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Cross-validation of four different survey methods used to estimate illicit cigarette consumption in Brazil

André Salem Szklo ,[1] Roberto Magno Iglesias,[2] Michal Stoklosa ,[3] Valeska Carvalho Figueiredo,[4] Kevin Welding ,[5] Paulo Roberto Borges de Souza Junior,[6] Alessandra Trindade Machado,[7] Luis Felipe Leite Martins,[1] Hannah Nascimento,[4] Jeffrey Drope[8]

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For numbered affiliations see end of article.

Correspondence to
André Salem Szklo, Population Research Unit, Instituto Nacional de Câncer, Rio de Janeiro 20230-130, Brazil; andreszk@hotmail.com

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ABSTRACT

Objective To cross-validate estimates of the size of the illicit cigarette trade based on the results of four different survey methods.

Methods In 2018/2019, four non-industry-funded, large-scale studies were conducted in selected Brazilian cities: packs discarded in household garbage/PDG (1 city), packs littered in the streets/PLS (5 cities), a phone survey of tobacco users' purchase behaviors/VIGITEL (5 cities), and a face-to-face household survey of tobacco users' purchase behaviors/FTF-household (2 cities). The proportions of illicit cigarettes consumed were based on the price paid by smokers in their last purchase (VIGITEL or FTF-household) and/or direct observation of brand names and health warnings (PDG, PLS or FTF-household).

Results Based on PLS, the share of packs that avoided taxation ranged from 30.4% (95% CI 25.6% to 35.7%) in Rio de Janeiro to 70.1% (95% CI 64.6% to 75.0%) in Campo Grande; and PDG conducted in Rio de Janeiro found an even lower proportion point estimate of illicit cigarette use (26.8%, 95% CI 25.1% to 28.6%). In FTF-household, the share of illicit cigarette consumption based on the self-reported price ranged from 29.1% (95% CI 22.4% to 35.7%) in Rio de Janeiro to 37.5% (95% CI 31.2% to 43.7%) in São Paulo, while estimates based on pack observation ranged from 29.9% (95% CI 23.3% to 36.5%) in Rio de Janeiro to 40.7% (95% CI 34.3% to 47.0%) in São Paulo. For all cities, VIGITEL presented the lowest levels of illicit consumption, and most illicit brands were produced in Paraguay.

Conclusions Small differences in the estimated levels of illicit trade across methods were found, except for the phone survey. The cross-validation of estimates from independent studies is important to help effectively implement tobacco excise tax policy in Brazil and other low-income and middle-income countries.

INTRODUCTION

Brazil has experienced a large decline in smoking prevalence due to a complete package of tobacco control policies implemented in the last three decades.[1–3] Increases in tobacco excise taxes have been part of this package. Real cigarette price increases, particularly after the new cigarette excise tax rates went into effect in 2012, likely acted synergistically with other tobacco control policies to reduce smoking prevalence.[4 5]

However, because Brazil's neighbouring country Paraguay has lower taxes and prices, and part of its production is directed illegally towards the Brazilian market, a certain fraction of smokers likely migrated to cheaper illicit cigarettes to save money, thus increasing the proportion of illicit cigarette use among individuals who did not stop smoking.[6 7]

It is important to understand the expansion of the illicit market, as it may undermine efforts to further reduce smoking prevalence, mostly among lower income smokers.[8] Moreover, in many low-income and middle-income countries, the tobacco industry is the only source of estimates of the size of the illicit cigarette market, and it typically overestimates it to claim that evidence-based tobacco control policies result in an increased illicit market.[9–11]

In Brazil, cigarette purchase prices obtained from two nationwide Face-to-Face Household (FTF) surveys conducted in 2008 and 2013 by the Brazilian government were used to estimate the size of the illicit market (16.9% vs 32.3%).[6] More recently, available information on official legal sales provided by the Secretariat of Federal Revenues,[12] and on cigarette consumption from a phone survey conducted annually since 2006,[13] have been used to estimate trends in illicit cigarette use in Brazil (from 28.6% in 2012 to 42.8% in 2016).[7] Thus, Brazil's sustained and integrated nationwide monitoring system, largely in accordance within Article 20 of the WHO Framework Convention on Tobacco Control (FCTC) (on research, surveillance and exchange of information),[14] has not only allowed it to track the tobacco epidemic, but also to assess the effectiveness of the tax policy implemented in Brazil.

