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Estimating the Prostitution Population in the Netherlands and Belgium: A Capture-Recapture Application to Online Data

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Abstract

Evidence-based risk-prevention policies for people involved in prostitution require that reliable population estimates are built. This study proposes a methodological framework and novel data source for measuring their population in regions where the internet plays a predominant role in the industry. We derive single registration capture-recapture population estimates using the Zelterman approach. The resulting estimates for the Netherlands and Belgium are lower than previous rough estimates. We find that relative to the overall population of the two countries, the proportion of sex workers are roughly identical despite differing legal environments.

Keywords: Hidden population, Sex worker population, Population size estimation, Capture-recapture, Internet data

Author summary

Anahita Azam is an Economist at Statistics Canada. She received a Master of Economics from KU Leuven, where she conducted this research study. Her research focus is on applying quantitative methods to study the dynamics of prostitution markets in the Netherlands and Belgium. She recently was published in *European Societies* for documenting the effects on prostitution markets of the first Covid-19 induced lockdown. Before that, she received a Bachelor of Commerce from the University of Toronto's Rotman School of Management and worked in the Canadian financial sector.

Recent publication:

Azam, Anahita, Stef Adriaenssens and Jef Hendrickx. 2021. "How Covid-19 Affects Prostitution Markets in the Netherlands and Belgium: Dynamics and Vulnerabilities under a Lockdown." *European Societies* 23(sup1):S478-S94. doi: 10.1080/14616696.2020.1828978.

Jef Hendrickx is a Mathematician and Statistician. His teaching includes Statistics, Econometrics, Quantitative Methods and Research Methodology. His main research interests include the fields of informal and underground economies, and hard to reach populations and behaviour. Methodologically his core interests are in mixed and multilevel method modelling, and those (big) data and techniques that allow for the analysis of sensitive, hidden, informal, and underground activities.

Recent publications:

Adriaenssens, Stef, Jef Hendrickx and Johanna Holm. 2021. "Class Foundations of Sexual Prejudice toward Gay and Lesbian People." *Sexuality Research and Social Policy*. doi: 10.1007/s13178-020-00525-y.

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Stef Adriaenssens is a sociologist teaching courses in *Economic Sociology* and *Policy* at the Faculty of Economics and Business (KU Leuven). His core research interests involve underground, informal, and poorly protected populations and their economic activities. More specifically, he published about topics such as tax evasion, black market work, and activities and groups that are often hardly recognized as work(ers), such as begging and prostitution.

Recent publications:

Adriaenssens, Stef, Tobias Theys, Dieter Verhaest and Nick Deschacht. 2021. "Subsidized Household Services and Informal Employment: The Belgian Service Voucher Policy." *Journal of Social Policy*:1-22. doi: 10.1017/S0047279421000428.

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Introduction

Although sex work and prostitution receive unusually frequent and emotional attention from the public, our understanding of the phenomena remain poorly documented. Aspects that are hotly debated regarding the life of female sex workers (FSW), is the disproportionate risk of being affected by sexually transmitted infections (Sabin et al., 2016) and mental health problems (Beattie, Smilenova, Krishnaratne, & Mazzuca, 2020), the alleged increased risk of human trafficking, exploitation and forced labour (Weitzer, 2015; Zhang & Vincent, 2017), and the parallel risk of being violently victimized (Deering et al., 2014). These and other factors are associated with FSW predominantly working underground, even where selling sex is not illegal. Concurrently, these problems increase the need for targeted interventions that aim to tackle them. For one thing, the use of risk-prevention services among FSW is rather low, while these interventions are feasible and effective (Viswasam et al., 2020).

