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Overlapping crime: Stability and specialization of co-offending relationships

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ABSTRACT

Dyadic analyses of relationships between criminals have mostly ignored the multiplex nature of criminal ties. This study attempts to provide a more complete assessment of co-offending networks by incorporating the different types of crime that relate individuals with each other. Drawing on a large dataset of arrests in Quebec between 2003 and 2009, we focus on co-offending stability and specialization and illustrate how co-offending networks based on different types of criminal activities overlap. We portray a pattern of co-offending, which extends debate of criminal specialization/versatility to the dyadic level. Our study illustrates the ways in which the frequency and spectrum of crime include a relational component. More generally, the article emphasizes the need to consider the semantics of network ties, and further, the association between different types of networks, which ultimately offers a reassessment of social structure.

A large amount of crime is committed by pairs of individuals or by groups. At the same time, research that explicitly investigates how such co-offending affects individuals remains at the fringes of criminology (for some exceptions see Warr, 1996; Warr, 2002; Bouchard and Spindler, 2010; Svensson and Oberwittler, 2010; Andresen and Felson, 2010; Carrington, 2002; Piquero et al., 2007; van Mastrigt and Farrington, 2009). Research on co-offending is heavily influenced by Reiss (1986, 1988) (see also Reiss and Farrington, 1991), who found that half of all burglaries and robberies are committed by two or more offenders. While Reiss focused on specific types of crime and revealed a strong prevalence of co-offending, more recent research on general crime finds less co-offending. Studies using large official records suggest that co-offending varies between 10 and 20 percent across crime events (van Mastrigt and Farrington 2009; Hodgson, 2007; Stolzenberg and D'Alessio, 2007), i.e. 80–90 percent of all criminal offenses are committed by single individuals. Looking at crime involvement, the percentage of individuals taking part in co-offending varies between 20 to 45 percent; i.e. more than 55 percent of all criminals only commit crime alone. Using Canadian arrest records, Carrington (2002) found that 24 percent of offenders are linked to co-offending events. Furthermore, this proportion is much higher amongst youths (44 percent) than among adults (20 percent) (Carrington 2002). Other research reveals similar patterns. For example, van Mastrigt and Farrington (2009) found that 30 percent of offenders are involved in co-offending, Hodgson (2007) found that 35 percent of offenders co-offend with others, and McCord and Conway's (2002) study of youth patterns reveals that 40 percent of young criminals co-offend with others. Much of the discrepancy between these recent studies and Reiss' seminal research can be attributed to the types of crime under investigation. Reiss focused on criminal activities that are more likely to require a co-offender (e.g. burglary and robbery). Many of the less serious types of crime and violent crime, however, is committed by solo offenders (e.g., vandalism, shoplifting, assault). The importance of co-offending as a crime commission enhancer, however, is accepted by most researchers in the field. Tremblay (1993) provides the general statement that continues to drive this field of research: "In a variety of situations, the probability that a given violation will occur will partly depend on motivated offenders' ability to find 'suitable' co-offenders" (p.17).

Early research on co-offending stresses the need to study, for example, the recruitment in co-offending circles (Reiss 1986). Reiss suggested that high-rate offenders "frequently change co-offenders" and that they "may actually be composed of subpopulations of 'joiners' and 'recruiters'" (p.142). This specific joiner/recruitment distinction was subsequently refuted by Warr (1996), who demonstrated the more transient nature of such roles in co-offending settings. The same observation was substantiated by McGloin and Nguyen (2012), who found some evidence for offending instigation across types of crime. Most of these

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studies are consistent with Tremblay's (1993) argument that the co-offending process is not so much determined by the behavior of the more frequent offenders, but by the level of co-offending opportunities that are available in any given criminal opportunity structure. Hence, individuals could conceivably shift from one co-offender to the next (and back to past co-offenders), while taking on transient instigator or joiner roles across a sequence of crime events. What matters most is the availability of co-offenders within a wider network.

The current article follows Tremblay's general statement and focuses on stability and specialization/versatility issues in co-offending. We begin this article by reviewing past research in this specific area and present the data and analytical framework for this research. Our results, general argument, and conclusions reflect our conceptualization of co-offending relationships as a multiplex network built around dyadic dynamics.

