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ESTIMATING THE SIZE OF REGIONAL INNOVATION NETWORK THROUGH A CAPTURE-RECAPTURE APPROACH

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Abstract *The effectiveness of inter-organizational collaboration rely on several factors, among which the composition of cooperation participants (partners in the inter-organizational network) and the number of cooperation participants (size of the network) play an important role. Thus, it is crucial to have a reliable estimate of the number of alters and the composition of collaboration networks. This task can be viewed as a particular case of hard-to-reach population estimation. In this work, we propose an adaptation of capture-recapture approach to estimate the number of actors in the personal networks of firms participating in the POR-FESR 2007-2013 call in Friuli Venezia Giulia (a region in the north-east of Italy). The alters (other organizations, also not regionally bounded) they listed in their network before and after their participation to the call will be considered as the two lists on which the proposed capture-recapture approach is applied.*

Keywords: *Innovation networks, Personal network, Hard-to-reach populations, Capture-recapture*

1. INTRODUCTION

Innovation at a regional level is considered a key factor for competitiveness, and it is recognized that it can occur through interaction, collaboration, and knowledge exchange among firms, academic institutions, and various government agencies (Etzkowitz and Leydesdorff, 2000). For this reason, national and regional governments in several countries have developed programs and centers to enhance local innovation (Strand and Leydesdorff, 2013). Several aspects are crucial for a successful implementation of government interventions: the local productive structure, proximity and localization, the role of academia, and the composition of inter-organizational networks. These latter can be viewed as the so-called personal

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networks of the organizations in a given region. Personal networks are networks viewed from the standpoint of an organization (ego) managing its ties with alters (Chua et al., 2011, p. 103). Furthermore, improving such networks is often the principal target of policy interventions to foster innovation. For instance, many regional innovation policies support individual firms (ego) to create a sustainable network of collaboration with different actors, mainly universities and research centres, and indirectly favor firm-to-firm collaborations.

In the literature, it is well-known that the effectiveness and profitability of inter-organizational collaborations depend on several factors that influence the performance of the interaction activities: i) the composition of the cooperation participants (partners in the personal network) and ii) the number of the cooperation participants (size of the personal network) (see for instance, Balling, 1998; Bison, 2006).

Thus, in dealing with regional innovation analysis, it is crucial to estimate both the size and the composition of the collaborations of the individual firms (or organizations) by looking at the type of actors involved in their personal networks (i.e., other private firms, universities/departments/individual researchers, research centers/individual researchers, and other organizations). Unfortunately, this task has not yet been directly addressed for several reasons. Most of the empirical studies on innovation networks rely on archival data concerning a specific formal collaboration types (e.g.: patents, project participation) and do not consider collaborations arising from informal contacts; population and sub-population sizes are unknown – since they are not regionally bounded – and it can be very hard to identify the list of possible actors involved.

In this work, in order to overcome these problems we propose an adaptation of the classical capture-recapture (CRC) approach to estimate the size and the composition of the personal networks of firms involved in regional innovation networks. CRC is a statistical method widely used to estimate the size of hard-to-reach populations (or sub-populations) when two or more samples are drawn from the population or two or more lists of ascertained cases from the population are available. The number of individuals observed in a sample and the number of those observed in both samples is used to estimate the amount of those not selected in any sample.

However, when dealing with such networks, there is an additional issue, the lack of general agreement on how to define what an “innovative firm” is. In our approach, we apply the proposed CRC method to a set of firms located in Friuli Venezia Giulia (a region in the north-east of Italy) who responded to the POR-

FESR 2007-2013 call, named “Innovation, research, technology transfer and entrepreneurship”. These firms can be considered as innovative, since the call they responded to was intended to promote innovative activities.

In detail, we use the lists of partners (i.e. other organizations, also not regionally bounded that we will call “alters”) they claimed to have before and after their participation in the call. These lists will be considered as the two lists to which the proposed CRC approach is applied. The idea is to account for unobserved alters (and thus to estimate the regional innovation network size) using the number of alters observed only before or only after participation in the call and the number of alters common to both.

Our proposal is innovative because we use survey data rather than archive data in order to consider even informal collaborations; we use personal networks information in order to retrieve lists of actors; in addition, since the population total is unknown, the CRC approach allows us to overcome the limitations of other methods (e.g. Network Scale-up).