The size and working conditions of FSW need to be documented so that public health interventions can be effectively targeted and evaluated. This information, among which are reliable estimates of the number of sex workers, is often lacking. In the sex worker population estimations that have been published in the past decades, the capture-recapture methodology is the dominant approach. The general approach is to estimate the sex worker population with at least two samples from the population, with an identification of the sampled cases. The overlap between the samples allows researchers to model the total population. One salient feature of existing high-quality population estimates in the literature is their strong concentration in low- and middle-income regions (Geibel et al., 2007; Karami, Khazaei, Poorolajal, Soltanian, & Sajadipoor, 2017; Karami, Mirzaei, Khazaei, & Bathaei, 2017; Khan, Bhuiya, & Uddin, 2004; Kimani et al., 2013; Kruse et al., 2003; Minh et al., 2004; Mutagoma et al., 2015; Paz-Bailey et al., 2011; Vuylsteke et al., 2010). To our knowledge, only one cutting-edge estimation from a high-income country has been published (McKeganey, Barnard, Leyland, Coote, & Follet, 1992). Two reports also provide very rough and intuitive capture-recapture-based estimates of sex worker populations in Oslo and New York (Brunovskis & Tyldum, 2004; Curtis, Terry, Dank, Dombrowski, & Khan, 2008). This scarcity is not surprising, as the data collection process of the classical capture-recapture design is costly and time-intensive. Precisely in developed economies, we propose a new approach that allows for a much easier data collections strategy with the help of internet data.

This contribution aims to illustrate how these internet-based estimates with an adapted capture-recapture approach are feasible and relevant, with a case study of FSW in two high-income European countries, the Netherlands and Belgium. Aside from adding to the existing knowledge and estimates, this study illustrates the potential of internet data with a single-source estimate. In contrast to the time-consuming and costly direct application of traditional capture-recapture designs, online data sources can be exceptionally practical for estimating prostitution supply. Self-evidently, this approach only works for regions where the internet plays a pivotal role in the organization of prostitution (Cunningham & Kendall, 2011). Since this internet data source results in a single list of counts based on one or more reviews per sex worker, it requires a different design. We make use of the relatively newer single-registration approach in the capture-recapture methodology. Here, the frequency of counts is utilized to estimate the frequency of zero counts. The sum of observed and zero counts provides a total population estimate.

To our knowledge, this is the first FSW estimate with internet data and a single-source capture-recapture approach. Also, this is the first capture-recapture estimation of FSW for these regions, although some estimates have been proposed, mostly based on existing surveys and reports. One publication estimates that the population of female sex workers in 2000 represented 0.6% (Netherlands) and 0.4% (Belgium) of the adult female population (15–49 years) (Vandepitte et al., 2006); another adjusts this to be 0.3% for the Netherlands (2002) and 0.2% for Belgium (2008) (Prüss-Ustün et al., 2013). Most recently, an NGO (Fondation Scelles, 2016, 2019) assessed that 20-30,000 FSW were active in the Netherlands in 2013; for Belgium, an estimated 23,000 FSW were active in 2016, and between 15,000–20,000 in 2019. Recounted as proportions, this results in the highest estimates: 0.53-0.79% (Netherlands), and 0.66-0.91% (Belgium) of the adult female population.

Method

Data

The dataset for this study is crawled from *hookers.nl*, a market leader for prostitution reviews in the Low Countries. The website is open to the public of at least 18 years old. It is based on reviews by clients of their experience with sex workers and contains substantial standardized information related to the experiences. For Belgium and the Netherlands, no other website has this kind of reach and provides client reviews: our one-year sample of 24,246 reviews has been contributed by 5,446 distinct clients and provides reviews about 5,417 unique sex workers. Internet traffic is considerable: for our sample period of a year (February 2019-2020), the estimated average monthly traffic is 1,458,262 visits (analytics website SEMRush.com, February 22, 2021). Data from this website have been utilized in previous studies to calculate premiums for risky behaviour in sex work (Adriaenssens & Hendrickx, 2012), the value-added of prostitution for Belgium (Adriaenssens & Hendrickx, 2019), and the effects of the first Covid-19 lockdown (Azam, Adriaenssens, & Hendrickx, 2021). The features of *hookers.nl* offer many advantages for researchers, including the purposes of the present study.

