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Volunteering and firefighters' response time

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Abstract

One out of ten Brazilian cities has a fire station, but because of volunteering in the Santa Catarina state this ratio is one out of two. While it is clear the volunteering is useful to spread the service, it is not clear whether the firefighter's service quality worsens with the volunteers. The article's purpose is analysis this by considering the response time as a quality indicator. Exploring a database of more than 600,000 attended emergencies, and using propensity score matching and regression procedures, it is concluded that are not worsens in the response time when volunteers are in the teams. This it is pointing that a similar volunteering policy can raise the coverage rate of the emergency services, and consequently it can improve social welfare.

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1 Introduction

In Brazil, the firefighter services are duties of military corporations subordinated to the state governments, and the legislation also allows the existence of civil firefighters hired by public or private institutions under the military supervision. Despite this, after a big fire occurred in 2013, it was noticed that only 10% of the Brazilian cities has a fire station, because the institutions do not allocate enough resources to spread these services (Atiyeh 2013, Dal Ponte et al. 2015).

In the context, the case of the state of Santa Catarina stands out because its number of cities with fire stations has gone from 9% in the 1990s to 54% nowadays; whereas in other parts of Brazil this number has remained practically unchanged in the same period. The explanation is that in the 1990s were promulgated laws to easy volunteering in the public services, and the state has using this to recruit volunteer firefighters. Around 18,000 people have already volunteered, 4,000 concluded the training process and 500 were incorporated in a complementary framework to the 2,500 professional firefighters. In this proceeding, the military have been redistributed by the cities, and mixed garrisons were formed with the volunteers. Today, half of the fire brigades are mixed in some proportion.

While the volunteering is clearing helpful to increase the service availability, it is unclear what its impact on the service quality for at least three reasons. First, the basic training for professionals is longer than for volunteers (1,200 and 400 hours, respectively), so the initial competencies can be different. Second, the professionals have exclusive dedication to the job and obligation to maintain a routine of training, while the volunteers have no obligations. Third, the motivation to the firefighter volunteering and how it can affect the service remain obscure, because the Brazilian policymakers never investigated this.

By revising the literature, it is noticed that in some way these doubts are also present in other countries. For example, more than half of the fire stations in the US are mixed or fully voluntary garrisons, but this happens only in small cities, because in big cities the governments prefer exclusively professionals brigades (McChesney 1986, Brudney & Duncombe 1992, Simpson 1996). Probably, this it is related with the fact that potential losses caused by inadequate services are higher in places with more population – e.g., out of control fires cause more harm and risks to lives when there are more adjacent buildings –, which justifies investing in teams of exclusive dedication. In contrast to the US case, in the Brazilian case analyzed here, the volunteering is also present in large cities, so the discussion of service quality is even more relevant.

Furthermore, for the North-American context, Carpenter & Myers (2010) applied methods in experimental economics to conclude that the decision to the firefighter volunteering is positively correlated with altruism as well as with concern for social reputation. However, it is difficult to trace a relationship among these elements and the volunteers abilities to be a firefighter, and, consequently, with the impact on the service quality.

About the analysis of the firefighter's service quality in the literature, the first point to observe is that attendances are basically split in two groups: emergency medical care (EMC), and fire control. Although the original motivation of the profession descends from the latter, the literature shows that fire control represents less than 10% of the current firefighters activities (Thompson & Bono 1993, Kiran & Corcoran 2017). Thus, many papers use the minutes that emergency responders take to arrive at the scene of an incident from the time that the emergency response system was activated – named "response time", or RT – as an indicator of quality, because: (i) it is a metric that can be applied both for EMC and fire cases; (ii) it is easy to measure and to interpret; (iii) there is large empirical evidence that the shorter RT implies less human and capital losses; and, (iv) it is frequently used as the main indicator in service emergency contracts by the public sector (Zech 1982, Duncombe & Yinger 1993, Duncan 1999, Blackwell & Kaufman 2002, Athey & Stern 2002, David & Brachet 2009, Blanchard et al. 2012, Brachet et al. 2012, Kiran & Corcoran 2017). However, it is important clarify that the RT is unsuitable for a differentiated presentation of quality as a multidimensional construct. In fact, authors like Steffen (1988) and Donabedian (2005) show that the quality concept in urgent care is not consensual, but this idea represents the rescuers abilities in understand the situation, and so decide for an appropriate procedure and execute it. Under this perspective, the RT indicates the possibility to increase the quality, because it points to the time availability to take actions to reduce damages.