The remainder of the article is organized as follows. In Section 2, after introducing the issue of network estimation in the context of hard-to-reach populations, we briefly recall the two widely used network-related approaches for hard-to-reach populations. Section 3 describes the proposed capture-recapture approach to estimate the number of alters in a personal network. In Section 4 we present some characteristics of the respondents’ firms located in Friuli Venezia Giulia (Section 4.1) and discuss the results of our application (Section 4.2). Finally, Section 5 ends the paper with some concluding remarks.

2. ESTIMATING THE NETWORK SIZE

The task of estimating the magnitude of a regional innovation network and the corresponding distribution of the kinds of actors involved can be thought as a particular case of hard-to-reach sub-populations size estimation, where the overall population size is unknown. The problem of sampling and counting hard-to-reach sub-populations is common in public health studies where sub-populations of interest are often groups of individuals practicing stigmatized behaviors or illegal activities. Obtaining reliable estimates of the size or the prevalence of these sub-populations through standard survey methods has been proved to be complicated (Bernard et al., 2010).

Recently, a growing interest has been devoted to the use of social networks– in particular personal networks– to count hard-to-reach sub-populations. Personal networks are the relational data collected from a respondent (known as “ego”) about his interactions with other people (known as "alters"). Also, personal network data serves as a substitute for directly interviewing these network members ("alters"). Therefore, the composition of personal networks of respondents can be used to gather information on other people directly through ego's answers.

It is possible to distinguish two streams of research related estimating sub-populations size in networks: 1) network scale-up methods and 2) capture-recapture like methods using multiple respondent-driven samples or several sub-population lists.

Generally speaking, network scale-up methods (NSUMs) use information from respondents' personal networks to estimate sub-populations size. The NSUMs were first proposed by Bernard et al. (1991) to estimate the number of people who died in the 1985 Mexico City earthquake by means of the personal knowledge of respondents. They assumed that the proportion of alters in an ego's network that are members of a sub-population, averaged over all egos, can be seen as a good approximation of the proportion of people in the targeted sub-population. The scale-up estimator (Killworth et al., 1998a,b) and its improvement (McCormick et al., 2010; McCormick and Zheng, 2007) allows for the estimation of the size of the unknown sub-population by using responses to questions about the number of people known in the unknown sub-population combined with the degree estimate (i.e. the number of alters in an ego's network). The data over all egos are scaled up and the estimates of many individuals are combined. In general, network scale-up estimate requires three pieces of information: *i*) the number of target groups (sub-populations) known (collected by a survey); *ii*) the respondents' network size of (estimated from a survey); and *iii*) the number of people in the entire population (known).

The other network-related approach for hard-to-reach sub-population size estimation adopts a variant of CRC methods (Fienberg et al., 1999; Rocchetti et al., 2011).

For network information, CRC considers the overlap of two network-based samples or respondent-driven samples (RDS) to estimate sub-population size (Paz-Bailey et al., 2011). Alternatively, CRC is used considering a second capture based on an administrative list or the distribution of an identifiable token (Paz-Bailey et al., 2011; Salganik et al., 2011). Recently, Dombrowski et al. (2012) proposed a CRC method within a RDS to estimate the size of hidden populations. They develop a peculiar matching procedure (the "telefunken method") in the sampling scheme in order to estimate the overlapped portion of two samples. The "telefunken method" uses the last three digits of the respondents' mobile phone number (encoded as being either even or odd, and low or high). Together with height, approximate weight, hair color, eye color, gender, and race/ethnicity, this produced a six-bit code for each respondent that served to match the respondent to contacts reported by other study respondents (Dombrowski et al., 2012).

3. THE CAPTURE-RECAPTURE APPROACH

3.1. MOTIVATION

In this paper we are interested in the estimation of the composition and the number of alters in the personal network of firms at a regional level. We consider collaboration relations either formal (e.g. collaboration on projects, co-patenting activities) or informal (e.g. personal advices, sharing of information and knowledge). Let F, U, R, and O denote private Firms, Universities/departments/individual researchers, Research centers/individual researchers and Other organizations involved in the personal networks of regional firms, respectively[2]. Let N and ${}_iN$, for $i = \{F, U, R, O\}$, be the population and sub-population sizes we want to estimate.