The anonymity of reviewing customers (with a pseudonym) and the limited interference by moderators allow us to have a fairly clear view of the market. Customers posting a review are guided through standardized forms to provide information about the sex worker and outline their experience, such as the day, time, duration, and price of the visit. Next, customers can list and rate the services received, and enter any free-form comments. All reviews for a particular sex worker are centralized in a thread under her name with some identifying features. Moderators check each review and decide on the features of the sex worker based on the agreement between reviews. They also monitor and remove reviews that are posted in the incorrect discussion board, that are misinformed, or posted for slandering the sex worker. In this study, a review is defined as an entry that provides both a price and the duration of the encounter. Article 3 of the so-called 'DSM Directive' [26] allows for the mining of publicly available data to which one has lawful access, provided it is done for scientific purposes by research organizations. We took several precautions to protect the anonymity of those in the dataset. The clients contributing to the reviews are only known under a pseudonym, whereas sex workers are identifiable by their selected name. Anonymity in the dataset is ensured by entirely removing the clients' pseudonyms after recording the number of unique observations and sex workers' names are replaced by a unique random number.

As illustrated in Figure 1, the cities from which these reviews are generated are spread out across the Netherlands, with a higher density of reviews being written about encounters in The Hague and Amsterdam. In Belgium, the greatest number of reviews are located around Antwerp and the reviews are almost exclusively written in Flanders - the Dutch-speaking northern part of Belgium - and Brussels. Since French is the vehicular language in Wallonia, this region may be better covered by French websites such as *quartier-rouge.com*. Therefore, the reviews on *hookers.nl* and any conclusions drawn from this study only apply to the northern part of Belgium.

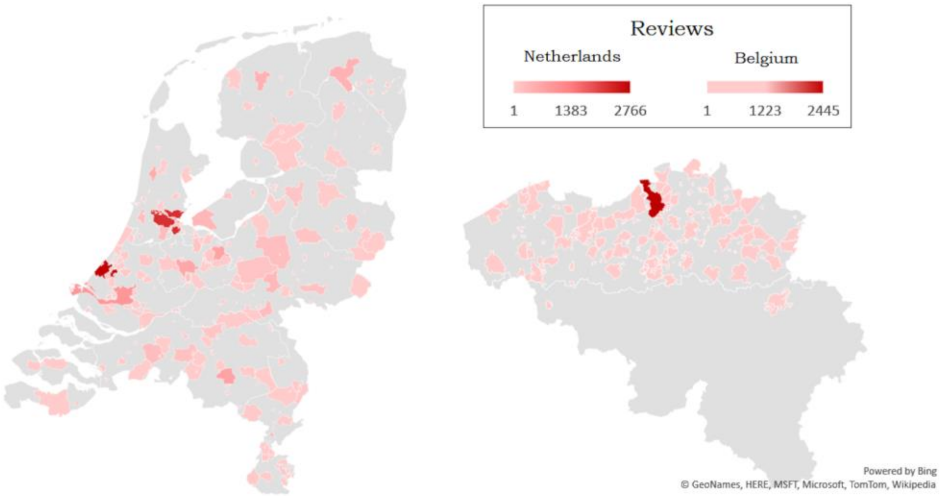

Figure 1. Review density by cities in the Netherlands (left) and Belgium (right)

Table 1 outlines descriptive statistics of relevant variables for this study. The frequencies listed refer to the number of sex workers and the proportions are for specific covariate categories relative to the total 5,417 sex workers in the dataset. The covariates listed are constant over the period since they either refer to intrinsic characteristics of the sex worker or because they are determined based on consensus from all reviews listed for that worker. Specifically, we determine the appearance and hygiene ratings based on the agreement of all ratings provided in the reviews for a particular sex worker. If there is not an agreement between all the reviews, we assign a missing category for that covariate. Although this leads to some data loss, constant categories are necessary for data modelling. Also, since the period is only one year long, this reduces the possibility of significant variation in the clients' reviews, which is indicated by the relatively small missing categories for many covariates. To further encompass heterogeneity, the missing categories are also included in the model.