Variations in dyadic stability in crime

Co-offending relationships almost certainly evolve. As in most social contexts, relationships emerge, disappear or change their nature in time. DeLisi and Piquero (2011) identified the need to situate co-offending more explicitly in criminal careers research. Such is potentially important as it helps to illuminate whether co-offending is simply a characteristic of criminal events or whether there are distinctive trajectories for co-offending relationships, which ultimately determine the structure and organization of criminal groups. The issue of specialization/versatility in offending takes an important role in criminal careers research. Yet, previous work almost exclusively focuses on individual offenders and excludes co-offending relationships from the analyses. As noted by Sullivan et al. (2006), there is a respectable amount of studies on offender specialization. Several researches find low levels of specialization among offenders in the long run. Individuals seem to do all sorts of crime over the course of their criminal careers (Brennan et al., 1989; Farrington et al., 1988; Kempf, 1987; Lattimore et al., 1994; Simon, 1997). At the same time, methodological concerns about the way this previous research aggregates measures over time and over individuals have been raised (Sullivan et al., 2006) and led to increased use of individual-level diversity measures instead (Mazerolle et al., 2000; McGloin et al., 2007; Piquero et al., 1999; Sullivan et al., 2006). Several studies (Mazerolle et al., 2000; Piquero et al., 1999) put the issue in developmental context and find that age brings about a decline in the amount of crime versatility. Older offenders are more specialized. Similarly drawing on individual-level measures, others (Osgood and Schreck, 2007; Sullivan et al., 2006; Sullivan et al., 2009) find more specialization than previous studies suggest. Surprisingly, the empirical and theoretical debate on specialization/versatility of offending has not been held on the dyadic level yet. Are co-offending relationships specialized or versatile? In general, criminal careers research neglects the life-span and trajectory of co-offending relationships. Although, a large amount of crime occurs in pairs or groups, this has not been adequately considered in this context. DeLisi and Piquero (2011) identified the need to establish co-offending more explicitly in criminal careers research. McGloin et al., 2008 examined youth co-offending with a Philadelphia-based longitudinal dataset and found that co-offending relationships are generally short-term; co-offending partners are not reused. They also offered an initial assessment of co-offending stability, i.e. the reuse of co-offenders in subsequent criminal incidents.[1] They propose a 'co-offender stability measure' (CSM), which is derived on the individual-level. It takes the value "zero" when there is no overlap and individuals co-offend with different individuals in repeated criminal incidents. In contrast, the measure takes the value "one" for individuals who co-offend with specific alters all the time. While theoretical focus rests on co-offending relationships, the actual CSM measure is still calculated on the level of individuals. A more sophisticated approach, however, would include this individual-level information on a higher level in a cross-classified model where the actual co-offending dyad (or actor pair) remains the unit of analysis. In line with previous work (Reiss and Farrington, 1991; Sarnecki, 2001), McGloin et al. (2008) find only little evidence for co-offender stability. At the same time they acknowledge that some individuals repeatedly co-offend with each other. Another important study was conducted by McGloin and Piquero (2010), who examined the link between non-redundant networking and offending versatility. Using egocentric density as a main indicator of network redundancy, they found that individuals with lower density (or less redundancy) in their personal networks are more likely to be versatile in their group offences. Such a finding was consistent with other research on criminal networks that demonstrated the benefits of brokerage for increasing offenders' earnings (Morselli and Tremblay 2004) and reputation (Morselli 2009). Lantz and Hutchison's (2015) extended McGloin et al.'s research to address stability patterns in co-offending groups over time and examined how co-offending ties impact individual criminal careers. They found that the duration of co-offending relationships increases if they were drawn from larger groups with more dispersed offending structures, once again reiterating the importance of low density network structures, while also nuancing the importance of considering the types and mix of crimes in which offenders take part.

Some studies indicate substantive differences in types of criminal activities and co-offending patterns. One recent study, for example, demonstrated the importance of simply gauging the size of a co-offending group in order to estimate the events that are related to organized crime in a specific region (see Hashimi et al., 2016). Another research examined how crime involvement and frequency vary within a co-offending population and found that a) offenders with more co-offenders (the core segment of the population) are more involved in crime, b) those who are directly co-offending with this core (the peripheral segment of the population) are also more criminally active, and c) dyadic stability amongst co-offenders is more prevalent than initially expected (Morselli et al., 2015).

The current study builds on this past research and focuses on the stability and specialization of co-offending relationships. We conceptualize co-offending in a multiplex way, where individuals are related with each other repeatedly and commit different types of crime. First, co-offending stability investigates the way in which individuals reuse previous co-offenders in subsequent criminal incidents. Are co-offending relationships stable or do individuals disregard previous co-offending partners? Second, co-offending specialization examines the nature of those relationships where individuals co-offend with each other more than once. Do individuals commit the same type of crime with specific co-offenders and develop specialized relationships? By answering these two questions, we extend the debate on specialization/versatility in crime to the dyadic level and infuse criminal network studies with developments in criminal career research. At the same time, we highlight the importance of group processes and co-offending for crime.

[1] McGloin et al. (2008) refer to this as "co-offender stability" and distinguish it from "stability of co-offending", which has a slightly different meaning in their study and simply assesses whether a particular individual keeps committing crime together with others (no matter with whom). We find the latter definition less fortunate as co-offending, in our opinion, explicitly refers to specific dyads (pairs of actors). Instead, we mean the reuse of specific co-offenders when we talk about co-offending stability.

Table 1
Number of co-offenders per event.

Number of co-offenders per event	Events	Percent
2	58,934	77.12
3	12,258	16.04
4	3388	4.43
5	1037	1.36
6	360	0.47
7	172	0.23
8	81	0.11
9	35	0.05
10+	153	0.20
Total	76,418	100.00

Table 2
Types of criminal activities.

Type of offense	Freq.	Percent
Assault	9749	12.76
Robbery	3382	4.43
Extortion	3473	4.54
Car theft	4398	5.76
Break and enter	11,566	15.14
Simple theft	16,950	22.18
Fraud	5145	6.73
Mischief	4863	6.36
Drugs	11,826	15.48
Other	5066	6.63
Total	76,418	100.00

Drawing on a large dataset of arrests (and co-arrests) in Quebec between 2003 and 2009, our study illustrates the ways in which the frequency and spectrum of crime are influenced by an underlying relational component. More generally, the article emphasizes the need to consider the semantics of criminal network ties and the association between different types of networks, which ultimately offers a reassessment of criminal structure.