Although there is no single agreed method for best estimating illicit trade, because different approaches might be necessary to meet a variety of market conditions, regulatory environments and/or budget restrictions, there are potential issues with the method used in the latest estimates of trends in illicit cigarette use in Brazil.[7] In particular, the accuracy of the gap method used in those estimates might be reduced if the proportion of under-reported use has changed over time. Fortunately, there are several other recognised methodologies to assess the size of the illicit tobacco trade and to better understand its characteristics.[8 15–17] In 2018/2019, four different studies were conducted in Brazilian state capitals, each generating estimates of the size of the illicit cigarette market: (1) systematic inspection of cigarette packs discarded in household garbage/PDG; (2) systematic inspection of cigarette packs littered in the streets/PLS; (3) a phone-survey of tobacco users' purchase behaviours/VIGITEL

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and (4) a FTF survey of tobacco users' purchase behaviours/FTF-household. These approaches make it possible to achieve the major aim of the present study: to cross-validate estimates from different methods to understand the possible methodological limitations of single methods which are important for the implementation of tobacco tax policy in Brazil and in other low-income and middle-income countries. To our knowledge, our study represents the first-ever detailed comparison of more than two methods[17] to estimate the size of illicit cigarette trade based on evidence from large-scale studies.

METHODS

This study used data from four different methods, as follows:

The PDG survey

The PDG study was conducted from January to December of 2018 in Rio de Janeiro city,[18] in partnership with COMLURB (*Companhia Municipal de Limpeza Urbana*), the firm that routinely collects household garbage in all neighbourhoods of the city (around 145 000 tons/month).

The applied research unit of COMLURB collected an additional 24 tons/year of household garbage for its regular research on recycling behaviour. The sample size for each neighbourhood was proportional to the total average monthly amount of household garbage collected in each of the 156 neighbourhoods of the city.[19] Although household garbage was not systematically collected, the COMLURB allocated trucks to cover the most populous residential streets within each neighbourhood. The trucks followed a predetermined route and moved block by block until the defined sample size of household garbage was achieved. This sampling strategy also made the sample proportional to both the number of people and the expected number of smokers living in each neighbourhood (see online supplemental figure 1).[19–21]

The COMLRUB employees were instructed to separate all PDG by neighbourhoods at no additional cost to the firm. Then, tobacco control experts from the Brazilian National Cancer Institute coded cigarette packs based on a structured set of questions related to packs' characteristics, such as brand name, presence of official tax stamp, and health warnings. With Brazil's tracking and tracing system in place since 2007, with direct monitoring of manufacturing facilities to avoid tax evasion, it should be theoretically straightforward to unequivocally determine whether the proper Brazilian tax was paid for a given cigarette pack. However, the system's unique pack identifiers are part of Brazil's excise tax stamp, which is torn and destroyed when a smoker opens their pack. Therefore, information about the pack's unique identifying number or about the presence of tax stamp itself could not be used for illicit cigarette pack identification. So, we used the direct observation of brand names and health warnings approved on the Brazilian market by the Health Regulatory Agency (ANVISA, *Agência Nacional de Vigilância Sanitária*)[22 23] to distinguish legal and illicit packs.

Neighbourhoods' specific sampling weights based on the amount of household garbage collected were used to estimate the overall share of illicit packs and respective 95% CI in Rio de Janeiro.

The PLS survey

The PLS survey, conducted between January and April 2019, was aimed at understanding the proportion of illicit cigarettes consumed in five Brazilian state capitals (Rio de Janeiro, São Paulo, Campo Grande, Belo Horizonte and João Pessoa). The PLS was a weighted probabilistic sample survey with one selection stage (n=70 census tracts per city) based on the probability of smoking (figure 1; see detailed sampling strategy in online supplemental appendix 1).[20 21]

Data collectors were instructed to pick up all packs littered in selected census tracts. The same criteria used for the PDG survey to distinguish between legal and illicit packs was applied to the PLS survey.[22 23]

We used census tracts' specific sampling weights to estimate the share of illicit packs and 95% CI in each city.

The FTF-household survey

The FTF-household survey was also conducted in Rio de Janeiro and São Paulo between January and April 2019. We used information on smoking prevalence[20] and gender–age distribution for census tracts selected for the PLS survey (see online supplemental appendix 1),[21] to predict the gender–age distribution of the smoking population and determine the quota of smokers to be interviewed (n=11 per census tract).

To estimate the proportion of individuals using illicit cigarettes (FTF-householdpriceindiv), we first calculated the price paid per pack in each smoker's last purchase by combining two questions: 'The last time you bought manufactured cigarettes for yourself, how many cigarettes did you buy?' and 'In total, how much money did you pay for this purchase?'. Illicit consumption was based on individuals who reported having paid less than the minimum price established by law,[5] that is, 5.0 Rreais per pack. Individuals who reported having bought single sticks (around 5%) were excluded from the analysis because it was impossible to define a valid criterion for the cut-off price point. In general, single stick vendors charge high retail margins, therefore, the price of a single cigarette, even an illicit one, is usually much higher than the minimum established price.