In light of this, the research obtained unprecedented access to the data of the E-193 system used in Santa Catarina – similar to the E-911 system used in North America. Thus, it was possible to tabulate the 650,403 occurrences attended by the firefighters between 2010 and 2016, split between EMC and fire cases. In 77% of these records was possible to measure RT, how many volunteers were involved in the procedures and other control variables. Then, the research goal was to estimate counterfactual situations of changes of professionals by volunteers, or supplementation of teams with volunteers, with the intent to infer if the RT worsens with these movements in equivalent situations.

As it will be stated, using the potential results framework and matching protocols well-established in the literature, there is no evidence of worsen. Therefore, there is an indicative in favor of the hypothesis that the volunteers do not cause loss of quality in the analyzed case. Thus, especially in Brazil, this suggests that volunteering policies can raise the coverage rate of the firefighters and other emergency services, maintaining quality and consequently improving social welfare.

The remaining of the manuscript is organized as follows: section 2 shows the data; section 3 discusses the empirical strategy and the estimated results; and, section 4 presents the conclusions.

2 The data

The Figure 1 shows the map of Santa Catarina, where: white areas are cities with no firefighters (136 in total); light and dark gray areas are cities with mixed and no mixed brigades (81 and 78 in total), respectively; and, dark balls illustrate regions with higher population density. It is observed that in the areas with higher population density there are both mixed and no mixed brigades, which means that the situation presented here is different from the regular case discussed in the literature, in which the volunteering is more intense in less populous areas (McChesney 1986, Brudney & Duncombe 1992, Simpson 1996).

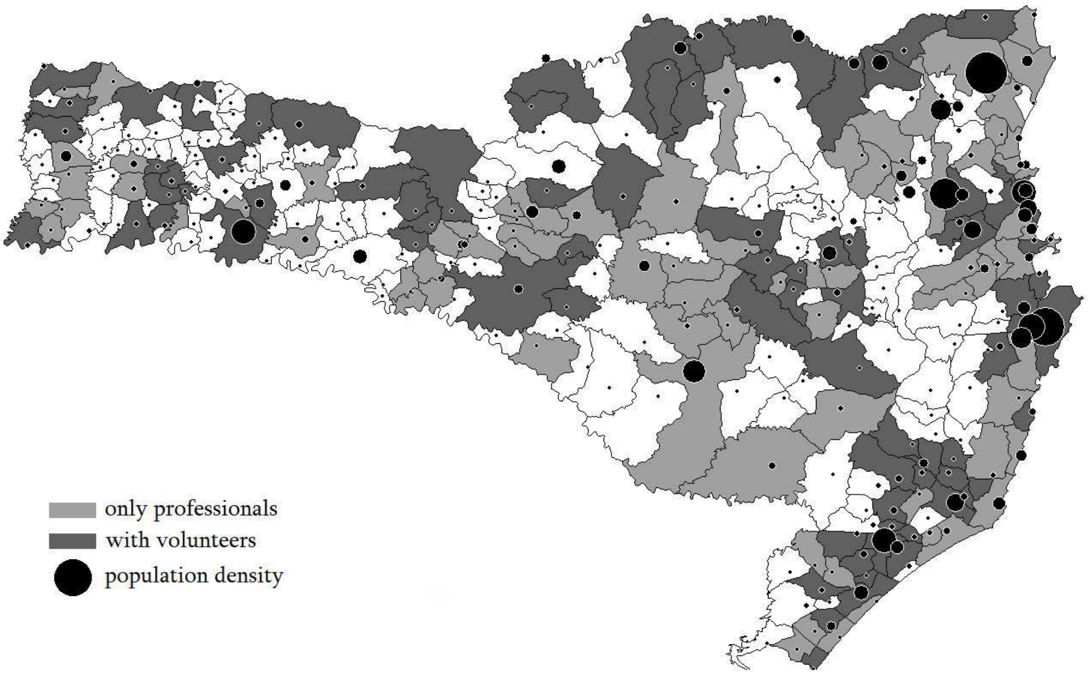


Figure 1: Map of Santa Catarina indicating the presence of fire stations and the population density in 2016. Data source: Military Firefighters Corps of Santa Catarina (CBMSC).