Data

Our study draws on a large dataset that covers a subset of all individuals arrested in the province of Quebec over a 7-year period (2003–2009). Information was extracted from the MIP (Module d'Information Policière), a centralized database used by virtually all police organizations in Quebec. While using these data, we recognize that it is usually not possible to determine how and when infractions came to the attention of the police. For instance, an offender may have been under investigation for a certain time during which he or she committed a number of infractions without being immediately arrested; alternatively, an offender may confess a number of additional crimes after being arrested. In both cases, police officers do not necessarily have the resources to document the incidents, search out alleged victims, etc., so these crimes may well be dismissed at a later date. To avoid these problems, we analyzed only those infractions that occurred closest to the date of arrest. Non-criminal incidents and offenses that are committed by solo offenders were also excluded from the analysis

In total there are 76418 unique criminal events in our study population. All of these are events where at least two offenders co-offended with each other in Quebec between 2003 and 2009. In the majority of cases (77 percent) there are exactly two co-offenders (see Table 1). The rest (23 percent) comprise events with more than two co-offenders. Practically, such an individual-event dataset corresponds to the structure of a two-mode relational events network. Individuals share unique events in which they co-offend together. Even more so, each event is of a specific type. Table 2 gives an overview of the distribution of events per type. From a conceptual point of view one can illustrate the data structure as depicted in Fig. 1, where the color of the events represents the type of criminal activity.[2] Links between individuals and events mean that individuals participate in a specific criminal event. Each event has exactly one type.

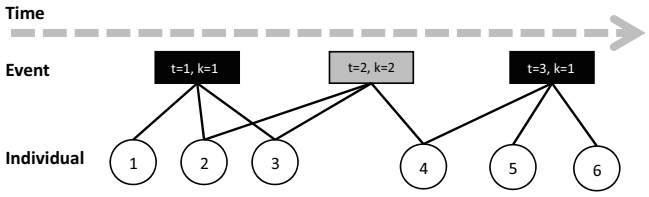

Fig. 1. Illustration of data structure.

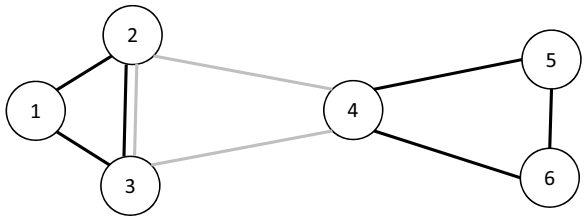

Fig. 2. One-mode projection of individual-event data from Fig. 1.

A straightforward way to handle two-mode network data is generating a one-mode (lower-level) projection (see Fig. 2). Such a transformation effectively collapses the information into a single level. One only focuses on individuals and translates the relationships between individuals and events into relationships between individuals, where an individual-individual relationship means that two individuals co-offended with each other in the same event (alternatively, one can also project to the level of events). Normally, one-mode projections need to be performed with caution as often information is lost. In fact, a lot of effort has recently been put into the development of techniques for un-projected two-mode data.

Our network $N = \{V, E\}$ consists of a set of vertices and undirected edges (co-offending ties) between these vertices. The set of vertices simply represents all unique individuals: $V = \{v_1, v_2, v_3, v_4 \ldots v_N\}$. In our dataset there are 110 664 unique individuals who had been arrested for co-offending. In contrast to non-temporal, non-multiplex, and single-mode networks, the edges representing the co-offending relationships are not simply defined as pairs of vertices, but as quadruples which represent a co-offending relationship between individuals i and j at time t of type k. Keeping the information on time (not depicted in Fig. 2) and type of criminal event (depicted as color of the co-offending ties in Fig. 2) allows seamless transformation between two-mode and one-mode projection in both directions. In total, there are 164 619 undirected quadruples in the data defining the time and type-conserved relationships of the one-mode projection. Theoretically, we can represent these quadruples as E_{ijtk} taking the value "one" if individual i co-offended with individual j at time t with offense type k and "zero" otherwise. Practically, however, we never construct the full four-dimensional matrix E, which would hold the vast number of $110\,664^2 * 76\,418 * 10$ entries (we look at 10 different types of crime).

[2] In Fig. 1, t refers to different points in time and k refers to different types of offenses.

Table 3
Number of arrests per offender during the observation period.

Offenses per person	Freq.	Percent
1	85,438	77.20
2	13,350	12.06
3	4823	4.36
4	2297	2.08
5	1306	1.18
6+	3450	3.12
Total	110,664	100.00

Results

Co-offending stability

Not all individuals commit crime repeatedly. Previous research, however, indicates that many individuals do, that is, there is a high rate of recidivism (Gendreau et al., 1996; Johnson et al., 1997). Obviously, the repetition of criminal activities is hard to assess. This is even more so for studies using police arrest data. The simple fact that individuals get arrested might change their behavior to become more cautious and avoid future arrests. At the very extreme, an arrest might lead to an individual being sent to prison and taken out of business for the time of incarceration. But getting arrested does not necessarily reduce chances for futures arrests. In fact, law enforcement personal often draw on experiences with criminal offenders and put individuals under higher scrutiny and observation when they are aware of individuals' criminal histories. In addition, studies show how incarceration in prison and exposure to other criminals educates individuals in the art of crime (Visher and Travis, 2003). They acquire skills, information, contacts and more, which often lead to a continuation of criminal activities once released. Sometimes, repeated arrests and convictions might even lead to individuals becoming professional criminals due to the lack of alternative non-criminal training.

Despite these difficulties, co-offending stability is assessed straightforwardly. Given that individuals get arrested again, are they more likely to co-offend with those individuals with whom they co-offended already before? Such a perspective avoids the issues above and focuses on the sub-group of individuals who get arrested repeatedly. Table 3 illustrates the number of arrests for the individuals in the study population during the observation period. In total, 110 664 individuals got arrested at least once between 2003 and 2009.[3] Around 77 percent of the individuals got arrested for one co-offense; almost 23 percent of the individuals co-offended and got arrested together at least twice.

How does the co-offending pattern look like for those 23 percent of individuals who got arrested multiple times? Do they co-offend with the same co-offenders (co-offending stability) or do they choose to commit crime with others with whom they had not co-offended (and got arrested with) before (see also McGloin et al., 2008 for this question)?