Table 1. Descriptive statistics of sex worker covariates

	Freq.	*Prop. (%)*
N	5,417	100
Age		
Under 25	1,457	26.9
25-30	1,719	31.73
30-40	1,572	29.02
40-50	489	9.03
50+	129	2.38
missing	51	0.94
Appearance rating		
Above expectations	921	17
As expected	1,208	22.3
Disappointing	357	6.59
missing	2,931	54.11
Body type		
Athletic	853	15.75
Chubby / fat	716	13.22
Normal	1,856	34.26
Slim	1,739	32.1
missing	253	4.67
Country		
Belgium	1,677	30.96
Netherlands	3,750	69.04
Cup size		
A	526	9.71
B	1,481	27.34
C	1,532	28.28
D	868	16.02
DD	219	4.04
E+	248	4.58
missing/other	543	10.02
Ethnicity		
African and Arabic	245	4.52
Asian	399	7.37
East European	1,717	31.7
South American	974	17.98
South European	297	5.48
West European	1,492	27.54
missing/other	297	5.48
Gender		
Transgender	301	5.56
Female	5,080	93.78
missing	36	0.66
Hair colour		
Black	2,168	40.02
Blond	1,492	27.54
Brown	1,034	19.09
Dark Blonde	254	4.69
missing	469	8.66
Height		
1.40 - 1.65	1,536	28.36
1.65 - 1.75	2,888	53.31
1.75 - 1.80	581	10.73
missing/other	412	7.61
Hygiene rating		
Excellent	1,807	33.36
Nice and fresh	1,530	28.24
Could be better	609	11.24
missing	1,471	27.16
Language		
Dutch	1,696	31.31
English	1,704	31.42
French	84	1.55
German	66	1.22
Spanish	170	3.14
missing/other	1,699	31.36
Piercing		
Yes	913	16.85
No	3,061	56.51
missing	1,443	26.64
Region		
North Holland	626	11.56
South Holland	586	10.82
North Brabant	449	8.29
The Hague	447	8.25
Gelderland	255	4.71
Amsterdam	252	4.65
Utrecht	237	4.38
Limburg	191	3.53
Overijssel	170	3.14
Groningen	165	3.05
Friesland	129	2.38
Flevoland	100	1.85
Drenthe	39	0.72
Zeeland	35	0.65
Antwerp	664	12.26
East and West Flanders	277	5.11
Limburg and Wallonia	224	4.14
Brabant and Brussels	207	3.82
Ghent and Ostend	121	2.23
Brussels	96	1.77
missing/other	147	2.71
Segment		
Private reception and escorts	1,931	35.65
Windows	1,461	26.97
Clubs and private houses	1,090	20.12
Erotic massage salons	532	9.82
Specialties	403	7.44
Silicone		
Yes	829	15.3
No	3,653	67.44
missing	935	17.26
Smoker		
Yes	883	16.3
No	2,226	41.83
missing	2,268	41.87
Tattoo		
Yes	2,043	37.71
No	1,768	32.64
missing	1,606	29.65

In terms of the segments, the specialities group encompasses various sub-segments. It includes categories such as BDSM, gangbangs, streetwalkers, and transgender workers that are classified as a separate category. Some of these categories such as streetwalkers and transgender workers are represented in other segments too. Similarly, it is necessary to attribute a few other covariate groups to the other category due to the minimal observations for these categories. These include red and grey hair colours and those that are very tall. Note that our sample includes both sex workers that identify as women, and as transgender women. This is supported by the clear distinction in the market between men having sex with women and men having sex with men (Gallárraga & Sosa-Rubí, 2016).

There are of course various niches in the commercial sex industry, some of which are not represented at all, while others may be underrepresented on *hookers.nl*. However, the setup of the website and its dominant role in the market attracts numerous clients and interactions. This implies that it provides data of sufficient quantity and quality to be representative of the mainstream heterosexual prostitution markets in the Low Countries.

Model specification

The single registration approach in capture-recapture methodology was developed partially to address hidden human populations that are only visible during their involvement with some administrative or criminal justice body. A single list of all sex workers on the website alongside the number of times they are reviewed by a client provides the frequency of observed counts of these events. This frequency can then be modelled to estimate the frequency of zero counts. The sum of observed sex workers and zero-counts provides an estimate for the total population of interest.

