

Barron, Kai; Gamboa, Luis F.; Rodríguez-Lesmes, Paul

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## Behavioural Response to a Sudden Health Risk: Dengue and Educational Outcomes in Colombia

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# Behavioural Response to a Sudden Health Risk: Dengue and Educational Outcomes in Colombia

Authors

*Kai Barron*

Gower Street, London, WC1E 6BT, UK.  
University College of London (UCL) and WZB-Berlin;  
email: [kai.barron@wzb.eu](mailto:kai.barron@wzb.eu)

*Luis F. Gamboa*

Departamento de Economía  
Universidad Jorge Tadeo Lozano  
Carrera 4 No. 22-61, Módulo 1, Of 502, Bogota D.C.  
Phone +573 – 3132205384  
email: [luisfw.gamboan@utadeo.edu.co](mailto:luisfw.gamboan@utadeo.edu.co)  
**(Corresponding Author)**

*Paul Rodríguez-Lesmes*

Assistant Professor  
Facultad de Economía  
Universidad del Rosario  
email: [paul.rodriguez@urosario.edu.co](mailto:paul.rodriguez@urosario.edu.co)

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The Stata routines and final datasets required to replicate the results of this paper can be found on the website <https://github.com/androdri1/DengueBehavioural>

## Abstract

Epidemics tend to have a debilitating influence on the lives of directly afflicted families. However, the presence of an epidemic can also change the behaviour and outcomes of those not directly affected. This paper makes use of a short, sharp, unexpected epidemic to examine the behavioural response of the public to a sudden shift in the perceived risk to one's health and mortality. Our analysis finds that unafflicted school students change their behaviour substantially, affecting important life outcomes. In particular, we find that between 1.9 to 4.7 fewer students, out of a typical cohort of 47 pupils, sit their school leaving examination for every additional 10 cases of *severe Dengue* per 10 000 inhabitants in a municipality. We rule out several possible mechanisms, leaving an increase in the salience of the disease's risks as a plausible explanation for our findings.

JEL Classification: I12, I15, I20, D80

# 1 Introduction

Confronted with a new epidemic, people must decide how to respond. Often information about the risks is scarce and imperfect, and people respond by adjusting their daily lives and taking extreme preventative action, such as avoiding public places and reducing hospital visits (Bennett et al., 2015). In this paper, we study the influence of an epidemic on the schooling outcomes of unafflicted students.

The sudden and unprecedented spike in the incidence of Dengue disease in Colombia during 2010 provides a good opportunity for studying how the public change their behaviour when there is a sudden outbreak of an epidemic. Dengue is currently the most prevalent mosquito-borne viral disease afflicting humans, with a 30-fold increase in incidence in the last 50 years and an estimated 50 million annual infections worldwide (WHO, 2009). During the 2010 epidemic, there was an increase of over 200 percent in the incidence in comparison to the previous year (Villar et al., 2015). Dengue can manifest as one of two strands - either as *classic Dengue*, a more common, but milder version of the disease akin to an episode of flu, or *severe Dengue*, a rarer, but far more serious condition that requires hospitalisation for around 80 percent of cases and can lead to death (Villar et al., 2015). While it is well documented that epidemics of this nature can have sizeable direct negative economic consequences for the families of those who fall ill (Clark et al., 2005), it is also of considerable interest to understand how this unexpected change in the profile of health risks faced by the population affects their behaviour, and thereby has an indirect effect on the economic outcomes of individuals who are not directly affected by the disease.

We make use of this “natural” experiment to study the influence of the Dengue epidemic on the participation in school leaving examinations (SABER 11 test) of approximately one million students. Saber 11 is the most important educational examination in Colombia because it is used as the main admission requirement in almost all the higher education institutions in Colombia (similar to the SAT in the USA). Therefore, taking this examination is essential for progressing to any form of further education facility after completing school.

In addition to being unexpected and widespread, the 2010 Colombian Dengue epidemic is particularly suitable for the study of the general public’s response to health risks for the following reason. While the relatively benign *classic Dengue* may cause students to miss school temporarily when someone in the household is infected, it is similar to a flu and unlikely to cause fear. Therefore, it is unlikely to substantially change the behaviour of individuals outside the households directly affected. In contrast, *severe Dengue* is a dangerous illness that is likely shift the perceived mortality risk and lead families to change their

behaviour and take preventative actions before anyone in the household is directly affected by the epidemic.

In our analysis, we use the temporal and geographic variation in the incidence of the two strands of the disease to estimate the impact of *classic Dengue* and *severe Dengue* on school attendance and test score attainment in the SABER 11 school leaving examinations. In doing this we exploit both municipality level and school level variables, with our main empirical strategy estimated employing a school-level analysis. The main benefit of the school level analysis is that it allows us to explore heterogeneity in the impact of Dengue within municipalities, according to school-level characteristics (discussed in more detail below). The central objective of our empirical strategy is to estimate the average impact of Dengue incidence using yearly variation during the years 2008 to 2012. This variation is predominantly driven by the unprecedented spike in incidence in 2010.

We find that an increase in the incidence of *classic Dengue* during the four months prior to the exam in 2010 in a particular municipality did not have a substantial effect on exam attendance or test taking behaviour. In contrast, however, we find that a higher incidence of *severe Dengue* in a municipality in the months preceding the exam led to a substantial reduction in the number of students who sat the examination. It is particularly striking that the estimated reduction in the number of students sitting the exam in a municipality with one additional case of *severe Dengue* per 10,000 individuals in the population in 2010 is, on average, substantially higher than the number of individuals (of any age) who actually had *severe Dengue* in the municipality. This suggests that the higher incidence of *severe Dengue* in the municipality led to a general reduction in the propensity of individuals to attend the exam, even amongst those unaffected by the disease.

There are several possible mechanisms that could explain this finding. We consider three leading candidates, namely that (i) the supply of schooling may have been reduced due to temporary school closures, (ii) older students may have missed school because they were caring for ill relatives (e.g. younger siblings), and (iii) there may have been an increase in awareness of the risks and severity of the disease when an additional member of the community became seriously ill, leading to preventative actions being taken by others in the community. In the discussion below, we present evidence suggesting that the supply of schooling remained relatively unaffected, and high school aged students did not change their time allocation at home substantially in response to the epidemic. An increase in public awareness of the risks of the disease remains as a leading plausible explanation for the behavioural response that we observe.

The general public's increased awareness and concern is reflected in Figure 1, which shows google searches for the term "Dengue" over five years in Colombia. Furthermore, news

headlines from this period, such as “*El Dengue asesino al alza*” (“Dengue, a rising killer”), published by El Tiempo on June the 20th, 2010) were likely to induce fear and uncertainty in the public.