In contrast to McGloin et al. (2008), who are interested on the dyadic level, but actually derive a measure on the individual-level, we focus on actor pairs instead. Out of 164 619 undirected quadruples forming the network of our multiplex one-mode projection, there are 130 823 unique, undirected pairs of individuals i and j with co-offending relationships. Table 4 shows the distribution of the number of co-offending per actor pair. For example, the value 2280 in the third row means that 2280 actor pairs (i, j) are characterized by three repeated co-offending events. And 12938 (=130 823–117 885) of these unique pairs of individuals i and j are relationships where i and j co-offended together more than once. That means only $\frac{12938}{130823} = 0.10 = 10$ percent of the pairs of individuals form a repeated co-offending relationship, i.e. they co-offend with each other more than once. Notice that we do not say anything about the actual timespan between co-offending events, which would be a fruitful avenue for further research, but rather focus on the amount of repetitions instead. Although there is clear evidence for co-offending stability, at first sight, the rate seems low and in line with previous research (McGloin et al., 2008; Reiss and Farrington, 1991; Sarnecki, 2001).

Table 4
Number of co-offenses per actor pair.

Number ofco-offenses per actor pair	Freq.	Percent
1	117,885	90.11
2	7377	5.64
3	2280	1.74
4	992	0.76
5	384	0.46
6	768	0.29
7	251	0.19
8	229	0.18
9	130	0.10
10+	698	0.53
Total	130,823	100.00

Table 5
Cross-tabulation of co-offending stability and potential co-offending stability.

	Potentially stable pairs		
Stable pairs	0	1	Total
0	104,196	13689	117,885
1	0	12938	12938
Total	104,196	26627	130,823

Table 6
Co-offending stability and number of arrests in percentage.

	2 arrests	3 arrests	4 arrests
no repetition	63.68	48.68	39.32
2 repetitions	36.32	22.68	17.17
3 repetitions	–	28.65	16.83
4 repetitions	–	–	26.68

However, one crucial element has been neglected so far. Many individuals (as shown in Table 3) get arrested only once. Hence, those individuals with only one arrest cannot be involved in any repeated co-offending relationship, simply because a repeated co-offending relationship between individuals i and j requires that both i and j to get arrested at least twice. Based on the total number of offenses per individual we can highlight those actor pairs (i, j) where both i and j offended more than once as potentially stable pairs. Only these actor pairs can form a repeated co-offending relationship. When we cross-tabulate the stability status of actor pairs with potentially stable actor pairs (see Table 5), we find that almost $\frac{12938}{26627} = 0.49 = 49$ percent of all actor pairs that could have had a repeated co-offending relationship actually exhibit such a repeated co-offending relationship at some point during the observation period. Or put in other words, when two individuals i and j co-offended together already once and both of them i and j get arrested for additional offences, there is a 49 percent chance that i and j get arrested together more than once during the observation period.

In Table 6 we present sub-group results that show at the dyadic level the amount of repeated co-offending (in percentage) between two individuals. The columns in Table 6 indicate how many times

[3] Notice this means that 110 664 individuals were involved in the 76418 unique criminal events in our study population, which comprises all events where at least two offenders co-offended with each other in Quebec between 2003 and 2009.

two individuals i and j could have potentially co-offended with each other. This is determined by the minimum number of times that either i or j got arrested for co-offending. For example, if individual i was arrested three and individual j seven times, there could have been maximally three repeated co-offending events involving both actors. The rows in Table 6 indicate how many repeated co-offending events did occur. For example, the value 28.65 in the third row ("3 repetitions") of the second column ("3 arrests") means that almost 29 percent of dyads are characterized by three repeated co-offending events out of those that could be characterized by maximally three repeated co-offending events. In contrast, for 23 percent of the dyads where i and j could have co-offended with each other up to three times, i and j only co-offended with each other twice.

Our results indicate that co-offending stability might seem low to begin with (see McGloin et al., 2008); only 10 percent of actor pairs co-offend with each other more than once. However, as soon as one factors in that only those actor pairs (i, j) could exhibit repeated co-offending where both i and j got arrested more than once, stability is much more pronounced. Almost half of the actor pairs that could form a stable co-offending relationship do co-offend with each other more than once. When individuals get arrested more than once, individuals are likely to co-offend with other individuals with whom they already co-offended with before.

Co-offending specialization

So far, we only focused on whether there are repeated co-offending relationships or not. What about the type of criminal offenses in sustained relationships? Do actor pairs i and j get arrested for the same type of offenses when they co-offend with each other more than once? This question relates to the specialization/versatility of offending debate (McGloin et al., 2007) and extends it to the dyadic level. Do individuals specialize in certain types of crime with certain co-offending partners?

One way to address this issue is adaption of techniques used at the offenders' level to the level of co-offending relationships. We calculate a concentration index H_{ij}^{*} for each actor pair (i, j) with regards to different types of crime. We look at 10 different offense types (see Table 2) in our data. Ideally, such a dyad-level concentration index takes the value "one" if all repeated co-offenses between individuals i and j are of the same type k, i.e. individuals i and j always commit the same type of crime together. In contrast, it takes the value "zero" if the co-offending relationship between i and j is characterized diversity. Notice, such an index only makes sense for actor pairs (i, j) where i and j co-offended with each other at least twice (see Table 4).