Smokers who reported having bought at least one cigarette pack in their last purchase were asked to physically show the last pack they had bought so that interviewers could take pictures of it (81.7% in São Paulo, 91.7% in Rio de Janeiro). In order to

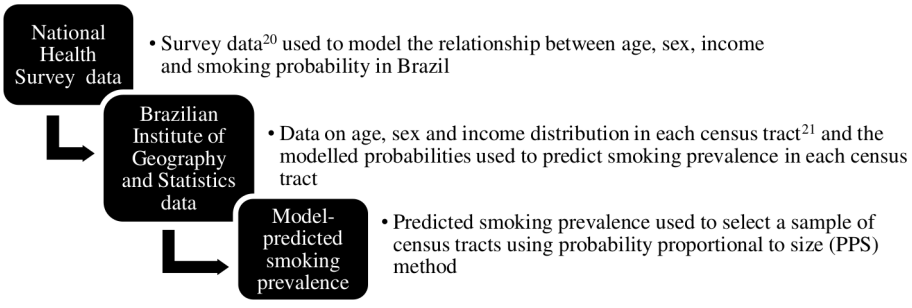

Figure 1 Sampling of census tracts using predicted smoking prevalence and PPS.

strengthen the comparisons between the FTF-household survey and the PLS/PDG surveys, we applied the same criteria to estimate the proportion of individuals using illicit cigarettes (FTF-householdbrandindiv). Finally, the proportions of illicit yearly cigarette consumption in Rio de Janeiro and São Paulo (FTF-householdbrandcigarette and FTF-householdpricecigarette) were estimated by also using information on consumption intensity from the FTF-household survey, which was based on two questions: 'Do you currently smoke?'; and 'On average, how many cigarettes do you smoke per day?'.

To establish a boundary between legal brands sold with discount and legal brands that did not pay taxes ('domestic tax evasion'), we defined a 'threshold price' (TP) based on the minimum legal price multiplied by the relative difference between the average price per pack paid by smokers of legal cigarettes who bought more than one pack in their last purchase and the average price paid by those who bought only one pack (−6%). Thus, legal brands authorised by ANVISA[22] with the presence of Brazilian health warnings[23] that were sold below the TP, that is, below 4.7 Reais, were also coded as illicit (FTF-householdpricebrandcigarette and FTF-householdpricebrandindiv).

Information on the country of origin was collected (for PLS and PDG surveys also), which allowed us to estimate the proportion of illicit cigarette consumption from Paraguay, a known route of illicit trade.[24]

Self-reported information on the cigarette brand name in each smoker's last purchase was also available, thus allowing us to perform a sensitivity analysis including smokers who did not show the pack of their last purchase. For these smokers, illicit consumption was based on individuals who (1) reported having paid less than TP for a cigarette brand authorised by the ANVISA or (2) reported having bought an illicit cigarette brand.

For all FTF-household estimates, we used sampling weights based first on the estimated number of smokers in selected census tract, and then on census tracts' specific sampling weights, to estimate the share of individuals and packs that avoided taxation and 95% CI in each city.

The VIGITEL phone survey

VIGITEL (*Vigilância de Fatores de Risco e Proteção para Doenças Crônicas por Inquérito Telefônico*) is a telephone survey conducted annually since 2006, between January and December, among adults with landlines living in all 27 Brazilian state capitals.[13] In the sampling process, VIGITEL uses landline telephone registry to randomly select households[13 25]; then, following a second sampling stage, one adult per household is selected. The poststratification weighting to compensate low coverage is used to minimise potential selection bias, particularly because smokers without landlines are more likely to be from lower socioeconomic groups. Detailed methods have been published elsewhere.[13]

In 2018, the same questions on manufactured cigarette consumption, and on the amount and price paid by smokers in their last purchase, used for the FTF-household survey allowed us to estimate both the proportion of individuals using illicit cigarettes (VIGITEL-indiv) and the proportion of illicit cigarette consumption (VIGITEL-cigarette) among the residents of the five Brazilian state capitals selected for the PLS survey. Unfortunately, no brand information was available.

STATA V.15.0 was used to account for the complex sample weights.[26]

Table 1 Proportion of individuals using illicit cigarettes by selected Brazilian state capital and survey methods, 2018–2019

	FTF-household			
City/ilicit	FTF-householdpriceindiv*†‡	FTF-householdbrandindiv§¶**‡	FTF-householdpricebrandindiv§¶††**‡	VIGITELindiv‡‡§§¶¶
Rio de Janeiro				
% of individuals	27.7 (22.6–34.0)	29.1 (23.5–35.5)	31.2 (25.4–37.6)	8.2 (4.3–15.1)
São Paulo				
% of individuals	32.1 (27.3–37.3)	36.4 (30.8–42.3)	37.5 (32.2–43.2)	18.8 (10.9–30.5)
Campo Grande				
% of individuals	n.avail.	n.avail	n.avail	26.4 (16.4–39.1)
Belo Horizonte				
% of individuals	n.avail.	n.avail	n.avail	14.9 (8.6–24.6)
João Pessoa				
% of individuais	n.avail.	n.avail	n.avail	20.8 (9.9–38.2)