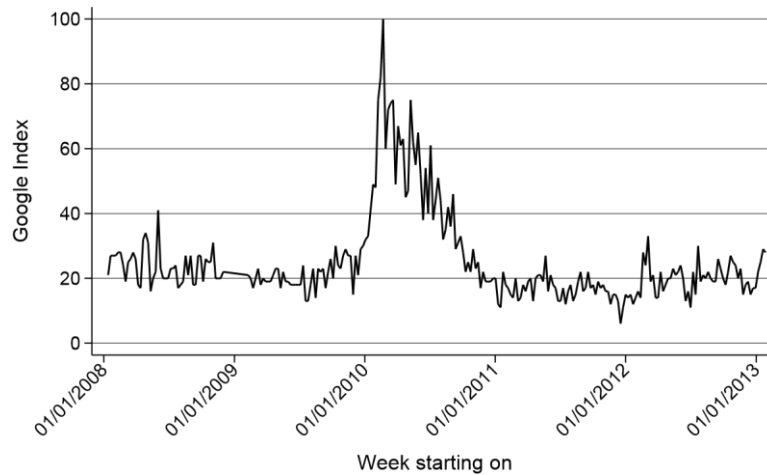


Figure 1: Web searches for “Dengue” in Colombia

The epidemic can therefore be viewed as a natural experiment that shifted the level of perceived mortality risk. In regions where only the incidence of *classic Dengue* increased, and people in the municipality were only afflicted by mild symptoms, the shift in the level of perceived mortality risk was likely to be small. However, one would expect that a spike in *severe Dengue*, along with the corresponding hospitalisation or death of several members of a community would result in a significant shift in the level of perceived mortality risk in that community. This paper studies the response to this heterogeneous shift in the perceived mortality risk across municipalities.

Our paper relates closely to the economic epidemiology literature demonstrating a “prevalence response”, whereby behaviour is a function of the underlying prevalence of a disease. Most of this literature has focused on HIV, and has studied the behavioural response to the receipt of public and private information pertaining to own and community risk of HIV (Ahituv et al., 1996; Lakdawalla et al., 2006; Thornton, 2008, 2012; Delavande and Kohler, 2012; de Paula et al., 2014; Gong, 2015). In addition, in work close in spirit to ours, Adda (2007) uses the 1996 “Mad Cow” crisis to show that there was a sharp drop in the amount of beef bought by French consumers once they became aware of the possible health risk, and the reduction was strongest amongst those who were medium risk individuals. Bennett et al. (2015) studies how public information, and peer-to-peer information transmission led to a

large reduction in hospital outpatient visits in response to the outbreak of the SARS epidemic in Taiwan in 2003.

In an early experiment in this literature, Viscusi (1997) provides evidence showing that when there is uncertainty regarding a new health risk and the public receives several different risk assessments, they tend to place inordinate weight on the high-risk assessment<sup>1</sup>. The author terms this behaviour an ‘alarmist reaction’ in response to the uncertainty regarding a new health risk. More generally, there is considerable literature exploring the behavioural response to different types of risks, including crime (Linden and Rockoff, 2008; Pope, 2008), smoking (Viscusi and Hakes, 2008; Gerking and Khaddaria, 2012), risky sexual behaviour (Lakdawalla et al., 2006; Chesson et al., 2006), and existing asymptomatic diseases (Oster et al., 2013; Thornton, 2012). Lastly, this paper speaks to the fairly thin, but important, literature that considers the educational implications of a disease outbreak: Archibong and Annan (2017) show that the 1986 meningitis epidemic in Niger increased the gender gap in the number of years of education attained by men and women, and Goulas and Megalokonomou (2016) study how high school students’ academic outcomes were affected by an increase in the laxity of school attendance policies due to the swine flu outbreak in 2009-10.

We contribute to this literature in several ways. Firstly, we provide support for the experimental results of Viscusi (1997) by showing that a new health risk of uncertain severity (e.g. an epidemic) can lead to a strong behavioural response by the general public, with important long-term negative consequences. More specifically, we show that each additional case of severe Dengue per 10 000 inhabitants in a municipality reduced attendance in the school leaving examination in 2010 by 1 percent.<sup>2</sup> This implies that the influence of a single case extends far beyond the individual and household directly afflicted by the illness.<sup>3</sup> There is a large literature documenting the substantial cost of reducing (or delaying) educational attainment (see, for example Card (1999); Carlsson et al. (2015); Light (1995); Krueger and Ashenfelter (1994); Angrist and Krueger (1991); Hansen et al. (2004)). This suggests that a drop in educational attainment due to an epidemic will lead to long-term negative outcomes.

Secondly, we explore the heterogeneity in the reduction in examination attendance observed in administrative data. Interestingly, we find that within a given municipality, in schools where the average household income is higher, the effect is far stronger, while in schools where household income is low, an additional case of Dengue per 10 000 inhabitants does not have a significant effect in reducing examination attendance. This could be interpreted as providing suggestive evidence that wealthier families panic more and change their behaviour more when faced with substantial uncertainty regarding a risk to their health and mortality. There is scope for more work in this area.

Overall, the results show that the impact of a sudden epidemic is not fully captured by the direct influence on the afflicted families. Rather, our results suggest that when other members of society are confronted with a threat to their wellbeing, some take extreme preventative action. We argue that this shift in behaviour because of the epidemic can exert a potentially long-lasting negative influence on the lives of the unafflicted. This evidence serves to make the point that in assessing the true impact of an epidemic, and designing policies to address it, it is very important to take into consideration the behavioural response and the implications of that response.

The remainder of the paper is structured as follows. Section 2 briefly describes the nature of dengue epidemics and their occurrence in Colombia during the recent past. Section 3 presents the data employed in the empirical strategy, which includes a school and student-level analysis and some exercises intended to assess the heterogeneous effects. Section 4 summarizes the main results and outlines some robustness checks that were carried out as a precaution against biased inference. Section 5 discusses the main findings and their limitations. Finally, section 6 concludes.

## 2 Dengue: An Overview

Dengue is the most prevalent mosquito-borne viral disease in the world. It is fast becoming one of the primary worldwide public health concerns due to its extremely rapid rate of expansion over the last decades. This expansion has taken place along both the extensive margin, with the mosquitos migrating to new countries and new altitudes, and along the intensive margin, with the incidence increasing in regions that were already affected. This trend is reflected in Figure 2. The WHO estimates that there are more than 50 million new Dengue infections and more than 22 000 deaths attributable to Dengue every year, worldwide (WHO, 2009).