For this purpose we derive the index H_{ij} based on a Herfindahl-Hirschman index (Hirschman, 1964). McGloin et al. (2007) use the index D instead, which is a different measure for diversity (see also Mazerolle et al., 2000; Piquero et al., 1999; Sullivan et al., 2006). Let M_{ij} be the total number of times individuals i and j co-offended with each other. Formally, M_{ij} is defined as:

$$M_{ij} = \sum_{t=1}^{T} \sum_{k=1}^{K} E_{ijtk}$$

For each of the $K = 10$ different types of crime recorded in our data, we calculate the share S_{ijk} of co-offenses between i and j that are of particular type k:

$$S_{ijk} = \frac{1}{M_{ij}} \sum_{t}^{T} E_{ijtk}$$

For example, when $S_{ijk} = 1$, individuals i and j only co-offend with regards to criminal activity type k. Like a Herfindahl-Hirschman concentration index we define H_{ij} as:

$$H_{ij} = \sum_{k=1}^{K} {S_{ijk}}^{2}$$

This unstandardized concentration index takes on value $H_{ij} = 1$ if all criminal co-offenses between two individuals are concentrated in one type of criminal activity k, i.e. the repeated co-offending relationship between i and j is highly specialized. The minimum of this unstandardized index, however, depends on the total number of co-offenses M_{ij} and the total number of categories K.

Normally, when standardizing a Herfindahl-Hirschman index, the theoretical minimum is simply determined by the number of distinct categories K (e.g. number of firms whose market share is examined). In our case not all co-offending relationships can exhibit all types of criminal activities, simply because in many cases there are more offense type categories than number of co-offenses between two individuals. One can show, however, that the theoretical minimum of the concentration index H_{ij} in our context is given as:

$$H_{ij\_min} = \begin{cases} \frac{1}{K}, \text{if } M_{ij} \geq K \\ \frac{1}{M_{ij}}, \text{if } M_{ij} < K \end{cases}$$

Using the theoretical minimum H_{ij_min} for each co-offending relationship, we can construct the standardized concentration index H_{ij}^{*}, which varies between "zero" (the co-offending relationship is as diverse as possible with regards to the type of criminal activity) and "one" (the co-offending relationship is highly specialized; all co-offenses between two individuals are of the same type).

$$H_{ij}^{*} = \frac{H_{ij} - H_{ij\_min}}{1 - H_{ij\_min}}$$

As outlined in McGloin et al. (2007), an index of this type has several advantages over earlier attempts to measure criminal specialization/diversity. Foremost, specialization is determined independently of transition probabilities between types of events. Specific, repeated co-offending does not have to happen in exact sequences for a relationship to be characterized as specialized. All what matters is the relative number of offenses of particular types during the observation period. See Sullivan et al. (2009) for a more detailed discussion of analytical strategies to assess offending specialization. Furthermore, our analyses remain on the dyadic level. This is advantageous as theoretically as well as conceptually, co-offending is a dyadic phenomenon.

As we are interested in repeated co-offending, we focus on those 12 938 actor pairs where individuals i and j co-offend with each other at least twice and calculate H_{ij}^{*} for all of these actor pairs. Fig. 3 shows the distribution of our concentration index that indicates the specialization/versatility of co-offending relationships regarding the type of criminal activity. Results are striking. More than 47 percent of all sustained co-offending relationships are completely specialized ($H_{ij}^{*} = 1$). Despite different encounters where individuals i and j co-offend with each other repeatedly in different events, the relationship is characterized by a single type of crime; i and j always get co-arrested for the same type of crime. Notice that the bi-modal distribution in Fig. 3 is not surprising, especially for actor pairs who co-offended with each other only a few times. For example, when i and j co-offend with each other twice, our index can only take either the value $H_{ij}^{*} = 0$ (the two co-offending relationships are of different type) or $H_{i}^{*} = 1$ (the two co-offenses were of the same

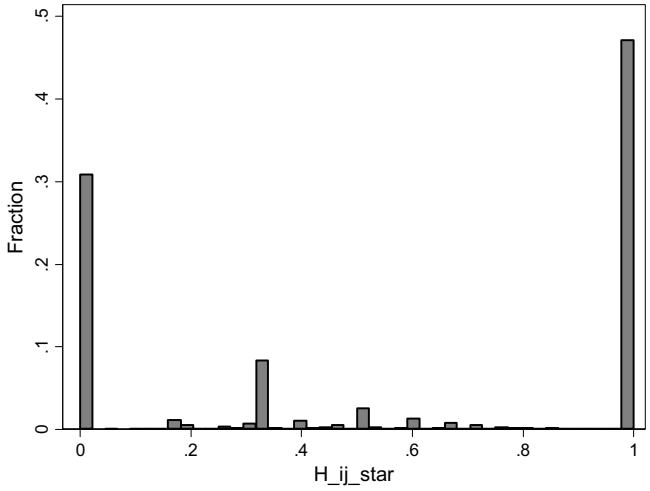

Fig. 3. Concentration in co-offending actor pairs regarding the type of criminal activity.

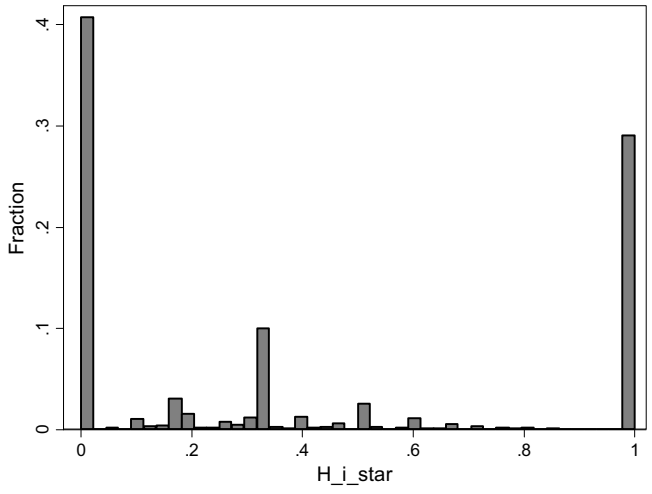

Fig. 5. Concentration in individuals' profiles regarding the type of criminal activity.