The Table 1 shows the numbers and frequency of professional and volunteer firefighters involved in the EMC and fires cases, and the following stands out: (i) more than 90% of the occurrences are EMC cases (less than 10% are fires), which is according to the North American and Australian standards (Thompson & Bono 1993, Kiran & Corcoran 2017); (ii) in both EMC and fire cases, more than 90% of the occurrences have no volunteers involved; (iii) there are no cases attended by a team formed only by volunteers; (iv) when there is a volunteer, more frequently is only one; (v) the emergencies are more frequently attended by teams of three firefighters.

	Volunteers			
Professionals	0	1	more	Total
2		0.8		0.8
3	70.5	3.6	0.3	74.4
4	13.3	1.2	0.4	14.9
more	9.0	0.5	0.4	9.9
Total	92.8	6.1	1.1	100%

(a) EMC, 595.147 cases

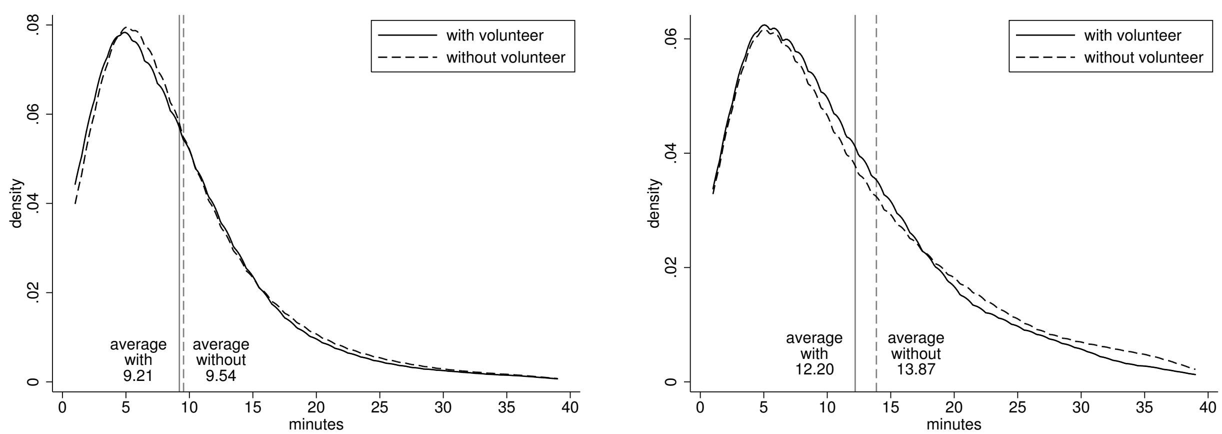
	Volunteers			
Professionals	0	1	more	Total
2		0.9		0.9
3	53.6	1.5	0.1	55.2
4	16.2	1.1	0.4	17.7
more	23.6	1.3	1.3	26.2
Total	93.4	4.8	1.8	100%

(b) Fires, 62,256 cases

Table 1: Numbers and frequency of professional and volunteer firefighters involved in the cases of EMC and fires emergencies attended between 2010 and 2016. Data source: E-193.

Except in unusual cases, by law the smallest number of rescuers in a team is three; which is important to understand the mechanism of contribution of the volunteers. To illustrate this, it is observed that there are about 18 firefighters in a regular fire station; as the typically work rotating is 24-hour shifts followed by two days off, it is expected six professionals on duty. But part of these firefighters may be absent (e.g., vacation) or doing another job (e.g., forensic activities). Thus, if in a moment there are five professionals and no volunteer on duty, this configuration allows the formation of only one team with at least three rescuers. However, if a volunteer shows up, there will be six firefighters and it will be possible to form two teams of three rescuers. Therefore, in case of a team is attending an occurrence, and a new emergency comes up in this period, the extra team can do the service, and this tends to reduce RT.