Dengue is transmitted between individuals primarily by the *Aedes aegypti* (Linnaeus) mosquito and can be caused by any one of four distinct dengue virus serotypes (Villar et al., 2015). According to the WHO classification, cases of Dengue fall into two categories, *severe Dengue* (previously referred to as dengue haemorrhagic fever) and *non-severe Dengue*, which we refer to as *classic Dengue* in this paper. *Classic Dengue* is comparable to the flu, with symptoms that are very unpleasant, but temporary and not life threatening (including: severe headache, abdominal pain, muscle and joint pain, mucosal bleeding, lethargy, nausea and vomiting (WHO, 2009)). In contrast, *severe Dengue* results in serious illness, and sometimes death. During 2010, it resulted in hospitalisation in approximately 80 percent of cases and



death in approximately 2 percent of cases in Colombia. However, the mortality rate has been substantially higher in the past - e.g. between 1990 and 1999 in Colombia, the mortality rate of *severe Dengue* was sometimes as high as 40 percent (Villar et al., 2015).<sup>4</sup> This history has contributed to the perception of the disease in Colombia as one to be feared.

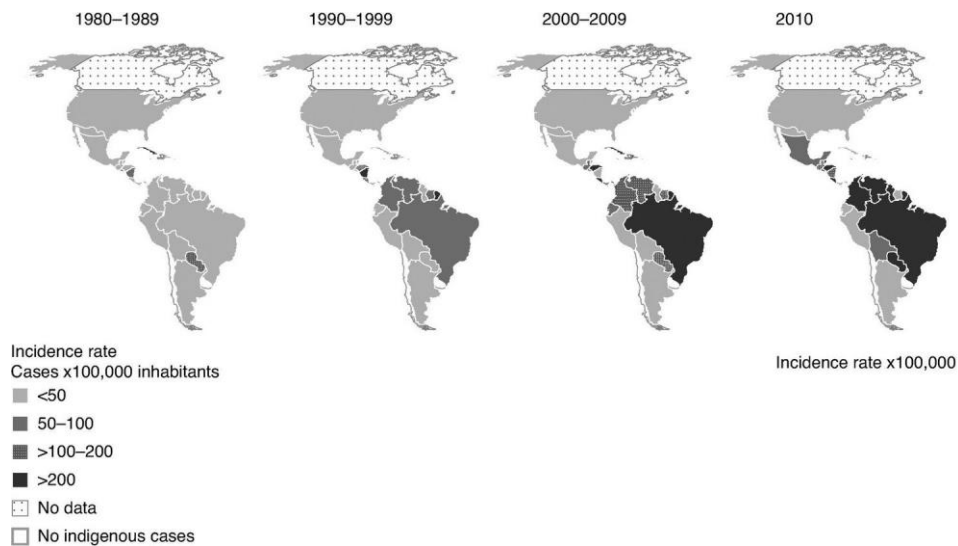


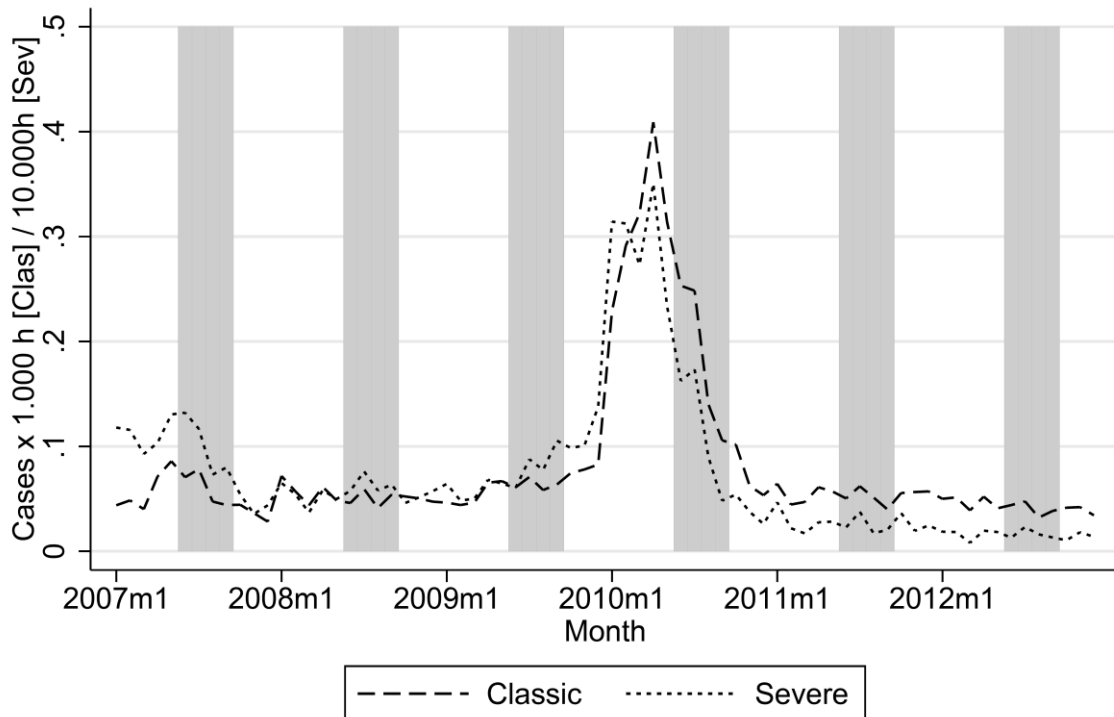
Figure 2: Dengue Incidence in the Americas, 1980-2010  
(reproduced from Tapia-Conyer et al. (2012))

According to Padilla et al. (2012), one of the primary reasons for the extremely rapid expansion of Dengue is climate change. This has contributed to the expansion of Dengue in two ways.

Firstly, it has increased temperatures and allowed mosquitoes to thrive in new regions and at higher altitudes. Secondly, there has been an increase in the frequency of droughts, resulting in an increase in reliance on water tanks as a means of water supply. Unfortunately, these stagnant water tanks provide ideal conditions for the *Aedes aegypti* reproduction<sup>5</sup>. The high prevalence of these water tanks means that when favourable climatic conditions do arrive, the mosquito population is in a position to multiply rapidly. This can result in a sharp spike in Dengue incidence.

In 2010, Colombia experienced a sharp spike of this nature when there was an unprecedented increase in Dengue incidence due, partially, to unexpectedly high rainfall variability (De La Mata and Valencia-Amaya, 2014). According to the *Instituto Nacional de Salud* (National Health Institute, or INS), which monitors the status of multiple diseases in Colombia, in 2010 there were 147257 reported cases of *classic Dengue*, and 9755 cases of

*severe Dengue*. The estimated incidence was 577 per 100 000 individuals for *classic Dengue* and 38.3 per 100 000 individuals for *severe Dengue* (Villar et al., 2015). Figure 3 shows clearly that the 2010 epidemic was both extremely sudden and sizeable, with the baseline incidence of Dengue in the years around the epidemic (2008, 2009, 2011, and 2012) being nearly flat.