In this context, in order to estimate ${}_iN$, for $i = \{F, U, R, O\}$ it can be difficult to use the NSUMs approach since information about the total population size of innovative actors (N) is unavailable. The reason we do not have access to the overall population size are almost three: first, there is no agreement on how to define what an "innovative actor" is (different data sources have different definitions of innovative actors); second, regional innovation systems are unbounded since even actors outside the territory can participate in the regional innovative processes; and finally, actors in innovation networks cannot be simply retrieved from archival data concerning formal collaboration (e.g., patents, project participation), since there is a considerable number of innovation activities derived from informal contacts (on the role of informal contacts for innovation, see for instance Salavisa et al., 2012).

For our purpose we use an adaptation of CRC by exploiting the personal network information collected from a group of ego's (innovative firms) and retrieving information on their alters before and after a regional innovative program call. Differently from other approaches (for example Dombrowski et al., 2012), we directly obtain information from ego's about alters in common during the two time occasions asking egos to report if the alters they collaborate with in the first wave are the same or not in the second wave. In this way, we do not have to adopt

[2] Henceforth, we will refer to these four types of actors with the acronym FURO.

any peculiar matching criteria to obtain information on alters overlapping on the two occasions.

3.2. METHOD

CRC is a statistical method widely used to estimate the size of hard-to-reach populations (or sub-populations) when two or more samples are drawn from the population. The simplest CRC model assumes the presence of only two samples. The number of individuals observed in a sample and the number of those observed in both samples is used to estimate the amount of those not selected in any sample. The idea of the method is to estimate the not sampled part of the population exploiting information from the overlapped units.

CRC can also be applied where two or more lists of ascertained cases from the population are available, as in our case.

Let L1 and L2 be the two available lists of alters. Let $n_{l_1 l_2}$ be the observed frequencies, where $l_i = (0,1)$, $l_i = 1$, denotes "observed alter", while $l_i = 0$ indicates "not observed alter"; so that n_{10} indicates the frequency of alters observed only in L1, n_{01} is the frequency of alters observed only in L2, and n_{11} is the frequency of those alters observed in both lists. The data can be regarded as a 2^2 contingency table for which the number of alters (n_{00}) in both lists is missing

Tab. 1: Contingency table for two lists

	L2		
L1	Observed	Not Observed	Total
Observed	n_{11}	n_{10}	n_{1+}
Not Observed	n_{01}	–	
Total	n_{+1}		

Under the assumption that L1 and L2 are independent and that alters are equally likely to be observed in each list (Brittain and Böhning, 2008), the proportion of alters observed only in L2 is roughly the same as the proportion of alters observed in both lists; that is:

$$\frac{n_{11}}{n_{+1}} = \frac{n_{1+}}{N} \tag{1}$$

where $n_{+1} = n_{01} + n_{11}$, $n_{1+} = n_{10} + n_{11}$, and N is the total unknown population size. Solving (1) for N yields the well known Lincoln-Petersen estimator (Lincoln, 1930; Petersen, 1896)

$$\hat{N} = \frac{n_{1+} \times n_{+1}}{n_{11}}. \tag{2}$$

Note that, if no alters are observed in both lists (that is $n_{11} = 0$) the estimator in (2) cannot be computed and its expectation has no finite form. The Chapman's modified form of the Lincoln-Petersen estimator (Chapman, 1951)

$$\hat{N}_c = \frac{(n_{1+} + 1) \times (n_{+1} + 1)}{n_{11} + 1} - 1 \tag{3}$$

allows to overcome these problems, as it is less affected by zeros and less biased than the estimator in (2). The variance of the estimator in (3) is

$$V(\hat{N}_c) = \frac{(n_{1+} + 1)(n_{+1} + 1)(n_{1+} - n_{11})(n_{+1} - n_{11})}{(n_{11} + 1)^2 (n_{11} + 2)} \tag{4}$$

and we can compute an approximated $100(1 - \alpha)\%$ confidence interval as

$$\hat{N}_c \pm z_{\alpha/2} \sqrt{V(\hat{N}_c)}$$

where $z_{\alpha/2}$ is the $1 - \alpha/2$ quantile of a standard normal distribution.

The two lists, L1 and L2, used to estimate the number of alters in the personal network of firms in Friuli Venezia Giulia are the lists of actors that firms claimed to have before (L1) and after (L2) the POR-FESR 2007-2013 call.

4. ESTIMATING THE SIZE OF REGIONAL INNOVATION NETWORK

4.1. CHARACTERISTICS OF FIRMS PARTICIPATING IN THE FVG POR-FESR 2007-2013 CALL

Information on alters comes from an original survey on 536 firms in Friuli Venezia Giulia that participated in the POR-FESR 2007-2013 call ("Innovation, research, technology transfer and entrepreneurship") in February 2010, regardless if they have been financed or not.