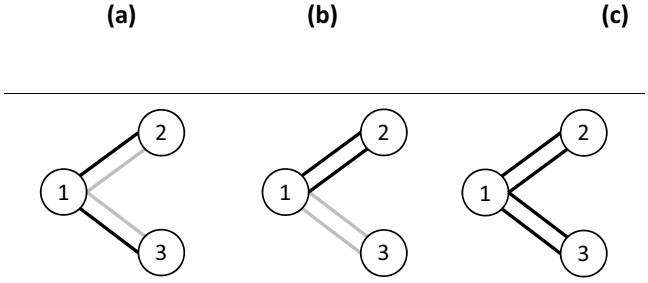

Fig. 4. Specialized vs. non-specialized co-offending ties.

type). Not only do we find support for co-offending stability, but also for co-offending specialization. Almost half of all co-offending relationships (actor pairs) are completely specialized around one type of crime.

Observed vs. expected co-offending specialization

In order to put the observed amount of crime specialization at the dyadic level into context, it makes sense to investigate if it is consistent with (or more or less than) the criminal career specialization of the individuals involved. Our intention is to compare the actually observed amount of crime specialization when two individuals repeatedly co-offend with each other with what one would expect by chance when offense type would not matter at all. Hence, we need to generate an expectation of how much crime specialization one would expect to find in the repeated co-offending of two individuals when the actual offense types would be randomly assigned to the co-offending events.

Fig. 4 illustrates the issue. Let us focus on the co-offending relationships from the viewpoint of individual 1. Individual 1 is involved in four quadruples E_{ijtk}. For reasons of simplicity, let us further assume that each of these quadruples corresponds to a unique criminal event (that is t is different for each quadruple). There are two types of relationships (black and grey) which stand for different types of criminal offenses (e.g. stealing a car and assault). In scenario a) individual 1 co-offends with each individual 2 and 3 twice. And the offense types are spread out equally. In other words, individual 1 does not specialize on the dyadic level. There is no preference for stealing cars or assaulting with either individual 2 or 3. The standardized concentration indices H^*_{ij} are lowest: $H^*_{12} = H^*_{13} = 0$. In contrast, in scenario b) individual 1 still commits four offenses as well (two of them stealing cars and two assaults as before). But this time, there is co-offending specialization. Individual 1 only steals cars with individual 2 and only assaults together with individual 3. Here, the concentration indices are at the maximum: $H^*_{12} = H^*_{13} = 1$.

The importance of individual offense profiles becomes obvious in scenario c). Here, individual 1 only steals cars; twice with individual 2 and twice with individual 3. Proceeding in an unadjusted manner, we observe two highly specialized co-offending relationships. The actor pairs $(1, 2)$ and $(1, 3)$ are both characterized by high specialization and $H^*_{12} = H^*_{13} = 1$. But clearly, there is a difference between the co-offending specialization in scenarios b) and c). The latter one is entirely driven by the distribution of offenses over individual 1. There is no way individual 1 could have had non-specialized co-offending relationships, simply because individual 1 only steals cars (no matter with whom). In scenario b), in contrast, dyadic specialization seems to be driven by something else than the individual offense profiles alone.

We examine the specialization of individuals' criminal profiles first. We approach node-level specialization in a similar way as we did on the dyadic-level before. This time, let M_i be the total number of offenses individual i gets arrested for. And furthermore, let S_{ik} be the share of these arrests in individual i's profile concerning criminal activity type k. For example, when $S_{ik} = 0.5$, this means that half of all the times individual i got arrested it was for crime of type k. We can then proceed and calculate a node-level concentration index H_i as:

$$H_i = \sum_{k=1}^{K} {S_{ik}}^2$$

Again, standardization is necessary to account for the fact that the theoretical minimum of this index depends on M_i and K. The logic for deriving the theoretical minimum is exactly the same as in the dyadic case:

$$H_{i\_min} = \begin{cases} \frac{1}{K}, \textit{if } M_i \geq K \\ \frac{1}{M_i}, \textit{if } M_i < K \end{cases}$$

Finally, the standardized concentration index H^*_i on the node-level ranges between "zero" and "one" and indicates how specialized an individual's criminal profile is. By design, this index only makes sense for individuals who got arrested at least twice. Fig. 5 shows the distribution of the index for the 23 percent of individuals

Fig. 6. Example calculation of expected concentration score, individuals' profiles.

(25226 = 110,664–85,438; see Table 3) in the data with more than one arrest.

$$H_i^* = \frac{H_i - H_{i\_min}}{1 - H_{i\_min}}$$

As it turns out 29 percent of individuals (who get arrested at least twice) only commit one type of crime. Their specialization index is at its maximum with $H_i^* = 1$. At the other extreme, over 34 percent of the individuals are as omnivore as possible ($H_i^* = 0$). Remember that most individuals only get arrested twice or a few times (see Table 3), hence, the bi-modal distribution of H_i^* is not surprising. For example, an individual i who gets arrested twice can only score values "zero" or "one". When the two arrests are of different type then $H_i^* = 0$ and when the two arrests are of the same type then $H_i^* = 1$. Most importantly, many individuals only get arrested for one type of crime, which automatically implies high specialization at the dyadic level as well (simply because the individuals are so specialized in what they do). Can we account for individual profile specialization when assessing the specialization of co-offending relationships? A straightforward way is to think of the expected amount of dyadic concentration $E\left(H_{ij}\right)$ when all co-offending specialization would be driven by individual offense profiles alone, i.e. the distribution of criminal activities over individuals.