Source: Own calculations using SIVIGILA data and 2005 Census population numbers. Vertical lines correspond to the 4 months prior to SABER 11 exam.

Figure 3: Municipal average incidence of Dengue fever per month

Aside from requiring sufficient rainfall for reproduction, altitude is the second factor that is important for determining whether a particular area is suitable for inhabitation by *Aedes aegypti*. Figures 4 and 5 show the incidence of *classic Dengue* and *severe Dengue* in 2008 - 2011 at different altitudes using a local linear approximation. These figures show that in 2010 there was a substantial increase in incidence at all altitudes, but perhaps more surprisingly, there was a considerable expansion of the disease to municipalities at altitudes above 1500m (Colombia is divided into 1123 Municipalities, which belong to 32 Departments), which in prior years were relatively unaffected<sup>6</sup>. Furthermore, Figure 6 shows that approximately 10% of municipalities transitioned from having 0 cases of *severe Dengue* in 2009 to being affected by the disease in 2010. A similar pattern is observed for *classic Dengue*. The geographical variation in *severe Dengue* incidence is illustrated in Figure 7. This figure presents the *severe*

*Dengue* incidence rates in 2010, colour coded according to the 2008 incidence, a pre-outbreak year. It shows that in 2010, the epidemic spread from endemic areas (shades of blue) to the areas where there were no cases in 2008 (shades of red).

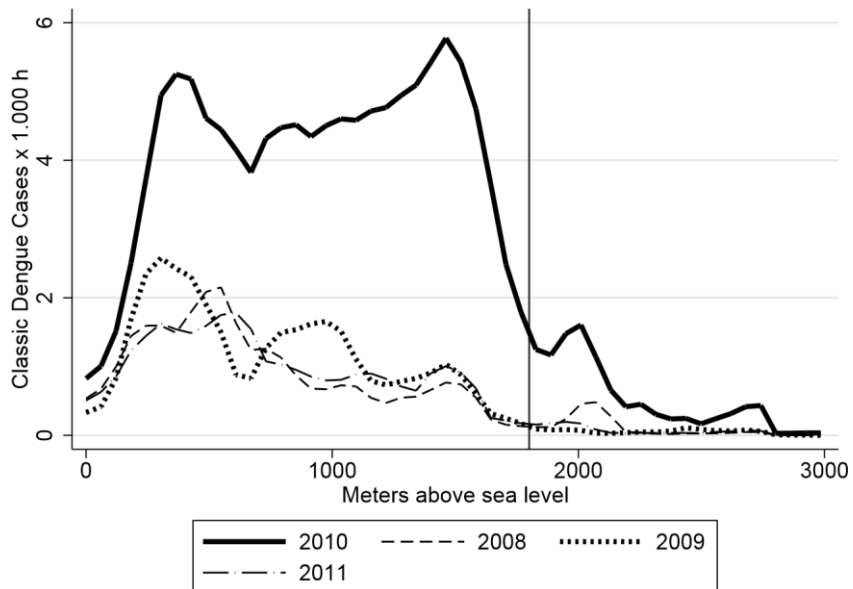
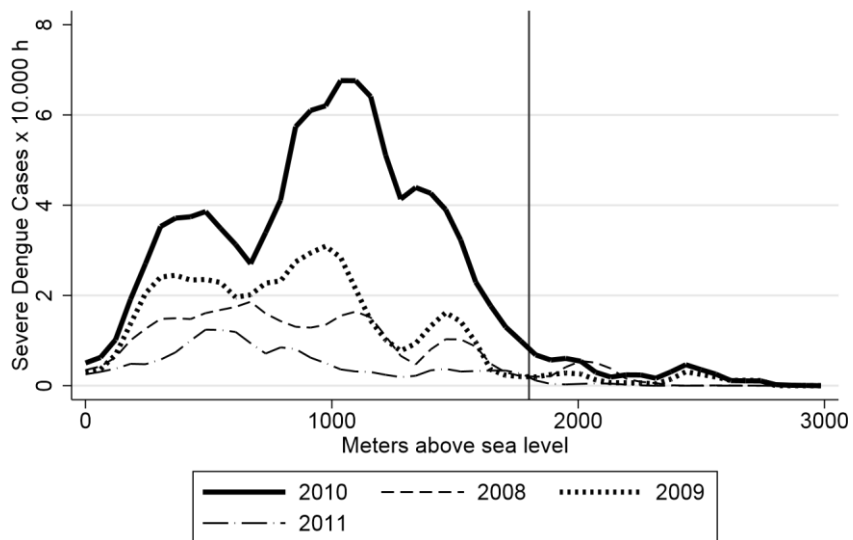


Figure 4: Municipal altitude and yearly incidence of classic Dengue fever



Source: Own calculations using SIVIGILA data and 2005 Census population numbers.  
Incidence rates are per calendar year.

Figure 5: Municipal altitude and yearly incidence of severe Dengue fever

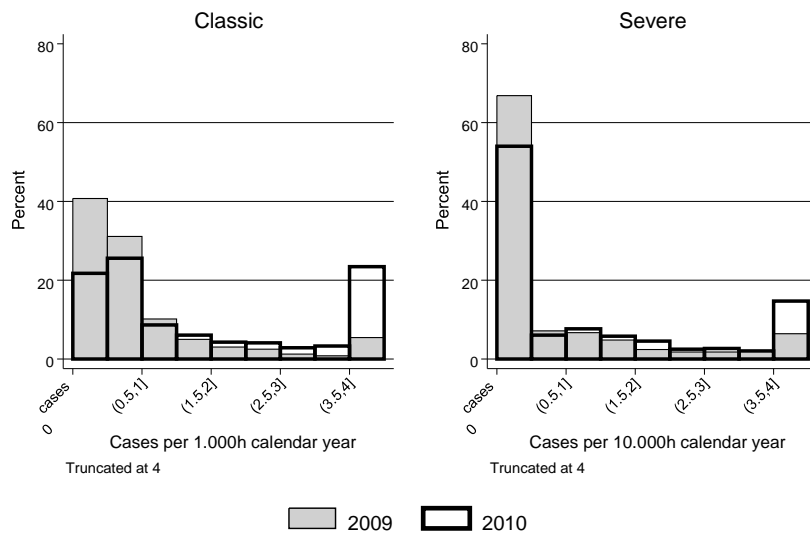


Figure 6: Distribution of classic and severe Dengue Incidence

Comparing the number of infections to the size of the Colombian population (approximately 46 million inhabitants in 2010), it is clear that the 2010 Dengue epidemic had a substantial effect. The direct economic costs of the disease were considerable, with Padilla et al. (2012) estimating that medical costs related to the disease during this year alone amounted to about US\$100 million. In addition to the public health costs, epidemics also place substantial pressure on households' budgets due to out-of-pocket health expenses and loss of productivity (Beatty et al., 2011).