The questionnaire was directed to the firms with the aim of collecting information on their collaboration activities with *FURO* actors before and after their participation in the call. These could be either located in the Friuli Venezia Giulia region or elsewhere: both in Italy and abroad.

The questionnaire was organized into six sections: section A was focused on the project submitted by the firms in the POR-FESR 2007-2013 call; in section B, firms listed “collaborations” (both formal and informal) activated before their participation in the call (these were approximately activated in a period of three years before the call for participation), and some characteristics of the collaborators; section C referred to collaborations activated after the participation in the call up to 2016 (with questions analogous to section B); section D contained a few questions to evaluate collaborations claimed in sections B and C; questions in section E were about the characteristics of the firms and the innovation introduced into their activities during the two time periods; and finally, section F collected information about the respondent.

The survey was conducted from November 2016 to January 2017 through an internet questionnaire (Computer Assisted Web Interviewing, CAWI). Despite the fact that web surveys usually exhibit lower levels of cooperation than other survey modes (Manfreda et al., 2008), we collected information from 277 firms, obtaining a high response rate (about 51.7%). We observe that 176 firms out of the 277 respondent firms declared to have at least one collaboration (63.5%). The response rate on collaboration (sections B and C of the questionnaire) can be affected by the huge effort in terms of memory asked to the respondents, because they have to reconstruct about ten years of activities.

The most represented provinces among the respondent firms are Udine (47.3%), Pordenone (28.2%), and Trieste (20.2%), while only 4.3% were located in Gorizia. However, no striking differences appear between the distribution of the provinces for the total of the firms who participated in the call and those we interviewed.

With regard to the size of firms, 32.8% of them are small (from 10 to 50 employees) and 32.1% are micro-firms (less than 10 employees). It turns out that 62.5% of the respondent firms operate in the manufacturing sector, 22.7% and 13.7% in the craftsmanship and the commerce sector, respectively, while only 1.1% operate the tourism industry. The average number of projects submitted by each firm is about 1.2; this result is in line with the POR-FESR 2007-2013 call, which allowed at most 2 submitted projects per firm. With regard to the characteristics of the respondent, about 84% of them are owner/managers of the firm and more than 60% declared to work in that firm for more than 11 years; about 30% for a number of years from 6 to 10, while only 9.7% for less than 5 years. Respondent firms declared to have 187 collaboration ties with different alters before their participation in the POR-FESR 2007-2013 call, 122 of which were still active after the call. Claimed collaboration ties activated with new alters after the call are 201.

4.2. ESTIMATION OF ALTERS THROUGH CRC

In the application to the real data set, we focused on the actors that firms claimed to have before and after their participation in the POR-FESR call (sections B and C of the above mentioned questionnaire). In particular, following the notation in Section 3.2, L1 denotes the list of actors with a collaboration activated before the POR-FESR 2007-2013 call and L2 denotes those actors with a collaboration activated after the POR-FESR 2007-2013 call. Figure 1 shows the hypothetical personal network of a firm for a single time occasion. For each alter (either before and after the call), the respondent was asked to indicate the type and its characteristics: the place where he is located, their relationship, the type of collaboration (either formal or informal), and the frequency of contact. Furthermore, in section B we also included a question about the duration of the collaboration, in particular if the collaboration was still active after the call. This last question was introduced with the aim of identifying alters in common to both lists. Thus, the personal network of the firms was provided on two time occasions, and each one was regarded as a list to be used for the estimation through the proposed capture-recapture approach.