The Figure 2 shows the RT kernel densities by type of emergency and presence (or not) of at least one volunteer. The vertical lines indicate the averages, and it is noticed that: (i) the RT in EMC cases tends to be a little more than nine minutes, whereas in the fire cases is around 13 minutes – this difference is explained by the fact that in the EMC cases the ambulances are more frequently used, while in the fire cases the trucks are more frequently used; and, (ii) in both emergencies types, the RT average is lower with volunteers – this difference is statistical significance in a 95% confidence interval.



(a) EMC

(b) Fire

Figure 2: RT *kernel* densities by emergency type. Data source: E-193.

The Table 2 shows the correlations between the daily averages for the numbers of attendances and RT for EMC and fire cases, teams and volunteers on duty – all values have statistical significance in a 95% confidence interval. It is noted that the number of attendances is correlated with the RT, because it raises the chances of having no team immediately available. On the following lines, the numbers 0.25 and 0.15 show that the quarters that get more emergencies also tend to have more teams on duty; and the RT tends to be lower when there are more teams on duty. On the last line, the numbers -0.08 and -0.04 indicate that there are fewer volunteers in quarters that receive fewer occurrences, which is a direct consequence of the allocation of military to places with more occurrences and fewer volunteers; finally, the number 0.07 shows that when there are more volunteers, there are also more teams, which reinforces the statement described above.

Variable	EMC Occurrences	Fire Occurrences	EMC RT	Fire RT	Teams	Volunteers
EMC Occurrences	1.00					
Fire Occurrences	0.28	1.00				
EMC RT	0.10	0.14	1.00			
Fire RT	0.02	0.13	0.16	1.00		
Teams	0.25	0.15	-0.02	-0.14	1.00	
Volunteers	-0.08	-0.04	-0.01	-0.02	0.07	1.00

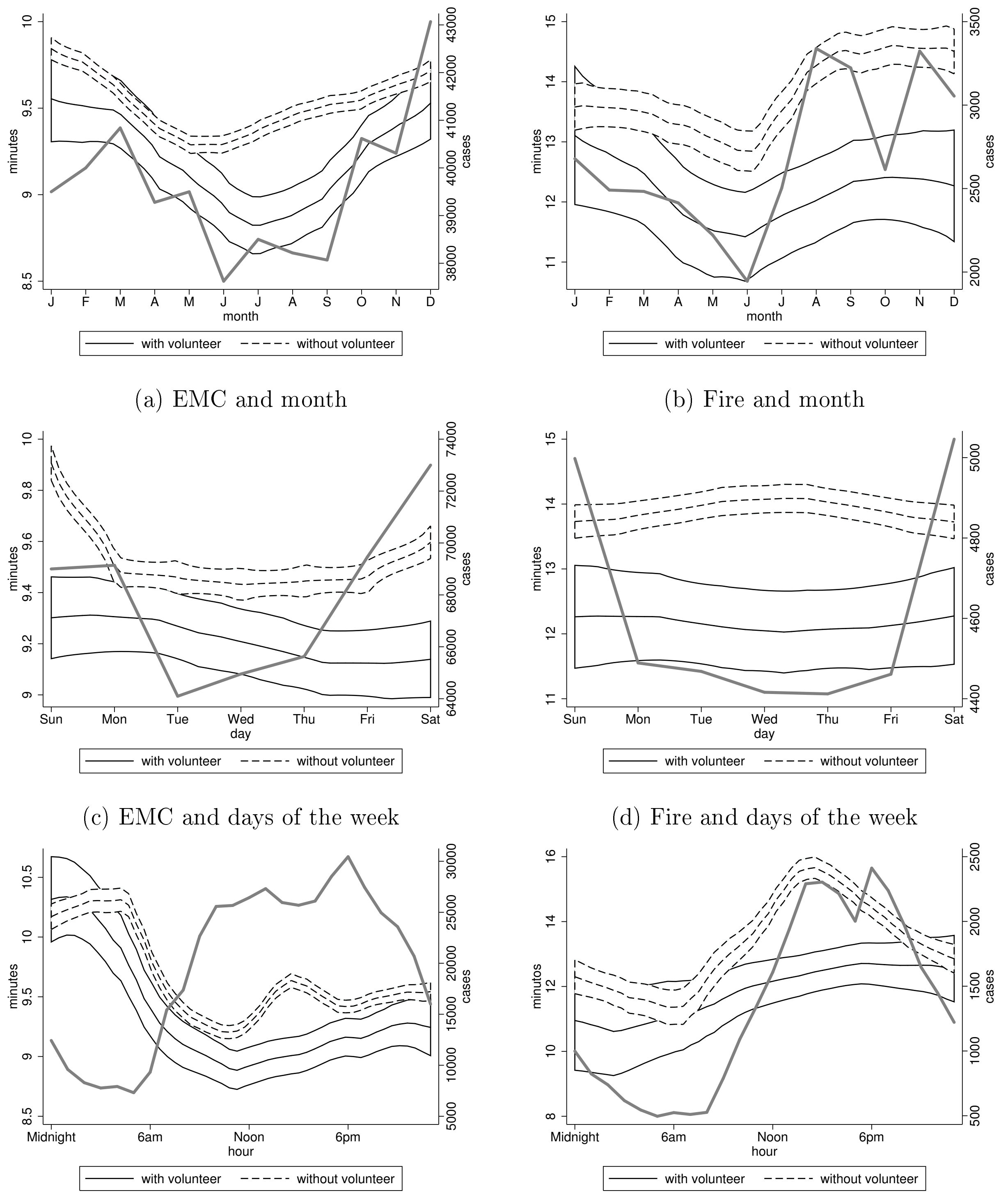
Table 2: Correlations between daily averages of EMC and fire attendances, RT, and numbers of teams and volunteers. Data source: E-193.