First, recall that S_{ik} is the share of arrests in individual i's profile concerning criminal activity type k and M_i is the total number of offenses individual i gets arrested for. Let us now turn to the actor pair (i, j). This relationship is characterized by M_{ij} repeated co-offenses and S_{ijk} is the empirically observed share of these co-offenses of type k. We want to know the expected share $E\left(S_{ijk}\right)$ as a function of S_{ik} and S_{jk} alone; that is, how many repeated co-offenses between i and j do we expect to be of a specific type k when only the general profiles of individuals i and j to get arrested for offense type k matter? The number of repeated co-offenses between two individuals cannot exceed each individual's total number of arrests. Each multiplex tie corresponds to exactly one event in which i and j were involved. Hence, from individual i's point of view the baseline probability for each co-offense with j to be of type k is determined by S_{ik} (if individual offense profile would be all that matters). Similarly, from individual j's point of view this is determined by S_{ik}. For example, let us assume a situation where individual 1 steals a car ($k = 1$, black color) three times and commits an assault ($k = 2$, grey color) once and where individual 2 steals a car ($k = 1$) once and commits an assault ($k = 2$) three times (see Fig. 6). In this scenario the values S_{ik} are calculated straightforwardly as $S_{11} = 0.75$, $S_{12} = 0.25$, $S_{21} = 0.25$, $S_{22} = 0.75$. Now let us assume that individuals i and j co-offend exactly once. What is this probability that this offense is stealing a car ($k = 1$) or making an assault ($k = 2$)?

Thinking further in terms of directed relationships, we can map out all potential types of combinations for this (one co-offense only) relationship between i and j (Fig. 7) and calculate the probability that from both i and j's points of view the co-offense was stealing a car ($S_{11}{}^* S_{21} = 0.1875$) or committing an assault ($S_{12}{}^* S_{22} = 0.1875$) (see Fig. 8). Notice that we also obtain probabilities that from i's point of view the offense was stealing a car and from j's point of view it was an assault ($S_{11}{}^* S_{22} = 0.5625$) and the reverse ($S_{12}{}^* S_{21} = 0.0625$). However, as co-offending is an undirected relationship, only the two possibilities characterized by $S_{11}{}^* S_{21}$ and $S_{12}{}^* S_{22}$ are valid (highlighted by dashes in Fig. 8). We

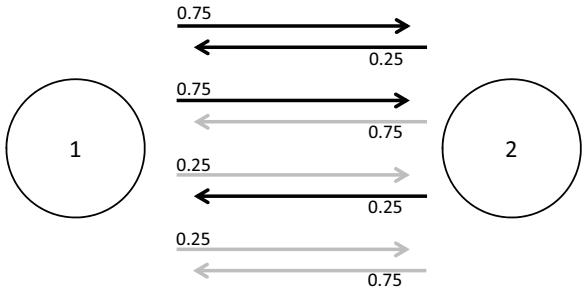

Fig. 7. Example calculation of expected concentration score, potential co-offenses.

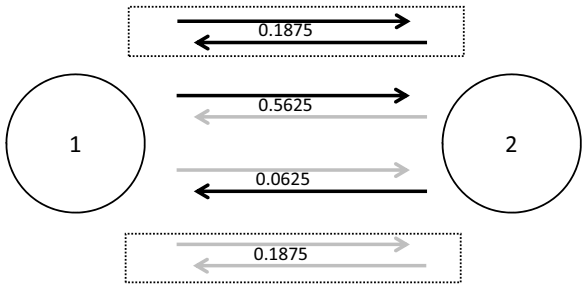

Fig. 8. Example calculation of expected concentration score, potential co-offenses, combined probabilities.

Table 7
Empirically observed vs. expected co-offending specialization.

	Frequency	Percentage
$H_{ij} > E\left(H_{ij}\right)$	1102	8.52
$H_{ij} = E\left(H_{ij}\right)$	7656	59.17
$H_{ij} < E\left(H_{ij}\right)$	4180	32.31
Total	12938	100.00

can now use the relative probability of these two possibilities to derive the probability that the offense was either stealing a car (0.5 = 0.1875/0.375) or committing an assault (0.5 = 0.1875/0.375). Coming back to repeated co-offending relationships, i.e. individual i and j co-offend multiple times with each other, the probability for every one of these offenses to be of particular type k corresponds to the expected share $E\left(S_{ijk}\right)$ of co-offenses between i and j to be of type k. Finally, in this example, we derive $E(S_{121}) = 0.5$ and $E(S_{122}) = 0.5$. We can then proceed and derive the expected co-offending specialization $E\left(H_{ij}\right)$ as:

$$E\left(S_{ijk}\right) = \frac{S_{ik}S_{jk}}{\sum_{l=1}^{K}\left(S_{ik}S_{jk}\right)}$$

$$E\left(H_{ij}\right) = \sum_{k=1}^{K} E\left(S_{ijk}\right)^2$$

Standardizing $E\left(H_{ij}\right)$ is less straightforward, but also not necessary in this case. All we need to know is if there is more (or less) co-offending specialization than expected under the assumption that only individual offense profiles matter. Hence, we want to know if $H_{ij} > E\left(H_{ij}\right)$. Recall the 12 938 unique actor pairs (i, j) with more than one co-offense together. In Table 7 we show for how many of these actor pairs the co-offending specialization is greater than what we would expect based on individual profiles alone, the same, or smaller. Interestingly, only for less than 9 percent of dyads, co-offending specialization exceeds the expected concentration; for most it is actually the same (59 percent); and for 32 percent it is

Table 8
Empirically observed vs. expected co-offending specialization for dyads and stability in percentage.