Unfortunately, the burden of the epidemic is not equally distributed between the poor and the wealthy. One implication of the higher incidence of water tanks used by low-income households for their water supply is that these low-income households therefore tend to be at higher risk of Dengue than high-income households (Baylis and Risley, 2013). While these direct effects are certainly very serious, the objective of this paper is to examine the influence that it has on human behaviour, or more specifically, to examine the indirect impact that a short, sharp, relatively unexpected and uncertain health shock can have via a behavioural response.

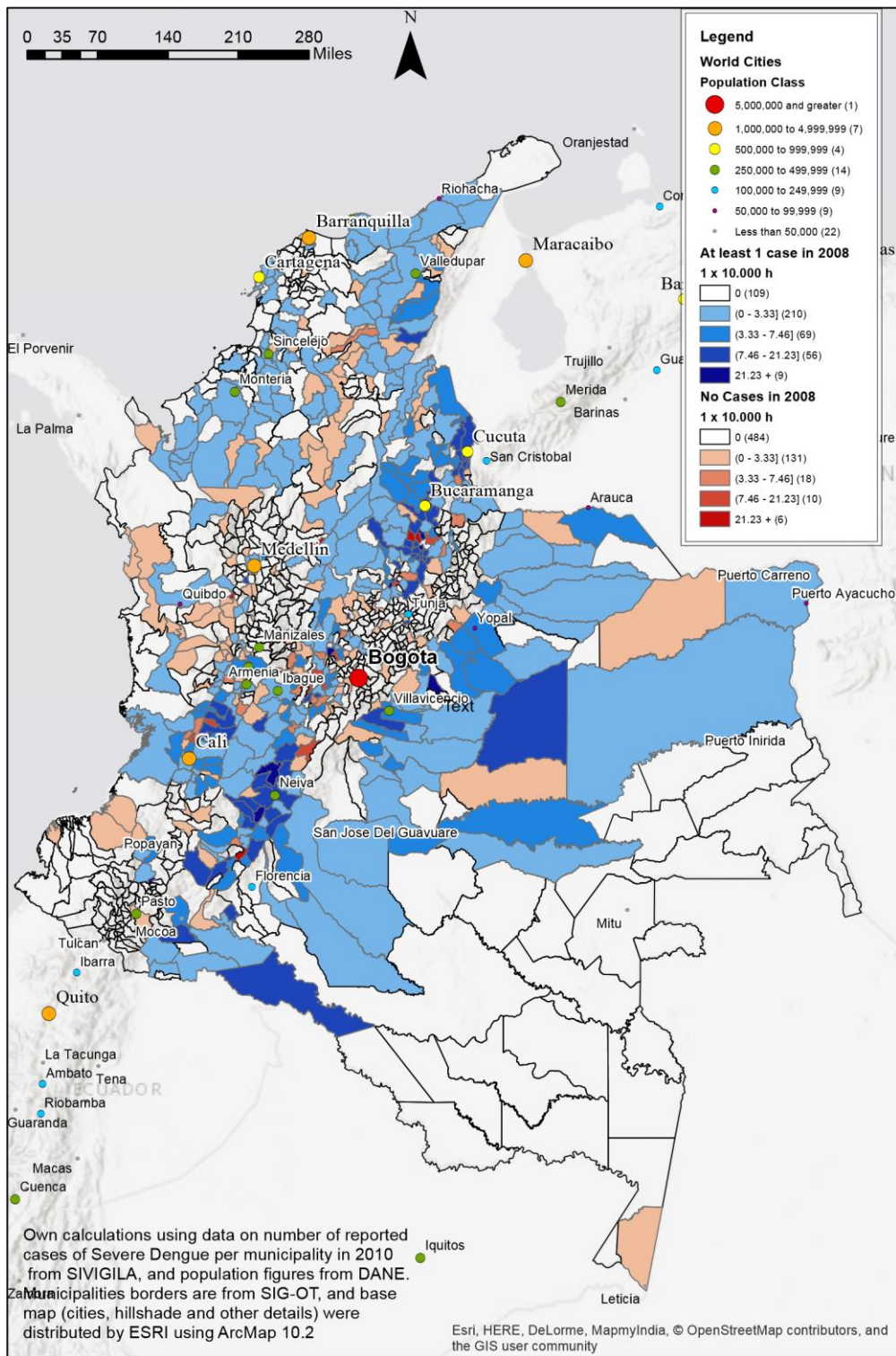


Figure 7: Geographical Distribution of severe Dengue Incidence in Colombia, 2010

## 3 Methods

### 3.1 Data

We use administrative data containing individual level schooling outcomes (e.g. examination attendance, and test scores for mathematics and language) from the high school leaving examination (named "SABER 11"), managed by ICFES<sup>7</sup>. The data also contains demographic information about the students and their families.

SABER 11 is the most important educational test taken during high school in Colombia because of its extensive use as a measurement of educational attainment. Each school student in the final (i.e. eleventh) year of high school is expected to take this examination. The test provides a national ranking that is used by universities in order to determine admission. Therefore, SABER 11 is important not only for students, as it is a requirement to continue their academic career, but also for schools as the average result is used by the government (and families) in order to determine the quality of the institution.

There are two dates for taking the test in the year. The decision regarding the timing of test taking is typically contingent on the academic calendar followed by the school. In Colombia the academic year usually corresponds to the calendar year, but a minority of schools follow the northern hemisphere academic year (September to June).<sup>8</sup> We focus on those schools where the academic year corresponds to the calendar year as the majority of the students (around 90%) attend these schools. In Figure 3, vertical lines correspond to the four months prior to the September exam date. As a result, it is plausible that the participation and performance in the 2010 exam was affected by the outbreak.

With respect to the SABER 11 test data, we also exclude schools that operate over the weekends or at night, which typically cater to young adults who are already working and want to finish their secondary education. After these exclusions, we have approximately two million observations available for analysis, covering the years 2007–2012. Table 2 describes the variables that we use from this dataset. Table 1 shows that Dengue rates were significantly higher in the months prior to the SABER 11 test in 2010 relative to other years. The table contains information about Dengue incidence rates in the four months prior to the exam in each year between 2007 and 2012.

Table 1: Dengue Incidence Rates 4 months before September SABER 11 test

Statistic	2007	2008	2009	2010	2011	2012
<b>C. Dengue 1000h (4M)</b>						
Mean	.28	.19	.26	.96	.22	.16
Stand. Dev	.78	.55	.87	1.8	.63	.44
Minimum	0	0	0	0	0	0
Median	0	0	0	.21	0	0
Percentile 75	.18	.17	.15	1.1	.21	.12
Percentile 95	1.7	.91	1.3	4.3	.96	.81
Maximum	10	8.4	13	22	13	5.2
1 year variation	.	-.087	.062	.7	-.74	-.056
<b>S. Dengue 10000h (4M)</b>						
Mean	.45	.24	.29	.66	.11	.071
Stand. Dev	1.7	.99	1	2.4	.55	.32
Minimum	0	0	0	0	0	0
Median	0	0	0	0	0	0
Percentile 75	0	0	0	.37	0	0
Percentile 95	2.7	1.4	1.8	3.3	.59	.43
Maximum	26	21	12	44	8.9	4.4
1 year variation	.	-.21	.049	.37	-.55	-.035

Source: Own calculations based on SIVIGILA data and DANE national census 2005 population numbers.