It is clear that number of occurrences received and RT are correlated; moreover, these variables are also correlated with temporal variables. To illustrate this, the Figure 3 shows graphs for the number of attended occurrences (gray lines) and confidence intervals (of 95%) for the RT average by type of emergency and volunteer involvement in regard to month, day of the week and hour of the day.

Firstly, Graph 3(a) indicates a positive correlation between attended occurrences and RT in the EMC cases; and, Graph 3(b) indicates the same for the fire cases. On these graphs, it is noticed that in the months of January, February and March the confidence intervals for the RT in the cases with presence/absence of volunteers are overlapped, indicating that there is no difference of average that is statistically significant in this period. In fact, these months are the period of school vacation in Brazil, in which the presence of volunteers might be emptied and, in consequence, the chances of forming extra (or bigger) teams and differentiation in the RT are reduced.

Graphs 3(c) and 3(d) show that the numbers of EMC and fire cases, respectively, raise on weekends, and, in both types of emergencies, the average RT is smaller in the presence of volunteers. Graphs 3(e) and 3(f) illustrate the numbers of EMC and fire cases, respectively, in relation to the hour of the day, in which is noticed that the number of occurrences is reduced between midnight and the morning. Besides, during that time there is no difference statistically significant in the RT average concerning the presence/absence of volunteers in the team, which can be explained by the fact that the presence of volunteers is reduced during such time of the day.

Lastly, according to the literature, it is important to highlight that other variables are potentially correlated with the number of emergencies and the RT, such as: population density, local GDP per capita, temperature and rainfall (Lambert et al. 2012, Marshall et al. 2014, Kiran & Corcoran 2017). To illustrate this, the Table 3 shows such correlations for the daily averages for all quarters observed in the database, indicating that: (i) places with higher population density and GDP per capita tend to show more emergencies and less RT; (ii) on hotter days the occurrences and the RT tend to raise in the cases of fire; (iii) on rainier days there are more occurrences and higher RT in the cases of EMC.



(a) EMC and month

(b) Fire and month

(c) EMC and days of the week

(d) Fire and days of the week

(e) EMC and hour

(f) Fire and hour

Figure 3: Number of cases (gray line) and confidence intervals (of 95%) for the RT by type of emergency and volunteer participation in relation to month, day of the week and hour. Data source: E-193.