Applications of the single-registration capture-recapture approach often assume each individual count to be a realization of the same zero-truncated Poisson distribution. However, significant heterogeneity exists among real human populations reflected in an unequal probability of being observed in the sample. To model this heterogeneity, a common approach is to include characteristics (covariates) that allow for differentiation between subpopulations. The main assumption for a Poisson model with covariate adjustment is that all existing heterogeneity is observed and modelled by an individual's observed covariates. This is reflected by the Poisson parameter (λ) becoming a linear function of the covariates. However, for human populations, it is difficult to justify that all heterogeneity is observed and subsequently modelled. Thus, there is often some level of overdispersion present in the model. Overdispersion results in a downward bias in the population estimate derived from the truncated Poisson regression. Despite this bias, the Poisson approach is useful if treated as a lower bound test for the population estimate (van der Heijden, Cruyff, & Van Houwelingen, 2003). Thus, we employ the Poisson approach to test for the downward bias as described in the Annex.

Alternatively, our main model is based on the Zelterman approach (Böhning, van der Heijden, & Bunge, 2018), which uses only the ones and twos from the zero-truncated count distribution to minimize unobserved heterogeneity bias without completely relying on the covariates. The intuition is that if the Poisson parameter is not impacted by the changes in counts above two, then the core assumption only needs to be satisfied for counts one and two and there is less potential for bias overall. Moreover, the zero-counts – unobserved individuals –that we want to estimate are more similar to those rarely observed relative to those observed many times, justifying placing greater weight on the former (Zelterman, 1988). The inclusion of covariates in this model via a logistic link function further limits potential bias resulting in a more reliable population estimate.

The starting point for modelling the population with the truncated Poisson distribution is finding the probability of not being observed for each individual: $p_0 = exp(-\lambda_i)$, $i = 1, \ldots, N_{obs}$, where λ_i is the Poisson parameter for individual i. The probability of being present in the sample is then: $p_i = 1 - p_0 = 1 - exp(-\lambda_i)$. Since our Poisson parameter is a linear function of an individual's observed covariates, it is modelled as follows in equation (1) by a Poisson regression model:

$$\lambda_i = exp\,(\beta\,\mathbb{x}_i)\,, \quad (1)$$

where β is a vector of covariate effects and $\mathbb{x}_i$ is a vector of covariates that are categorically defined for all categories listed in Table 1.

As the Zelterman estimator only utilizes the first and second counts, an estimation for the parameter λ is $2\frac{f_2}{f_1}$ where f_1 and f_2 are the observed frequencies for counts one and two. Since we know $p_0 = exp(-\lambda)$ from the Poisson distribution, the estimated probability of not being observed in the Zelterman case is: $p_0 = exp\left(-2\frac{f_2}{f_1}\right)$. The previous formulas hold if there is no heterogeneity. To incorporate heterogeneity in the cases with counts one and two (with probability $1 - p_i$ and p_i respectively), we use the logistic regression to model this binary probability as $p_i = \frac{exp\,(\beta\,\mathbb{x}_i)}{(1 + exp\,(\beta\,\mathbb{x}_i))}$.

The parameter λ_i is subsequently estimated as outlined in equation (2) with p_i as a function of $\beta\,\mathbb{x}_i$:

$$\hat{\lambda}_i = 2\,\frac{\hat{p}_i\,(\beta\,\mathbb{x}_i)}{(1 - \hat{p}_i\,(\beta\,\mathbb{x}_i))} = 2\,exp\,(\beta\,\mathbb{x}_i)\,. \quad (2)$$

Then, using the Horvitz-Thompson estimator, the population estimates are derived as follows for the Zelterman model in equation (3) (Böhning & van der Heijden, 2009):

$$\hat{N}_Z = \sum_{i=1}^{N} \frac{I_i}{1 - exp\,(-2\,exp\,(\hat{\beta}\,\mathbb{x}_i))}\,, \quad (3)$$

where $I_i = 1$ if the individual is present in the sample and $I_i = 0$ otherwise. The $\hat{\beta}$ refers to the estimated coefficient of the logistic regression. The corresponding variance for the Zelterman point estimate and the base code from which we derive our models are provided by Böhning and Van der Heijden (2009).