*Individuals who reported having bought at least one cigarette pack in their last purchase and who informed having paid less than minimum price established by law, that is, less than 5.0 Brazilian Reais per pack.
†We excluded smokers who did not provide information on self-reported price per pack (0.8% in Sao Paulo and 0.0% in Rio de Janeiro).
‡P>0.150 in Pearson χ^2 tests for comparison of two proportions with sampling weight across FTF-household methods for Rio de Janeiro or São Paulo.
§91.7% and 81.7% of smokers interviewed in Rio de Janeiro and Sao Paulo, respectively, physically showed the pack of their last purchase at the moment of the interview and were included in the analysis.
¶We used the official list of legal brands authorised by the Brazilian Health Regulatory Agency and the direct observation of the presence/type of Brazilian health warnings to establish a boundary between both legal and illegal markets.
**The overall number of packs collected/showed was, as follows: for the FTF-householdbrand, Rio de Janeiro (680), and São Paulo (598).
††Legal brands authorised by the ANVISA with the presence of Brazilian health warnings, but sold below 4.7 Brazilian Reais were also coded as illegal.
‡‡The overall number of smokers who provided information on the amount and price paid in their last purchase was, as follows: Rio de Janeiro (154), São Paulo (188), Campo Grande (119), Belo Horizonte (165) and João Pessoa (80).
§§We excluded smokers who did not provide information on self-reported price per pack (18.9% in Rio de Janeiro, 14.7% in São Paulo, 26.9% in Campo Grande, 6.4% in Belo Horizonte and 7.8% in João Pessoa).
¶¶P<0.050 in Pearson χ^2 tests for comparison of two proportions with sampling weight (VIGITEL vs any other survey method).
FTF, Face-to-Face Household; n.avail., not available.

Table 2 Proportion of illicit cigarette consumption by selected Brazilian state capital and survey methods, 2018–2019

City/Illicit	PLS*†	FTF-household			PDG*†	VIGITEL-cigarette‡‡§§¶¶
		FTF-householdpricecigarette‡§†	FTF-householdbrandcigarette¶***†	FTF-householdpricebrandcigarette¶**††*†		
Rio de Janeiro						
% of cigarettes	30.4 (25.6–35.7)	27.8 (21.6–34.1)	29.9 (23.3–36.5)	31.7 (25.0–38.4)	26.8 (25.1–28.6)	9.3 (3.7–14.9)
São Paulo						
% of cigarettes	46.3 (36.4–56.6)	36.5 (30.9–42.1)	40.7 (34.3–47.0)	42.0 (36.0–48.0)	n.a.	20.1 (6.3–33.9)
Campo Grande						
% of cigarettes	70.1 (64.6–75.0)	n.avail	n.avail	n.avail	n.a.	27.9 (12.7–43.1)
Belo Horizonte						
% of cigarettes	66.3 (61.8–70.6)	n.avail	n.avail	n.avail	n.a.	19.1 (7.3–30.8)
João Pessoa						
% of cigarettes	55.3 (50.4–60.2)	n.avail	n.avail	n.avail	n.a.	26.2 (8.3–44.1)

*The overall number of packs collected/showed was, as follows: for the PLS, Rio de Janeiro (1,251), São Paulo (1760), Campo Grande (3907), Belo Horizonte (784), and João Pessoa (1051); for the FTF-householdbrand, Rio de Janeiro (680), and São Paulo (598); for the PDG, Rio de Janeiro (2705).
†P>0.136 in Pearson χ^2 test for comparison of two proportions with sampling weight across PLS, FTF-household and PDG for Rio de Janeiro or São Paulo (except for São Paulo: PLS vs FTF-householdpricecigarette, p=0.092).
‡Individuals who reported having bought at least one cigarette pack in their last purchase and who informed having paid less than minimum price established by law, that is, less than 5.0 Brazilian Reais per pack.
§We excluded smokers who did not provide information on self-reported price per pack (0.8% in Sao Paulo and 0.0% in Rio de Janeiro).
¶91.7% and 81.7% of smokers interviewed in Rio de Janeiro and Sao Paulo, respectively, physically showed the pack of their last purchase at the moment of the interview and were included in the analysis.
**We used the official list of legal brands authorised by the Brazilian Health Regulatory Agency and the direct observation of the presence/type of Brazilian health warnings to establish a boundary between both legal and illegal markets.
††Legal brands authorised by the ANVISA with the presence of Brazilian health warnings, but sold below 4.7 Brazilian Reais were also coded as illegal.
‡‡The overall number of smokers who provided information on the amount and price paid in their last purchase was, as follows: Rio de Janeiro (154), São Paulo (188), Campo Grande (119), Belo Horizonte (165), and João Pessoa (80).
§§We excluded smokers who did not provide information on self-reported price per pack (18.9% in Rio de Janeiro, 14.7% in São Paulo, 26.9% in Campo Grande, 6.4% in Belo Horizonte and 7.8% in João Pessoa).
¶¶P<0.050 in Pearsonχ^2 tests for comparison of two proportions with sampling weight (VIGITEL vs any other survey method, except for São Paulo/FTF-householdpricecigarette (p=0.061)).
FTF, Face-to-Face Household; n.a., not applicable; n.avail., not available; PDG, packs discarded in household garbage; PLS, packs littered in the streets.