Covariate	EMC Occurrences	EMC RT	Fire Occurrences	Fire RT
Population Density	0.10	-0.04	0.09	-0.03
GDP per capita	0.18	-0.03	0.02	-0.03
Temperature	0.20	0.01*	0.11	0.05
Rainfall	0.17	0.06	0.02*	0.02*

*Values statistically equal to zero with 95% confidence.

Table 3: Correlations between the daily EMC and fire cases, RT, population density, GDP per capita, temperature, and rainfall. Data source: E-193, Brazilian Institute of Geography and Statistics (IBGE) and National Institute of Meteorology (INMET).

The point is that in places with higher population density and GDP per capita there is more traffic, equipment, etc; which raises the chances of occurring accidents and fires whilst the RT would be lower because the distances traveled by the rescuers would be lower in such places. On the other hand, on hotter days people tend to move more, raising the chances of these emergencies occurring and expanding the RT due to heavy traffic and rescuers overlapping, and similar movements occur in raining days due to wet roads. Therefore, considering the covariates presented in this section, the empirical strategy to evaluate the effect of volunteers in the RT of the firefighters will be discussed in sequence.

3 The empirical strategy and estimated results

Clearly, the presence of volunteers allows the RT reduction by the raising the number of available teams. On the other hand, when comparing equivalent situations, it is not clear if the RT of teams composed entirely by professionals differs from the RT of mixed teams. For example, consider two emergencies in the same city, month, day of the week, hour, equivalent weather etc.; it is not clear if the RT of these emergencies differs when a rescue is done by a team of three professional firefighters, and other rescue is done by a team of two firefighters and one volunteer. However, if many comparisons systematically point out that there is no difference statistically significant on the average of the RT by these teams, the doubt will be solved in favor of the contribution of the volunteers to the system. And to promote such comparisons, the model of potential results can be used (Rubin 2005).

Under such framework, each emergency indexed by i has two potential results in the RT: $Y_i(0)$ if the occurrence is attended by a team composed only by professionals, and $Y_i(1)$ if it is attended by a mixed team. Thus, the metrics of the average treatment on treated (ATT) can be considered by $E(Y_i(1) - Y_i(0) \mid T_i = 1, X_i)$, in which: E is the mathematical expectation operator, T_i is a binary variable that indicates the treatment of the i-th case (i.e., $T_i = 1$ indicates mixed team), and X_i is a vector of the characteristics of this emergency. With these specifications, the ATT can be estimated through a linear regression $Y_i = \alpha T_i + \beta X_i + \xi_i$, in which: Y_i is the RT registered in fact (or a function of this, as the logarithm), α is a parameter that represents the ATT under the hypothesis that the definition of the treatment is independently determined, β is a vector of parameters, and ξ_i is a term of error (Khandker et al. 2009).

As in any linear regression, the endogeneity problem implies in biased estimated parameters; and in that case is realistic to imagine that the variable T_i is correlated with the term ξ_i, which is known in the evaluation literature as selection bias. In fact, ξ_i represents all the RT explanatory elements that are not incorporated to the treatment indicator and the controls – e.g, the rescuers' ability –, and there are many possibilities for a correlation among these unobserved elements and the volunteer presence. For example, if the volunteers do not contribute to the RT reduction, this fact is potentially caused by a lower ability than the professional firefighters' ability; or, like discussed by Carpenter & Myers (2010), if the volunteer motivation is just social reputation, this person can only delay the team.

To reduce the selection bias, the strategy is to estimate a group of regressions in subsamples of observed emergencies determined in a propensity score machting procedure, or PSM (Khandker et al. 2009). Such procedure aims to find groups of emergencies that are statistically similar in terms of the covariates, in which it is not possible to differentiate clearly which one is probably attended by a mixed team or not. As it was shown in Rosenbaum & Rubin (1983), such procedure tends to mitigate the selection bias by equating groups based on the observed covariates, allowing a more realistic estimation of the ATT – since it is impossible to observe the abilities, motivations etc.