Finally, we utilize another method to further reduce bias: divide the population into homogenous subgroups, separately estimate the population in these subgroups and combine them to get the overall population estimate. This procedure also results in a greater overall estimate, which is likely closer to the true population parameter (Sekar & Deming, 2004). A sufficiently large sample size within each covariate category is necessary for convergence in the segmented approach, which is only available to us between the two *country* distinctions - the Netherlands and Belgium. Thus, we use the two country covariates to test whether the sum of the segmented estimates is greater than the aggregated estimate, and if so, use the segmented analysis to further reduce the downward bias due to unobserved heterogeneity.

Results

This study employs the Zelterman approach with covariate adjustment to derive a range of population estimates provided in Table 2. The *null* model does not incorporate any covariates. The next section in the table lists the estimates yielded from various single covariate models to test the impact each covariate has on the population estimate. Then, a *full* model which incorporates all covariates is listed, followed by a segmented estimation by country. Comparisons between the models are done via a range of test statistics: log-likelihood (LL), Akaike information criterion (AIC), and log-likelihood ratio chi-squared (LR^2) for overall significance. We finally present the population estimates ($\hat{N}$ and CI).

Table 2. Prostitution population estimates from the Zelterman approach

Models	*LL*	*AIC*	*df*	LR^2	$\hat{N}$	*CI*
Null	-1694	3390	1	0	7652	(7323-7982)
Single covariate						
Piercing	-1694	3394	3	0.03	7651	(7321-7981)
Gender	-1694	3393	3	0.34	7650	(7320-7980)
Appearance	-1693	3395	4	1.05	7651	(7321-7980)
Hair colour	-1693	3397	5	0.9	7657	(7326-7989)
Cup size	-1693	3401	7	0.97	7662	(7330-7994)
Country	-1693	3390	2	1.62	7671	(7337-8005)
Silicone	-1693	3392	3	1.89	7658	(7327-7989)
Smoker	-1693	3391	3	2.22	7658	(7327-7989)
Tattoo	-1693	3391	3	2.68	7660	(7329-7991)
Age	-1692	3395	6	4.24	7669	(7336-8001)
Body Type	-1690	3390	5	7.41	7661	(7329-7991)
Height	-1689	3386	4	10.08**	7676	(7342-8010)
Language	-1689	3389	6	10.38*	7686	(7349-8023)
Segment	-1689	3388	5	10.08**	7683	(7346-8021)
Ethnicity	-1688	3390	7	11.55*	7686	(7349-8023)
Hygiene	-1683	3373	4	22.37***	7711	(7368-8054)
Region	-1679	3401	21	29.18*	7771	(7406-8135)
Full	-1637	3423	75	114**	8098	(7654-8541)
Netherlands	-1166	2464	66	98.72**	5499	(5156-5841)
Belgium †	-443	989	50	69.83**	3046	(2496-3596)

* $p < 0.10$, ** $p < 0.05$,*** $p < 0.01$

† Covariates appearance, gender, silicone, tattoo were excluded due to non-significance.

The best model fit and the highest population estimates are derived from the full model with all covariates included, which is in line with the expectations from Van Der Heijden et al (2003). Moreover, the covariates with a higher number of categories tend to have the greatest impact on the population estimate.

The segmented analysis by country was expected to account for some bias and result in a higher population estimate when the segmented estimates are summed, relative to the aggregate models (Sekar & Deming, 2004). This is indeed reflected in the results. Thus, we select the sum of the full models for each country to derive a population estimate of 8,545 for mainstream prostitution markets in the Netherlands and the northern half of Belgium.

Discussion

In discussions about prostitution policy, the lack of reliable knowledge often precludes evidence-based policies. This problem lies partially in the difficulty of acquiring reliable and valid data about this hidden population. This study proposes a new estimate of sex workers in mainstream prostitution in the Netherlands and Belgium, based on a novel online data source and cutting-edge capture-recapture techniques that fit the single-list data source. To do so, we first inventory existing population estimates for these regions and conduct a thorough analysis of appropriate methodologies available for the task.