In our main analysis, we use the examination and demographic data at two levels of aggregation: (i) firstly, we use it as a longitudinal panel dataset at school level; and (ii) secondly, we use it as a repeated cross-section at the individual level.

In order to assess the impact of the epidemic, we combine the data described above with information regarding severe Dengue and classic Dengue cases collected weekly at the municipality level by the INS. From it we construct the incidence of the illness for the four months prior to the exam date (see incidence rates in Table 1).

Last, in parts of our analysis, it will be useful to have measures of exogenous factors that tend to exacerbate or moderate the intensity of the epidemic in a particular region. In particular, we have collected rainfall and temperature data, measured across time and geographic location, spanning the period of the epidemic. This weather data provides us with exogenous shocks that vary across time and space, and can be used to instrument for the intensity of the epidemic. In addition, we also collect altitude data, which is also predictive of the intensity of the epidemic, but does not vary across time, and is therefore only useful in certain instances within our analysis. This data, along with other relevant municipality level variables are summarised in Panel C of Table 2.<sup>9</sup>

Table 2: Descriptive Statistics for year 2010

Variable	Mean	SD	Obs
<b>Municipality: general characteristics (CEDE, DNP, SIHO, ERA-Interim ECMWF)</b>			
Total population (1000s)	41	250	1122
Altitude (meters above sea level)	1168	917	1086
Avg. 2m temperature (C), last 8 months (Aug)	20	3.6	1081
Avg. Precipitation (mm)*100, last 8 months (Aug)	.5	.35	1081
NBI Poverty Index x (year=2010)	45	21	1122
Subsidized Health Care / Population	.7	.48	1118
Log income per capita	-.39	.46	1092
Municipality dependence on central Gov. transfers	.58	.19	1118
Log-population	9.5	1.1	1122
Inpatient Beds per 10.000h	7.2	11	855
A&E positions per 10.000h	1.1	1.2	855
Certified x (year=2010)	.45	.5	1098
<b>Municipality: other infectious diseases (SIVIGILA)</b>			
Influeza-like per 1000h, Cal Y	.2	.65	1122
<b>Municipality: emergencies due to natural events (SNIGRD)</b>			
Total individuals	.87	6.7	1123
Total dwellings	334	875	1123
Total roads	.92	2.7	1123
Total hectares	227	1429	1123
<b>School characteristics</b>			
Private management	.27	.44	8463
Public management	.73	.44	8463
Full-day shift	.36	.48	8463
Morning shift	.47	.5	8463
Afternoon shift	.17	.37	8463
Female-only	.041	.2	8463
Male-only	.0093	.096	8463
Mix gender	.95	.22	8463
% of women test-takers	53	18	8463
% of SISBEN 1/2 of test-takers	69	35	8463
Average Income of the Families	1.6	1.3	8456
Number of test-takers	47	44	8463

Source: Own calculations based on ICFES data, *Sistema Nacional de Informacion y Gestion del Riesgo* (SNIGRD), *Sistema de Informacion de Hospitales Publicos* (SIHO), *Departamento Nacional de Planeacion* (DNP), *Sistema de Vigilancia en Salud Publica* (SIVIGILA), CEDE municipality dataset, and ERA-Interim (ECMWF) weather and altitude data. Certified municipalities are those who are able to determine how they spend part of their education and/or certain health care resources according to previous performance assessments by Central Government. For those non-certified, such expenses are controlled directly by the departmental authorities. This classification depends on population size and on some administrative quality indicators. The NBI is a government multidimensional poverty index which considers quality of life and access to public goods.



## 3.2 Empirical Strategy

Across all of our empirical specifications, we exploit the variation that we observe in the Dengue incidence over time and across geographical area. The identification of causal effects relies on the exogeneity of idiosyncratic time-shocks to Dengue incidence. We exploit the variation in Dengue incidence generated during the 2010 outbreak, by implementing a strategy that considers yearly variation in Dengue incidence between 2008 and 2012. While there was some important variation on the incidence rate between 2008 and 2009 (i.e. due to endemic cycles), and between 2011 and 2012, most of the variation comes from the 2009-2010 and 2010-2011 variation due to the massive outbreak in 2010. Further, we argue that part of this variation in the intensity of the epidemic across time and geographical area was driven by exogenous weather triggers that exacerbated or dampened the intensity of the epidemic. We will use measures of rainfall and temperature to capture the variation generated by these weather triggers.

Importantly, our empirical strategy will include both time and school (or municipality) fixed effects.<sup>10</sup> These will capture all variables at the school or municipality level that do not change over time, as well as all shocks that might affect the entire country at a particular point in time. Therefore, time-invariant factors such as altitude and poverty in a particular region which do tend to be related to the intensity of the outbreak in the area are captured by these fixed effects. However, we do consider the influence of the interaction between these time-invariant variables and the incidence of Dengue (e.g. we ask questions of the type: Does an additional case of Dengue have a different impact in an impoverished area, in comparison to an additional case in a richer area?).

The identification strategy relies on the assumption that the time-spatial variation in the intensity of Dengue is exogenous with respect to other time-varying variables that might affect the outcomes of interest. In general, this assumption would only be violated if there were some unobserved factor that varied both temporally and geographically and explained the variation in the 2010 Dengue epidemic, as well as variation in our outcomes of interest. We will discuss the main factors associated with the intensity of the outbreak, in order to make it clear that this assumption is credible.

Our analysis considers the impact of both *severe* and *classic* Dengue, but the primary focus is on the results for *severe Dengue* due to our interest in the behavioural effects of the epidemic. As primary unit of analysis, we will consider outcomes at both the school and student level.

### 3.3 Outbreak Intensity Analysis

Before studying the impact of Dengue on educational outcomes, we start our analysis by understanding which variables are good predictors of the strength of the intensity. We report the results from a linear panel regression of *severe Dengue* incidence on an array of municipality level covariates. The regression includes municipality level fixed effects to control for time-invariant factors. This analysis highlights the characteristics which are correlated with the incidence of *severe Dengue*, and provides background information that helps to understand and interpret the main estimates.