RESULTS

Tables 1 and 2 present estimated proportions of illicit cigarette users and consumption, respectively, from different survey methods by city (Rio de Janeiro, 4 survey methods; São Paulo, 3 survey methods; and Campo Grande, João Pessoa and Belo Horizonte, 2 survey methods). There was a substantial difference in illicit trade levels among the cities, with Campo Grande having the highest and Rio de Janeiro having the lowest proportion point estimates of both individuals using illicit cigarettes (eg, 26.4% vs 8.2%) and illicit cigarette consumption (eg, 70.1% vs 30.4%). In addition, for each city, the proportion point estimate of individuals using illicit cigarettes was lower than the proportion of illicit cigarettes consumed.

There were also differences in estimated illicit trade levels among the methods, with the VIGITEL survey finding the lowest levels of illicit consumption. Specifically, we found that proportion point estimates for individuals using illicit cigarettes ranged from 8.2% (VIGITEL-indiv) to 31.2% (FTF-householdpricebrandindiv) in Rio de Janeiro and from 18.8% (VIGITEL-indiv) to 37.5% (FTF-householdpricebrandindiv) in São Paulo. We also found that point estimates of illicit yearly cigarette consumption ranged from 9.3% (VIGITEL-cigarettes) to 31.7% (FTF-householdpricebrandcigarette) in Rio de Janeiro, and from 20.1% (VIGITEL-cigarettes) to 46.3% (PLS) in São Paulo. Moreover, although CIs overlapped, PDG point estimate of illicit cigarette consumption was lower than that found for PLS survey in Rio de Janeiro, (26.8% vs 30.4%).

When we also considered legal brands authorised by the ANVISA with the presence of Brazilian health warnings, but sold below 4.7 Brazilian Reais, point estimates of illicit cigarette consumption for Rio de Janeiro (31.7%) and São Paulo (42.0%) were, respectively, only 6.0% and 3.2% higher than estimates based on 'direct observation of the pack' (table 3), thus suggesting that 'domestic tax evasion' was not a common illicit practice for Rio de Janeiro and Sao Paulo (see also online supplemental figure 2). Moreover, table 4 shows that the vast majority of illicit brands were produced in Paraguay.

Our sensitivity analysis (table 3) found that, when we combined estimates of illicit cigarette consumption from all smokers, final results were quite similar to the ones based only on smokers who showed the pack of last purchase (Rio de Janeiro, 30.3% vs 31.7%; São Paulo, 40.5% vs 42.0%).

DISCUSSION

Although Brazil was one of the most successful countries at reducing tobacco prevalence in recent years,[13 20] overall, the high rates of illicit cigarette consumption found in the selected Brazilian state capitals highlight the fact that the effectiveness of the tax policy implemented after 2011 in Brazil may have been undermined. The high levels of illicit trade likely result from weak law enforcement, little commitment to controlling the supply chain, a culture of purchasing illicit products, and a lack of international cooperation with Paraguay, the overwhelming main source of illicit cigarettes.[8 27–29]

Moreover, we found some differences in the estimated levels of illicit trade based on different recognised methodologies. Those differences reflect the possible methodological strengths and weaknesses of each method. First, we found differences in estimates from the two methods that used discarded pack observations: PDG and PLS. Specifically, in Rio de Janeiro, the PDG survey showed a lower point estimate of tax evasion than the PLS survey. While this source of direct evidence is potentially very informative, it is important to investigate the possibility of selection bias.[30 31] Lower-income smokers and/or heavy smokers, particularly those living in low-and-middle-income countries, who typically smoke more illicit cigarettes,[6] may be more likely to litter in the streets than their counterparts.[17 32] Heavy smokers may be also more likely to smoke inside their residences and, therefore, to discard packs in the household garbage, because they smoke more cigarettes per day and are more sedentary than light smokers.[6 33] Still, the estimate of tax evasion based on the PDG survey may be less biased and, as a consequence, lower than the corresponding estimate based on the PLS survey because: (1) in recent years, in Brazil, smokers and nonsmokers have been less