Therefore, the next step is to define the treatments. In this sense, it is noticed that the volunteers can take on the following conditions in the duty: (i) to allow the formation of an extra team when a professional is replaced by a volunteer; or, (ii) to raise the team size. The first one has already been discussed, and it is probably the main mechanism of contribution of the volunteers to the system. On the other hand, the volunteers also permits to raise the team size, for example, from three to four rescuers. This condition might also imply in the RT reduction in the cases that the vehicle needs to be loaded with special equipment, or when the emergency needs more than one type of vehicle – e.g., an ambulance and a truck, in which the first one makes way into traffic.

Moreover, as observed previously, the huge majority of the emergencies is attended by teams of three or four rescuers, and frequently there is only one volunteer by team. Thus, as described on Table 4, for the ordered pair (p, v), in which p and v represent the number of professionals and volunteers, respectively, four tests can be formulated to control the team sizes and the volunteer condition. In the tests #1 and #2 only teams of three and four rescuers are compared, respectively, in the face of the volunteer/professional changing. Complementary, in tests # 3 and # 4, teams of three and four are compared, respectively, in the face the addition of one volunteer.

Definition of the	Substitution for a volunteer		Increase of a volunteer	
case (p, v)	Test #1	Test #2	Test #3	Test #4
Control ($T_i = 0$)	(3,0)	(4,0)	(3,0)	(4,0)
Treatment ($T_i = 1$)	(2,1)	(3,1)	(3,1)	(4,1)

Table 4: Evaluation design.

For each kind of emergency, Probit regressions were estimated using the T_i definitions above and the controls discussed in the previews section: population density (inhabitants by

Km^2) and GDP per capita (R$ of 2016) in the city of the registered occurrence, temperature (degrees Celsius) and rainfall (millimeters) in the occurrence place and day, dummies indicating month, day of the week and hour, and fixed effects to the fire stations and vehicles. Because of the limited space, the tables with the estimated results are omitted, although the key messages can be summarized as follows: (i) in places with higher population density and GDP per capita, there is more chance of a team counts with a volunteer; (ii) in colder and/or rainier days, the odds of a volunteer to be present is lower; (iii) it is less likely that the volunteers are working in the ambulances instead of the trucks and other types of vehicles; (iv) throughout the night, the odds of a volunteer to be in a team is lower; (v) in the middle of the week, the chance of a volunteer to be in a team is higher; and, (vi) in the spring, summer and fall months, the odds of a volunteer to be in a team are higher than in winter. In short, the results point out that in days and times of the day that are less enjoyable (e.g., cold and rainy days and at night) the presence of volunteers is emptied. Thus, there is an indicative that the fire stations must not dependent on the volunteers in a high degree of intensity, under the risk of a severe reduction in the number of rescuers on duty in some determined days.

Following the PSM procedure, a set of Probit regressions were used to estimate the propensity scores for the volunteer participation in a team, and subsamples of statistically similar emergencies were selected using the criteria of the nearest neighbor under common support (Khandker et al. 2009). Hence, linear regressions $Y_i = \alpha T_i + \beta X_i + \xi_i$ were conducted using the samples with/without PSM, considering the dependent variable as the RT and as the natural logarithm of RT, and considering the same controls used in the Probit regressions.

The estimated results for the ATT are presented in the Table 5 – because of the limited space, the table omits the estimated results for the control parameters. In all the reported specifications, the magnitude of the estimated ATT is lower under PSM, which indicates that the bias of selection is in the sense of overestimate the benefits of volunteers participation. Nevertheless, in general, the numbers point out that there is no statistically significant raise on the RT when the emergencies are compared systematically the cases with three professional firefighters with the cases of two professional firefighters and a volunteer. In particular, in the EMC cases is noted that the RT can be reduced around half a minute when there is presence of volunteers, which is a point that might arouse a future investigation.

About the effects of the other covariates, in all tests the following pattern was observed: (i) in places with higher population density and GDP per capita, by considering the paired sample, when the estimated parameters are statistically different from zero, it is noticed that the RT tends to be lower; (ii) in rainier days the RT tends to expand; (iii) when the ambulances are used the RT tends to be lower; and, (iv) the issues related to the time of the day, day of the week and season of the year in which the emergency is registered are all important to explain the RT. Hence, such results have shown to be aligned with what was discussed previously, in the data description.

