in crime trips between areas, within the framework of a gravitation model. We have shown that both distance and intervening opportunities do explain a portion of variance in the number of crime trips. Distance explains as much as opportunities do, but adds an extra effect as well. The other way around, we have shown that intervening opportunities do not add extra explanatory power over distance.

This can be interpreted as showing that the effect of distance may be interpreted as containing two elements: the first one is covered by intervening opportunities. When a destination is far off, that implies, in general, that a great number of intervening opportunities will be met when travelling from origin to destination, enhancing the probability that the perpetrator will find a target before reaching that far-off destination. The second element of distance that explains part of the variation in crime trip intensity is independent of the number of opportunities met in between. We like to suggest that this second element is the pure cost effect of distance, in terms of travel time, labour or financial costs to be covered to get over a distance.

We have shown that the various definitions of intervening opportunities are almost equivalent in effect.

It should be noted that as a test of the use of the intervening opportunity concept in gravitational models, our analysis has some limitations.

First, The Hague is a rather homogeneous city, in which the number of intervening opportunities per area does not wildly vary. It may be worthwhile to replicate the analysis in a more heterogeneous context, for example, in a larger scale context where urbanized areas (high opportunity density) as well as rural ones (low density) are included.

Second, our operationalization of opportunities by way of the number of solved crimes committed in an area could be improved upon. This may be vulnerable to unequal clearance rates for different neighbourhoods. We may think of operationalizing the concept independently of crime figures, for example, by the number of dwellings (for analysing burglary), the number of commercial units (for analysing shop lifting), the population density (for analysing violent crimes) and so on. Reduction of the research to such specific crime types, however, reduces the data set available considerably, and would for The Hague probably be unwise. However, replication of our analysis for a larger city may bring such refined analysis within reach.

The third limitation we like to mention is the tacit assumption that crimes are committed starting from the home of the perpetrator, which is certainly not always true. Using police data will seldom allow a more refined analysis, as the starting point of a crime usually is not mentioned in such databases. We also have to be aware of the possibility that the home address of an offender is not reliably noted down in the database, as frequently changing addresses will not be covered adequately in this database. A replication using more precise information on where an offender lived at what period would therefore be worthwhile.

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