### 3.4 Analysis of test scores and attendance

#### 3.4.1 School Level Specification

As mentioned above, our main specification is at the school level.<sup>11</sup> Since Dengue incidence is measured at the municipality level, it is worthwhile highlighting the rationale for this choice. The primary reasons are, firstly, that it allows us to control for school level characteristics, thereby reducing the unobserved variation and improving the precision of our estimates. The second reason is that using a school level specification allows us to conduct a heterogeneity analysis and study how the impact of Dengue varies with observables within the municipality.

Our main analysis focuses on estimating the impact of the epidemic on attendance and test scores as there is a clear hypothesis for how the outbreak might affect these outcomes. In Appendix D (available in Supplementary Materials), we also report results related to class composition, with respect to gender and socio-economic level.

The school level impacts of Dengue are estimated using the panel of school level variables obtained by collapsing the SABER 11 administrative examination data at school level. For this specification, we exploit the fact that we observe the same schools over time to control for school level fixed effects. Therefore, we estimate the impact of Dengue incidence by using the following linear fixed effects panel estimator:

$$Y_{kjt} = \sum_{\tau=0}^T \delta_{\tau}^Y D_{jt-\tau} + \beta X_{kjt} + \gamma_k + \gamma_t + u_{kjt} \quad (1)$$

where  $Y_{kjt}$  is the outcome of interest for school  $k$ , in municipality  $j$ , in year  $t$ ;  $\gamma_k$  and  $\gamma_t$  are fixed effects for school and time respectively; and  $X_{kjt}$  is a vector of school and municipality level controls. The parameter that we are interested in estimating is  $\delta_{\tau}^Y$ , which reflects the impact of Dengue incidence, lagged by  $\tau$  periods, on the outcome of interest. Notice, we

include the lags to assess whether past Dengue incidence in the municipality plays any role in influencing the current outcomes.

### 3.4.2 Student Level Specification

Using the student level test data from SABER 11, we employ a similar specification to assess the influence of Dengue incidence on test scores. In this specification, we observe each student  $i$  in school  $k$  (where the errors are clustered at the school level), and estimate the following equation:

$$Y_{ikjt} = \sum_{\tau=0}^T \delta_{\tau}^Y D_{jt-\tau} + \beta X_{ikjt} + \gamma_k + \gamma_t + u_{ikjt} \quad (2)$$

Equation 2 follows a similar rationale to equation 1, with the exception of examining individual level outcomes, and the inclusion of individual level variables in the set of controls,  $X_{ikjt}$ .

### 3.4.3 Heterogeneous Effects

It is also of considerable interest to examine whether we observe heterogeneity in terms of which types of schools and municipalities were most affected by *severe Dengue* as this can help us to understand the mechanism driving the influence of the epidemic. The following specification allows us to interact a polynomial in a given observable characteristic with the treatment variable (Dengue incidence):

$$Y_{kjt} = \delta D_{kt} + \sum_{z=1}^{\#Z} (\delta_{2,z} D_{kt} \cdot Z_{zkjt} + \delta_{3,z} D_{kt} \cdot Z_{zkjt}^2 + \varphi_{1,z} Z_{zkjt} + \varphi_{2,z} Z_{zkjt}^2) + \beta X_{kjt} + \gamma_k + \gamma_t + u_{kjt} \quad (3)$$

where we consider heterogeneous effects in  $\#Z$  observable variables, indexed by  $z$ ; and  $Z_{zkjt}$  refers to a specific one of these variables for school  $k$ , municipality  $j$  and year  $t$ . In addition, we include fixed effects for the municipality and year, as well as a vector of controls,  $X_{kjt}$ , as in equations 1 and 2.

Table 3: Determinants of Severe Dengue Incidence (cases per 10.000h in the 2010 calendar year)

Regressors	$\bar{x}$	Below 2000 masl			Below 1000 masl	1000-2000 masl
		(1)	(2)	(3)	(4)	(5)
Altitude x (year=2010)	89.86	0.0005*** (0.0002)	-0.0004 (0.0002)	-0.0004** (0.0002)	0.0034*** (0.0011)	-0.0065*** (0.0016)
Avg. 2m temperature (C), last 12 months (Aug)	19.8	-0.7638*** (0.0736)	-0.7921*** (0.0735)	-0.3952*** (0.0832)	-0.7673*** (0.0784)	-0.8761*** (0.1355)
Avg. Precipitation (mm)*100, last 12 months (Aug)	0.528	-3.4004*** (0.6158)	-2.9169*** (0.5819)	-2.3260*** (0.5320)	-1.3342* (0.7089)	-3.6475*** (01.1033)
NBI Poverty Index x (year=2010)	3.492		-0.0650*** (0.0119)	-0.0327*** (0.0113)	-0.0352*** (0.0080)	-0.0735*** (0.0281)
Certified x (year=2010)	0.034		0.0014 (0.4101)	0.4011 (0.3769)	0.1099 (0.3895)	0.0771 (0.7313)
Year = 2009	0.077	0.6770*** (0.1199)	0.6906*** (0.1200)	0.4470*** (0.1041)	0.9570*** (0.1373)	0.0476 (0.2364)
Year = 2010	0.077	2.1203*** (0.2070)	5.8752*** (0.8968)	2.6510*** (0.8629)	3.1655*** (0.7154)	15.4000*** (03.8813)
Year = 2011	0.077	0.1627** (0.0765)	0.1393* (0.0774)	-0.1163 (0.1003)	0.1466** (0.0715)	0.042 (0.1954)
Year = 2012	0.077	-0.0062 (0.0514)	-0.0174 (0.0520)	-0.2064*** (0.0606)	-0.0395 (0.0500)	0.0008 (0.1090)
Classic Dengue per 1000h, Cal Y	0.441			0.4994*** (0.0816)		
N Observations		5118	5022	5022	2826	2166
N Clusters (Departments)		853	837	837	471	361
Adjusted R <sup>2</sup>		0.114	0.139	0.254	0.177	0.184

† Linear panel fixed effects regression at municipality level with Severe Dengue Incidence (10.000 cases per hab., calendar year) as a dependent variable. Certified municipalities are those who are able to determine how they spend part of their education and/or certain health care resources according to previous performance assessments by Central Government. For those non-certified, such expenses are controlled directly by the departmental authorities. This classification depends on population size and on some administrative quality indicators. The NBI is a government multidimensional poverty index which considers quality of life and access to public goods. A summary of the variables included in this table is presented in Table 2. Robust standard errors in parenthesis. Significance: \* 10%, \*\* 5%, \*\*\* 1%.

## 4 Results

### 4.1 Analysis of the outbreak intensity

Table 3 presents an analysis of the relationship between municipality level variables and Dengue incidence rates. As one might expect, there is a clear relationship between *severe Dengue* and the economic profile of the municipality, summarized here by the poverty index. Interestingly, altitude, which has a strong influence on local climatic conditions, has a different

sign at low altitudes and high altitudes (Columns 4 and 5). At low altitudes (Column 4), an increase in altitude is positively correlated with *severe Dengue*, whereas at higher altitudes (Column 5), it is negatively correlated. This implies an inverse-U shaped conditional correlation between altitude and *severe Dengue* in 2010.