Table 3 Proportion of illicit cigarette consumption by self-reported price and/or pack characteristics

	Rio de janeiro		São paulo	
	Illicit cigarette		Illicit cigarette	
FTF-household	N	%	N	%
Smokers who showed the pack of their last purchase at the moment of the interview (n=680 Rio de Janeiro; n=598 São Paulo)	–	–	–	–
Direct observation of the pack (FTF-householdbrandcigarette)*†	199	29.9 (23.3–36.5)	218	40.7 (34.3–47.0)
Self-reported price per pack (FTF-householdpricecigarette)‡§†	199	29.1 (22.4–35.7)	200	37.5 (31.2–43.7)
Direct observation of the pack complemented with self-reported price below threshold price (FTF-household pricebrandcigarette)¶†	213	31.7 (25.0–38.4)	225	42.0 (36.0–48.0)
All smokers (n=742 Rio de Janeiro; n=724 São Paulo) "Final combined" illicit cigarette use*¶**†	222	30.3 (24.0–36.6)	260	40.5 (34.9–46.0)

Smokers who showed the pack of their last purchase and all smokers. Rio de Janeiro and São Paulo cities, 2019.
*We used the official list of legal brands authorised by the Brazilian Health Regulatory Agency and the direct observation of the presence of Brazilian health warnings to define the legal status.
†P>0.300 in Pearsonχ^2 tests for comparison of two proportions with sampling weight across methods for Rio de Janeiro or São Paulo.
‡Individuals who reported having bought at least one cigarette pack in their last purchase and who informed having paid less than the minimum price established by law, that is, <5.0 Brazilian Reais per pack.
§We excluded smokers who did not provide information on self-reported price per pack (0.2% in Sao Paulo and 0.0% in Rio de Janeiro).
¶Legal brands authorised by the ANVISA with the presence of Brazilian health warnings, but sold below 4.7 Brazilian Reais were also coded as illegal.
**For smokers who did not show the pack of their last purchase, illegal consumption was based on (1) individuals who informed having paid less than 4.7 Brazilian Reais for a cigarette brand authorised by the ANVISA or (2) who informed having bought an illicit cigarette brand.
FTF, Face-to-Face Household.

exposed to secondhand smoking inside their own households due to the increasing denormalisation of tobacco use and awareness of tobacco-related harms to others,[1 34 35] thus likely contributing to a reduction in the expected difference in the probability of discarding in the household garbage between heavy and light smokers; (2) although selection of PLS' census tracts made sure that geographical regions representing all socio-economic strata were in the sample, even in the wealthiest districts, lower-income individuals might be more likely to be out on the streets[36]; (3) it is also possible that littering in the streets per se likely provides more biased estimates of illicit consumption than discarding garbage in the residence, as smokers who litter in the streets are flouting the law and, therefore, it is reasonable to consider that they may also be more likely to circumvent tax laws, irrespective of the degree of nicotine dependence.[17 30 32]

Different periods of data collection (eg, PLS was mostly conducted during summer time), different sampling frames to represent the city of Rio de Janeiro, and the likely different probabilities of the inclusion of littered packs from non-residents may have also partially explained the differences found between the PLS and the PDG surveys.

Recruitments for the FTF-household surveys in Rio de Janeiro and São Paulo were partially based on a 'non-probabilistic sampling design' involving a quota sampling strategy, and therefore differences in socioeconomic status and smoking behaviours between 'gender–age quota' and 'gender–age real sample' of smokers living in selected census tracts may have biased estimates of FTF-household surveys. Indeed, the proportions of smokers with a low educational level and high nicotine dependence were higher in the household surveys than those expected for the Rio de Janeiro and São Paulo smoking population (see online supplemental table 1).[20 21] On the other hand, FTF-householdbrand was not subjected to the likely systematic difference between illicit and non-illicit cigarette smokers with regard to discarding packs on the streets or in the household garbage. Moreover, one may consider that this method was essentially the same as direct observation of the pack (ie, similar to the 'gold-standard' measure) since we only included smokers who had the

Table 4 Proportion of illicit cigarette consumption from Paraguay*, according to PLS, FTF-householdbrandcigarette, or PDG survey, 2018–2019

City	PLS†	FTF-householdbrandcigarette†	PDG†
Rio de Janeiro			
% of brands from Paraguay	100.0	100.0	99.6 (98.8–99.9)
São Paulo			
% of brands from Paraguay	99.7 (98.9–99.9)	100.0	n.a.
Campo Grande			
% of brands from Paraguay	99.7 (99.5–99.9)	n.avail.	n.a.
Belo Horizonte			
% of brands from Paraguay	99.6 (97.8–99.9)	n.avail.	n.a.
João Pessoa			
% of brands from Paraguay	96.8 (94.5–98.2)	n.avail.	n.a.