	RT		ln RT	
Test	without PSM	with PSM	without PSM	with PSM
#1 for EMC				
Estimated ATT	-0.5890***	-0.2118	-0.1511***	-0.0594***
	(0.1751)	(0.2313)	(0.0157)	(0.0201)
Observations	335,629	8,219	335,629	8,219
R^2	0.090	0.163	0.105	0.248
#2 for EMC				
Estimated ATT	0.7108***	0.6200	0.0586***	0.0577
	(0.1406)	(0.6309)	(0.0132)	(0.0551)
Observations	79,382	6,532	79,382	6,532
R^2	0.127	0.173	0.134	0.215
#3 for EMC				
Estimated ATT	0.0961	-0.0111	-0.0014	-0.0009
	(0.0768)	(0.0947)	(0.0068)	(0.0084)
Observations	348,465	35,123	348,465	35,123
R^2	0.090	0.102	0.103	0.122
#4 for EMC				
Estimated ATT	-0.2166	-0.0453	-0.0365**	-0.0053
	(0.1566)	(0.2299)	(0.0147)	(0.0211)
Observations	68,093	6,981	68,093	6,981
R^2	0.132	0.147	0.141	0.187
Test #1 for Fire				
Estimated ATT	0.8271	0.2912	0.0702	0.1860
	(0.8980)	(0.8118)	(0.0605)	(0.1951)
Observations	16,945	698	16,945	698
R^2	0.120	0.216	0.148	0.244
Test #2 for Fire				
Estimated ATT	0.1909	0.0415	0.0272	0.0064
	(0.8405)	(1.4601)	(0.0576)	(0.0861)
Observations	5,634	820	5,634	820
R^2	0.183	0.230	0.207	0.263
Test #3 for Fire				
Estimated ATT	-0.8900	-0.0950	-0.0519	-0.0517
	(0.6744)	(0.9766)	(0.0446)	(0.0599)
Observations	17,152	1,196	17,152	1,196
R^2	0.120	0.182	0.148	0.226
Test #4 for Fire				
Estimated ATT	-0.4743	-0.9243	-0.0034	-0.0361
	(0.7225)	(1.0013)	(0.0549)	(0.0715)
Observations	5,500	724	5,500	724
R^2	0.190	0.296	0.212	0.314

Control variables and fixed effects omitted; robust standard errors between parentheses; *p $<$ .05; **p $<$ .01; ***p $<$. 001.

Table 5: Estimated ATT by emergency, specification and sample with/without PSM.

4 Conclusions

In Brazil, the state of Santa Catarina has been exploring a volunteering policy to raise the coverage rate of firefighters services. The volunteers' mechanism of contribution is in the possibility of expanding the number of rescue teams, and it tends to reduce the RT overall. However, up to the present investigation, it was unclear if, under equivalent situations, the mixed teams would have equivalent performances of the fully professionals teams. Using policy evaluation protocols, the research analyzed thousands of attendances to conclude that there is no worsen in the RT to be attributed to the volunteering.

Besides, the analysis verified other four secondary results. First, the volunteering in Brazil is present in the big cities too, differently of the US case, where the volunteering is intense in places with lower population density. Second, 10% of the occurrences are fires cases, whereas the others are EMC cases – like in US and in Australia, for example. Third, the average RT in fires cases is 13 minutes, and in the EMC cases is nine minutes – because frequently an ambulance is allocated in the EMC cases, and it travels faster than other vehicles. Fourth, the volunteers' presence is emptied in cold and rainy days – it is an indicative that the fire stations must not depend on the volunteers on a high degree of intensity, under the risk of a severe reduction of the rescue teams in such days.

For future research, similar techniques applied by Carpenter & Myers (2010) may be used to study the special motivation of the volunteers in this Brazilian case. Moreover, currently the policymakers of the state of Santa Catarina are discussing some awards to volunteers, like the provision of a special health plan. Under this scenario, possibly some social crowding-out effect will occur; for example, the prize can attract people less altruistic and more interested in the pecuniary benefits, or it can put away the altruistic people who believe that it harms the social reputation – similar to the situations discussed in Bénabou & Tirole (2006), Bowles & Polania-Reyes (2012). Therefore, the case here analyzed may still generate interesting researches.

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