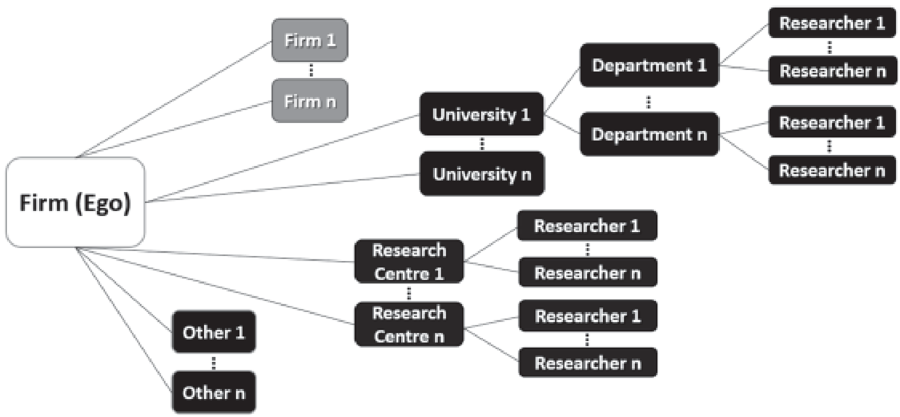

Fig. 1: Example of personal network for a time occasion

Due to response bias and/or non-response reasons, lists L1 and L2 are incomplete. Furthermore, the questionnaire structure, the adopted data collection method (CAWI), and the related respondents' burden allow us to consider the two lists–under the assumption of independence–as proper data for the application of the CRC approach to estimate those alters missed by both lists. Table 2 shows the contingency table from the survey (all types of alters).

For the overall network, the Chapman estimator on two lists provides an es-

Tab. 2: Observed contingency table for all types of alters

L1 \ L2	Observed	Not Observed
Observed	122	65
Not Observed	201	–

timated total number of 494 alters (with 388 observed), so that, adding up the number of egos, leads to an estimated total size of 670 actors activated by firms in the FVG POR-FESR innovation network. Table 3 reports the observed alters, the corresponding estimates, and the 95% confidence intervals for the total network and by alter typologies. From Table 3, we observe that, among the alter typologies, the most represented are firm-firm and firm-university relationships, with a percentage of about 41% and 40% of the total, respectively. The average degree (i.e. # of alters) is 2.8 for each ego.

Tab. 3: Estimation of $\hat{N}$ and CI

Alter typologies	Obs ties	${}_i\hat{N}_c$	95% CI
Total	388	494.21	[453.84 ; 534.58]
Firms	163	198.96	[176.75 ; 221.17]
University[1]	148	194.83	[167.74 ; 221.92]
Research Centre[2]	55	66.05	[54.12 ; 77.98]

[1] University includes Departments and individual researchers

[2] Research centre includes individual researchers

5. DISCUSSION AND CONCLUDING REMARKS

In this work we focused on the estimation of the number of alters in the personal network of firms in a given region.

Our proposal follows a capture-recapture approach in RDS, with the main difference that it does not need any particular matching procedure to obtain the overlapped part of the two samples. We used the Chapman's modified form of the Lincoln-Petersen estimator, that allowed us to obtain the estimated number (either in total and by typology) and the confidence intervals of alters involved in the personal network of firms participating in the POR-FERS call in the region of Friuli Venezia Giulia.

Our approach is extremely flexible, because if any data collection scheme has two or more overlapped lists of alters, one can use the proposed estimator. If the available lists are representative of the population of interest (e.g. the population of innovative firms), then, the estimates can be used to obtain an estimation of the size and the composition of the network for the entire population.

This case study on firms in the Friuli Venezia Giulia region that took part in the innovative call POR-FESR demonstrates an example of the usability of the present approach. In particular, estimating the average composition of personal networks in a regional innovation system can be used to plan, evaluate, and tune-up some regional innovation policies implemented for specific purposes.

From the application of the proposed method, we observed about 494 overall number of ties activated on a network of 670 “innovative” actors and an average of 2.8 alters per ego. It is hard to say if these can be considered “optimal” sizes for an innovation network in a small to medium region as the magnitude of the network and of the number of alters depend on the specific aim of the collaborations. Our method also allows us to cast light on the average composition of the local firm personal networks. From our results, it seems that the personal network composition is quite heterogeneous (the major proportion of relations are activated between firms and between firms and universities). From the literature, it is known that where the development and conveyance of new knowledge is concerned, the presence of heterogeneous partners is an advantage, “because they bring from the point of view of their partners more innovative inputs and thereby increase the chance of basis innovation” (Bison, 2006, p. 35). From another perspective, we notice a small tendency to collaborate with research centers (and even less with other organizations, and likewise, government agencies and public institutions). If the purpose of the explored regional policy was to enhance these kinds of collaborations, the estimates provided by our method can convey suggestions to policy makers.

One limitation of this study is represented by the presence of only two lists on collaborative relationships; in this case, the assumption of independence between the lists cannot be avoided. If more than two lists are available, it is possible to overcome this problem, and modeling the relation among the lists can be performed. This results in a more reliable estimate of the number of alters.

Future directions will be focused on applying our procedure in a more complex scenario, when multiple lists of alters and eventually covariates (for both ego and alters) are available.

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