*Based on 'direct observation of the pack'.
†We excluded illicit packs which did not provide information on the country of origin (missing or not visible/legible on the packs): PLS, Rio de Janeiro 3.1%, São Paulo 0.8%, Campo Grande 15.4%, Belo Horizonte 18.6%, and João Pessoa 3.5%; FTF-householdbrandcigarette, Rio de Janeiro, 27.6% and São Paulo, 42.8%; PDG, Rio de Janeiro 1.5%.
FTF, face-to-face household; n.a., not applicable; n.avail., not available; PDG, packs discarded in household garbage; PLS, packs littered in the streets.

pack of their last purchase with them during the interview. It is worth noting that the small relative difference in point estimates of illicit cigarette consumption between direct observation of the pack (FTF-householdbrandcigarette) and self-reported price (FTF-householdpricecigarette) strengthens the validity of using, at no additional cost, information based on purchasing prices obtained from a representative FTF survey (the National Health Survey-PNS) conducted every 5 years since 2008 by the Brazilian government to produce estimates of illicit cigarette use in the country.[20] Furthermore, as self-reported brand information will start to be routinely collected in the next PNS surveys, we will be able to combine price and brand information moving forward to learn more about the illicit market in Brazil.

Estimates based on purchasing prices (FTF-householdpriceindiv, FTF-householdpricecigarette, FTF-householdpricebrandindiv, FTF-householdpricebrandcigarette, VIGITEL-indiv and VIGITEL-cigarette) likely have some recall or rounding bias.[31] Moreover, there may be an increasing tendency over time to under-report average daily cigarette consumption due to the growing social disapproval associated with smoking, particularly among heavy smokers, thus resulting in lower estimates of illicit yearly cigarette consumption.[37 38] It is worth mentioning that because VIGITEL and FTF-householdprice only used one criterion (ie, purchasing price) to determine the legal status of a pack, this could also partially explain the lower share of illicit packs found using these methods. Finally, the likely differential information bias on lower smoking prevalence and lower cigarette consumption related to conducting phone surveys across different socioeconomic status groups may have also explained the even lower estimates of illicit cigarette consumption found in the VIGITEL survey.[7 37–40]

The VIGITEL survey uses a telephone landline sampling frame and therefore may not represent the totality of individuals of the cities surveyed,[13 21 25 39] particularly because smokers without landlines are more likely to be from lower socioeconomic groups and may also respond differently to smoking behaviour questions than smokers with higher socioeconomic groups in the VIGITEL survey (eg, may consume more illicit cigarettes).[6 39] Moreover, the high proportion of missing information for the amount and price paid by smokers in their last purchase (around 15%) may have increased selection bias. Still, given its annual collection, the VIGITEL survey may be particularly useful for the purpose of tracking trends over time in illicit cigarette use among its target population.[13 25] In order to reduce selection bias, Brazil could consider adding the brand question and/or expanding the VIGITEL survey to include the population segment with mobile phone. Data from the VIGITEL survey is also being used to estimate trends in illicit cigarette use for the whole country by annually comparing Brazil's tax-paid sales with individually reported consumption from the VIGITEL survey.[7] In 2018, for instance, the proportion of illicit cigarettes consumed in Brazil was estimated at 31.4%,[41] which was almost 20 percentage points lower than the estimate provided by the tobacco industry (49.6%).[42] The national estimate of illicit consumption for 2018 was closer to the estimates found in this paper for the two most populous Brazilian cities, that is, Rio de Janeiro and São Paulo, than to those found for the other three cities included in the PLS survey, although, all together, these five cities represent only 12.8% of the Brazilian smoking population.[20]

Apart from findings about differences among estimates coming from different methods, our results reveal some interesting patterns regarding illicit cigarette use within the studied populations. In particular, the PDG survey showed, as expected,[43] that poorer neighbourhoods had higher proportions of illicit cigarette use (online supplemental table 2). And both the FTF-household and the VIGITEL surveys also showed high internal consistency. For instance, illicit cigarette consumption was positively associated with the amount of daily cigarette consumption and low educational level (online supplemental table 3).