	2 co-offenses	3 co-offenses	4 co-offenses	5 co-offenses	6 and more co-offenses
$H_{ij} > E\left(H_{ij}\right)$	7.16	16.36	7.66	6.70	5.02
$H_{ij} = E\left(H_{ij}\right)$	72.22	44.74	41.73	36.35	45.04
$H_{ij} < E\left(H_{ij}\right)$	20.62	38.90	50.60	56.95	54.96
Total	100.00	100.00	100.00	100.00	100.00

less. Hence, there is generally less specialization at the dyadic level than one would expect from the individual profiles. In Table 8 we investigate this further and relate dyadic specialization with dyadic stability. Instead of pooling all actor pairs together, we show subgroup results for dyads of different duration. For example, the first column in Table 8 shows results for those dyads where individuals co-offend with each other exactly twice, the second column where individuals co-offend with each other exactly three times and so on. Overall, the same pattern as for the pooled analysis emerges. Generally, there is less specialization at the dyadic level than what one would expect by chance from individual offense profiles. Interestingly, however, this dyadic variety (less specialization than what one would expect from the individual profiles), is more pronounced for dyads that are also characterized by stability. When individuals co-offend with each other more, their relationship is more diverse when it comes to the type of crime they commit. From this we can conclude that almost all co-offending specialization at the dyadic level is driven by individual offense profiles. It is the scenario depicted in Fig. 4c) and not the one in Fig. 4b) which leads to specialized co-offending relationships.

Conclusion

In social networks analysis the multiplex nature of social relationships – individuals are often related with each other in more than one way – received only little attention so far (Szell et al., 2010). Much emphasis has been put on network topology; the overwhelming part of existing social network analysis conceptualizes social interaction in a simplified (often binary) way (Wasserman and Faust, 1994). Recently, scholars began to portray social interaction more diversified, for example through the analysis of weighted networks (e.g. Onnela et al., 2007; Opsahl et al., 2010; Opsahl and Panzarasa, 2009). This type of work explicitly acknowledges that relationships have different weights; some ties are stronger (more intense) and others weaker. Another stream of research explicitly focuses on the development of social relationships in time (Barrat et al., 2008; Snijders et al., 2010), including the repeated occurrence of relational events (Butts, 2008). Scholars also just started to examine how different types of relationships (e.g. friendship, advice) influence each other in time (Snijders et al., 2013). But still, the analyses of multiplex social networks are rare. In criminology, such analyses are even more absent. Studies about co-offending are limited and hardly investigate differences in co-offending relationships in terms of stability and specialization. Individuals are frequently related with each other in more than one way. And especially for criminal relationships, there are many different types and qualities of criminal ties (Andresen and Felson, 2012). A general challenge for social network analyses is to acknowledge such differences and to question what social relationships actually mean. Only such efforts will fruitfully combine methodological advances with substantive interests.

In the current study, we focus on co-offending in Quebec. Two aspects that embody the need to refine existing research strategies received particular attention. First, individuals co-offend with each other repeatedly (co-offending stability); criminal relationships most certainly evolve. And second, co-offending relationships are of different qualities and stretch different types of crime (co-offending specialization). While a large body of research focuses on the development and careers of criminals (e.g. (DeLisi and Piquero, 2011), this type of research hardly extends to criminal relationships yet. Criminal ties evolve and previous criminal encounters shape and define the future of these relationships. We argue that stronger emphasis on co-offending is needed within the context of criminal careers research. Such a perspective opens new ways for interpreting and understanding criminal structure and organization. Being in line with previous results (see McGloin et al., 2008) our findings indicate that co-offending stability seems low to begin with; only 10 percent of actor pairs co-offend with each other more than once. At the same time, as soon as one considers the fact that only those co-offender pairs could be stable where both individuals co-offend more than once, the picture changes dramatically. Almost half of the actor pairs that potentially could co-offend with each other more than once do co-offend with each other more than once.

Our findings indicate that individuals are likely to co-offend with the same people again. Our findings stipulate that criminal relationships are pretty stable. Trust needs to be built up and a functioning working relationships needs to be established. Second, offending can take very different forms. While existing research acknowledges differences in types of crime, the analyses of criminal networks hardly take such differences into account, but rather focus on loosely defined "co-offending" instead. Scholars are well aware of criminals' careers going through different stages with age (Carrington, 2009). However, the way in which criminal relationships themselves evolve remains largely unknown. Our study moves into this direction by focusing on the issue of specialization/versatility in co-offending relationships. Are co-offending relationships characterized by particular types of crime? Our analyses reveal that co-offending relationships are specialized. In consequence, when individuals co-offend with each other repeatedly they are likely to commit a type of crime they already committed with each other before. Looking more closely, however, it turns out considering individuals' profiles is crucial. Co-offending relationships are highly specialized when the offenders who are involved are generally specialized in what they do. Considering this in our analyses our findings reveals an interesting pattern: The composition of individuals' criminal profiles would lead to even more co-offending specialization than what can be empirically observed. Hence, although we effectively find high levels of specialization in co-offending relationships this seems to be driven by individual offense profiles and less by preferences of individuals to commit only certain types of crime with certain co-offenders.

Our analyses shed light on previously unknown aspects of co-offending and illustrates the ways in which the frequency and spectrum of crime includes a relational component. But also more generally, we investigate the multiplex nature of social relationships; an aspect that has not received much attention so far although it seems crucial in understanding social relationships. Hence, we emphasize the need to consider the semantics of network ties, and further, the association between different types of networks, which ultimately offers a reassessment of social structure.

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