We adopt a cost- and time-efficient adaptation of the capture-recapture methodology using a logistic regression as per the Zelterman approach to estimate the population supply. For the Netherlands and the northern part of Belgium (Brussels and Flanders, that is), we find that an estimated 8,545 sex workers were active in mainstream prostitution markets between February 2019-2020. When broken down by country, an estimate of the supply in the Netherlands is 5,499, and 3,046 for Brussels and Flanders.

This study makes an important methodological contribution. We test the role of covariates in determining population size by introducing observed heterogeneity into the model. Covariates with a greater number of categories tend to reduce overdispersion in traditional Poisson models, but in the Zelterman case, weaker covariates with few observations per group could increase variance and lower the predictive power of the model without providing any useful insights about the population. Thus, a careful analysis should be conducted to identify which relevant covariates can best model heterogeneity in the population.

The estimate we derived is approximately 0.15% for the Netherlands and 0.18% for the northern part of Belgium of the adult female population (15-49 years old)[1]. This is interesting from a policy perspective as, despite the differences in the legal approaches taken by the two national governments, the estimated size of mainstream prostitution markets is approximately the same. In comparison with the previously discussed estimates from various sources – 0.3% to 0.8% of the adult female population for The Netherlands and 0.2% to 0.9% for Belgium (Fondation Scelles, 2016, 2019; Prüss-Ustün et al., 2013; Vandepitte et al., 2006) - our estimates are considerably lower.

There may be several reasons why previous estimates are much higher. First, we should repeat who we aim to measure. We only attempt to cover explicit commercial physical sexual services covered under the definition of prostitution. Some phenomena that are in a grey area between personal sexual practices

[1] Sources are https://opendata.cbs.nl/statline/#/CBS/en/dataset/37325eng/table?ts=1610654980930 for the Netherlands and https://bestat.statbel.fgov.be/bestat/crosstable.xhtml?datasource=65ee413b-3859-4c6f-a847-09b631766fa7 for Belgium.

and selling physical sex such as compensated dating, for instance in so-called 'sugar daddy' relationships, are not included in the estimation. Second, our estimates only capture the visible segments and types of prostitution markets (such as private reception, escorts, window, clubs, massage salons, or streetwalkers). This mostly excludes strictly illegal (for example underage or trafficked) and niche markets. Also, we argue that the estimation only covers those people that explicitly work as commercial sex workers. These hidden segments may partially make up for the gap between our estimates and the previous ones.

Thirdly, there are undoubtedly clients that do not write reviews after their encounters. This absence may in theory lead to an underestimation, but that is unlikely as it requires that non-reviewed encounters cover a prostitution market that is entirely absent in our sample, which is also unlikely. Fourthly and most importantly, given the lack of consistent methodological soundness in the cited estimates, it is likely that that the latter are exaggerated. This complaint has been formulated before, particularly about the NGO-provided estimates (Adair & Nezhyvenko, 2016; Cusick, Kinnell, Brooks-Gordon, & Campbell, 2009). That being said, a combination of these factors may lead to a moderate downward bias in our estimates. Concurrently it seems likely that the existing estimates are upward biased.

In conclusion, the methodological analysis of this study provides motivation for utilizing the cost- and time-efficient procedures outlined above to obtain measures of hidden populations for a pragmatic and empirical approach to policy debates that have far-reaching implications.

Declarations

Funding

The authors received no specific funding for this work.

Conflicts of interest

The authors have no conflict of interest to declare for this study.

Ethical approval

As the study was based on existing internet data, the appropriate ethics committee of the university formally acknowledged that no ethics approval is required for the research.

Data availability

The data will be published on the DANS website (https://dans.knaw.nl). The files have been anonymized so that it is impossible to identify the persons included in the dataset. The provided dataset allows for a full replication of the estimations as per instructions in the author's note.