Not surprisingly, smokers who live in Campo Grande, a border state with Paraguay, presented a high proportion of illicit consumption. The high proportion of illicit consumption found in João Pessoa, either using the PLS or the VIGITEL survey methods, a city located in a poor economic region of the country, where law enforcement is also weak,[21 27] suggests that smugglers may be exploring 'new markets' for illicit cigarettes consumption in Brazil. In this sense, our findings may also create opportunities for the health sector in Brazil (and in other countries) to more assertively promote WHO FCTC multisectoral measures through the full implementation of article 15 of the WHO FCTC and the Protocol to Eliminate Illicit Trade in Tobacco Products.[14] As the Brazilian tax stamp is usually broken, and sometimes lost, when the pack is opened (online supplemental table 4), the track and trace system should have the security feature (stamp) with the unique identifier attached to the packaging in such way that the unique identifier is still visible once the pack is open, thus helping with the assessment of the size of the illicit market. While the tracking and tracing system is designed to prevent tax evasion by legitimate manufacturers, it cannot address the problem of illicit cigarettes being produced in illegal factories or smuggled across the border. Using licenses and movement control to secure the supply of manufacturing equipment and raw tobacco needed for cigarette production will alleviate the problem of illegal factories. Tighter border control and pressure on countries that are sources of illicit cigarettes to better control their tobacco companies will address the cigarette smuggling problem.

CONCLUSIONS

The tobacco industry has a long history of well-resourced opposition to effective tobacco control measures, including efforts to subvert tax policies.[8 29 44–46] In Brazil, cigarettes are subjected to a tax levied on the manufacturing of products (IPI, *Imposto sobre Produtos Industrializados*), which was last updated 4 years ago (ie, in 2016).[5] The negative consequences of not increasing final retail prices are expressed in the recently published WHO report on the global tobacco epidemic that showed that the most sold brand of cigarettes in Brazil has become more affordable.[47]

The promotion of independent studies using feasible methodologies to estimate the amount of illicit cigarette consumption in the country over time, as well as the subsequent cross-validation of these estimates to understand possible methodological differences and applicability, when resources permit, is of paramount importance to help effectively implement tobacco excise tax policy in Brazil and in other low-income and middle-income countries.

Author affiliations
[1]Population Research Unit, Instituto Nacional de Câncer, Rio de Janeiro, Brazil
[2]Fiscal Policies For Health, Health Promotion Department, World Health Organization, Geneve, Switzerland
[3]Institute for Health Research and Policy, University of Illinois at Chicago, Chicago, Illinois, USA
[4]Center for Studies on Tobacco and Health, National School of Public Health, FIOCRUZ, Rio de Janeiro, Brazil
[5]Institute for Global Tobacco Control, Johns Hopkins University Bloomberg School of Public Health, Baltimore, Maryland, USA
[6]Institute of Scientific and Technological Communication and Information in Health, FIOCRUZ, Rio de Janeiro, Brazil

What this paper adds

- In many countries, the tobacco industry is the only source of estimates of the size of the illicit cigarette market, and consistently, overestimates it to claim that evidence-based tobacco control policies will result in an increased illicit cigarette market
- This study represents the first-ever detailed comparison of more than two methods—systematic inspection of cigarette packs discarded in household garbage (or littered in the streets or showed during a face-to-face household interview), a phone (or a face-to-face household) interview about tobacco users' purchase behaviours—to estimate the size of illicit cigarette trade based on the evidence from four non-industry-funded, large-scale studies conducted in selected Brazilian cities.
- Large differences in the estimated levels of illicit trade across cities were found. On the other hand, only small differences across methods were found, except for the phone survey. The cross-validation of estimates of the illicit market from independent studies to understand their methodological differences and applicability is of paramount importance to help effectively implement tobacco excise tax policy in Brazil and in other low-income and middle-income countries.

[7]National Commission for the Implementation of the Framework Convention on Tobacco Control, Instituto Nacional de Câncer, Rio de Janeiro, Brazil
[8]Health Policy and Administration, School of Public Health, University of Illinois at Chicago, Chicago, Illinois, USA

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Competing interests None declared.

Patient consent for publication Not required.

Ethics approval The VIGITEL phone survey was approved by the Brazilian National Commission of Ethics in Research (CONEP), register number 13081/2008 as updated on 26 June 2013 (No. 355.590). As data were collected through phone interviews, verbal consent was obtained from the respondent at the time of telephone contact. All interviews were recorded. The Packs Discarded in the Household Garbage (PDG) survey was carried out with the cooperation of the firm (COMLURB) that routinely collects household garbage in Rio de Janeiro city, thus not involving human participants. The Face-to-Face Household (FTF-household) survey was approved by the National School of Public Health Review Board (CEP/ENSP) on October 5, 2018 (No. 2.943.976). For the American Cancer Society, the study protocol was approved by the Morehouse School of Medicine, their institutional review board of record.

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ORCID iDs
André Salem Szklo http://orcid.org/0000-0003-1903-6188
Michal Stoklosa http://orcid.org/0000-0003-2014-539X
Kevin Welding http://orcid.org/0000-0002-1833-6691

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