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ANNEX. Truncated Poisson model with covariate adjustment

The main limitation of the Poisson model with covariate adjustment is the assumption that all existing heterogeneity is observed and modelled by the observed covariates. As this is difficult to justify for human populations, there is often overdispersion present in the model resulting in an underestimation of the population size. We test the truncated Poisson model on our dataset to note this overdispersion and subsequently test if the Zelterman model can correct for some unobserved heterogeneity.

Using the Horvitz-Thompson estimator, the population estimates are derived as follows for the truncated Poisson in equation (A1)

$$\hat{N}_P = \sum_{i=1}^{N} \frac{I_i}{1 - exp\,(-exp\,(\hat{\beta}\,\mathbb{x}_i))}, \quad \text{(A1)}$$

where $I_i = 1$ if the individual is present in the sample and $I_i = 0$ otherwise. The $\hat{\beta}$ refers to the estimated coefficient of the Poisson. The corresponding variance for the truncated Poisson point estimate is defined by Van der Heijden et al (2003).

The resulting Poisson estimates are documented in Table A2. In addition to the test statistics derived for the Zelterman models, a Lagrange Multiplier (LM) test statistic for overdispersion is derived for each Poisson model.

The Poisson approach yields a total population estimate of 5,599 for the Netherlands and the northern part of Belgium. For the Netherlands, the population estimate is 3,873, whereas it is 1,726 for Brussels and Flanders.

Covariates with a greater number of categories tend to reduce overdispersion in the truncated Poisson model, have a better model fit, and provide a larger population point estimate. For the Poisson case, it is thus advisable to include all available covariates as this provides an estimate with the lowest level of overdispersion. Similar to the Zelterman model, the segmented analysis by country also accounts for some bias and provides a higher estimate when the segmented models are summed relative to the aggregate models.

It is important to note the striking difference between the Poisson and Zelterman point estimates. Insights for this difference can be derived from the LM test statistics, indicating a clear presence of overdispersion in the truncated Poisson model. As discussed, this violation of a core assumption for the model implies that the Poisson point estimate can only be interpreted as a lower bound for the population. Subsequently, other models that better account for unobserved heterogeneity, such as the Zelterman approach, should be utilized for an accurate picture of the population (van der Heijden, Bustami, et al., 2003).

Table A1. Prostitution population estimates from the Poisson approach

Models	*LL*	*AIC*	*df*	LR^2	X^2_{LM}	$\widehat{N}$	*CI*
Null	-19206	38416	1	3.36	83315***	5483	(5466-5499)
Single covariate							
Tattoo	-19204	38413	3	9.43**	83264***	5483	(5467-5499)
Country	-19197	38398	2	23.15***	83147*	5483	(5466-5499)
Piercing	-19189	38384	3	38.83***	83010***	5484	(5467-5500)
Silicone	-19189	38384	3	39.18**	83010***	5484	(5467-5500)
Gender	-19171	38349	3	74.36***	82566***	5484	(5467-5500)
Age	-19157	38327	6	102***	82419***	5485	(5469-5502)
Smoker	-19156	38319	3	104***	82447*	5486	(5487-5502)
Height	-19137	38282	4	143***	82056***	5486	(5469-5503)
Cup size	-19132	38277	7	154***	82019***	5487	(5470-5504)
Appearance	-19131	38271	4	154***	82073***	5488	(5470-5505)
Segment	-19103	38216	5	212***	81620***	5490	(5472-5507)
Language	-19101	38215	6	214***	81647***	5491	(5473-5508)
Hair colour	-19097	38203	5	223***	81393***	5489	(5471-5506)
Ethnicity	-19052	38118	7	313***	80615***	5491	(5474-5509)
Hygiene	-19011	38031	4	394***	80208***	5497	(5478-5515)
Body type	-18953	37917	5	510***	78943***	5497	(5479-5515)
Region	-18652	37347	21	1112***	73889***	5517	(5496-5538)
Full	-17771	35691	75	2876***	58880***	5588	(5559-5618)
Netherlands	-12134	24400	66	2158***	41407***	3873	(3846-3899)
Belgium	-5506	11130	59	959***	15565*	1726	(1710-1742)

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$