Lower rainfall levels, which assist the reproduction of the mosquito (as it is more likely to find stagnant water), are a strong predictor of the intensity of the outbreak. Other variables such as the municipality's degree of control over health expenses (i.e. being a 'certified' municipality<sup>12</sup>) are irrelevant once poverty levels are taken into account.

It is also important to consider the relationship between poverty and Dengue incidence. Table 3 shows that wealthier municipalities (low NBI poverty index) have a higher Dengue incidence. An explanation for this is the fact that here we are considering municipality level variation. Therefore, while urban municipalities tend to be wealthier *on average*, they contain a large number of poor individuals living in densely populated urban slums, with inadequate access to public goods, in particular, piped water. The coincidence of these two factors, high population density and poor access to public services, provide ideal conditions for Dengue outbreaks. In contrast, while the rural municipalities are poorer on average, the lower population density implies less conducive conditions for Dengue. Therefore, our results suggest that Dengue incidence is higher in wealthier urban municipalities, but not that the rich are affected more by Dengue.

Taken together, these results provide support for the validity of our main identification assumption (i.e. that our results are not driven by another variable that covaried with Dengue in 2010). Firstly, the outbreak comprised a sharp and unexpected increase in Dengue that occurred over a relatively short period of time. Secondly, the majority of factors that one would expect to drive an epidemic of this nature are fixed over the short period of time we are considering (e.g. altitude, demography of population, health care and public health system characteristics). Furthermore, the main type of variable that we may expect to vary across time and also influence the epidemic are climatic factors. However, we are able to control for both climatic variation and natural disaster information with our control variables.

## 4.2 Test Attendance

We begin our analysis of the outbreak effects by examining the impact of 1 additional case of Dengue (per 10 000 inhabitants for *severe Dengue* and per 1 000 inhabitants for *classic Dengue*) on the number of students who took the school leaving examinations in 2010 using equation 1.

The results are displayed in Table 4. Firstly, columns (2) and (4) show that an increase in *classic Dengue* has no significant effect on participation in the SABER 11 examination. However, columns (1) and (3) show that there is a large contemporaneous effect of *severe Dengue* on attendance in the examination. More specifically, the magnitude of the estimates suggests that for each additional case of *severe Dengue* per 10 000 inhabitants in the municipality, 1 percent fewer students attended the examination. This implies that if there is an increase in *severe Dengue* cases by 10 per 10 000 inhabitants, in the average school cohort of 47 pupils, 4.7 - 5.2 fewer pupils attended the examination (using the estimates from column (1) and (3) respectively). While it is important to stress that having 10 cases of *severe Dengue* per 10 000 inhabitants is in general fairly rare, over 10 percent of municipalities in Colombia had an incidence rate at least this high during the 2010 epidemic.

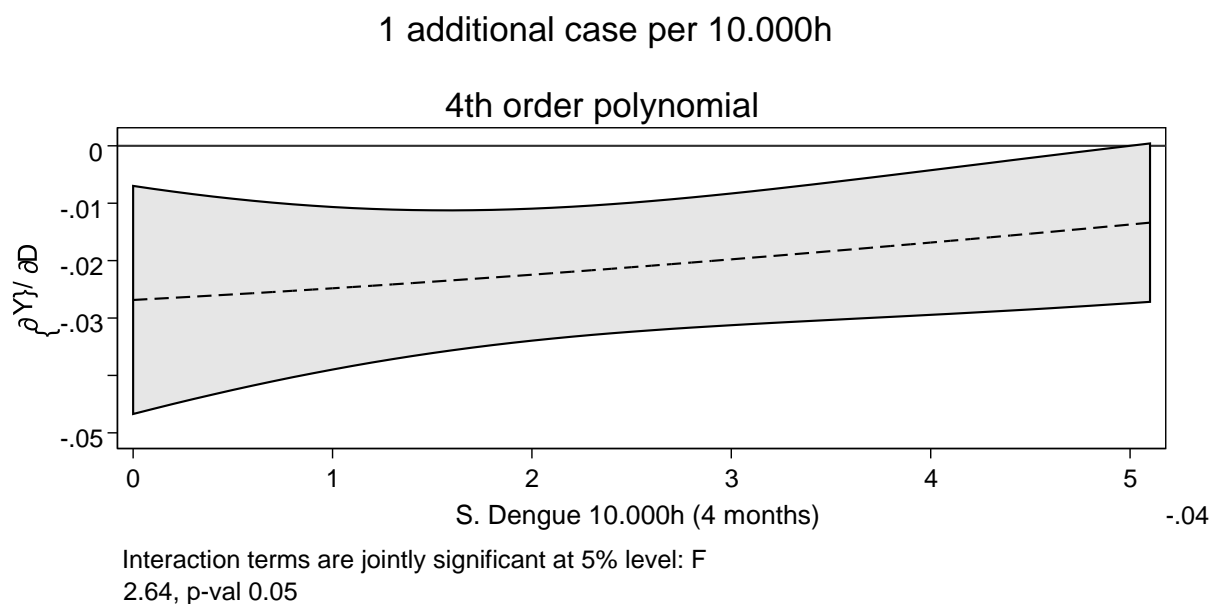
Table 4: Number of test takers per school and Dengue Incidence

	LOG(Number of students who presented the test)				LOG(Number of schools per municipality with at least 1 SABER 11 test taker)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
S. Dengue 10000h (4M)		-0.010**		-0.011**	-0.036		-0.003	
	(0.0050)		(0.0050)		(0.0340)		(0.0210)	
L.S. Dengue 10000h (4M)			-0.005				0.033	
			(0.0040)				(0.0250)	
L2.S. Dengue 10000h (4M)			0				0.055	
			(0.0030)				(0.0400)	
C. Dengue 1000h (4M)		0.002		0.004		-0.068		-0.023
		(0.0050)		(0.0050)		(0.0590)		(0.0370)
L.C. Dengue 1000h (4M)				0.003				0.036
				(0.0050)				(0.0470)
L2.C. Dengue 1000h (4M)				0.005				0.08
				(0.0070)				(0.0830)
Observations	37299	37299	30862	30862	3935	3935	2998	2998
Schools/Municipalities	8839	8839	8746	8746	837	837	836	836
Municipalities	837	837	836	836	837	837	836	836
Adj. R squared	0.0217	0.0209	0.0241	0.023	0.0424	0.0425	0.0191	0.0191

Linear fixed effects panel regression at school level (see Equation 1). S. Dengue is the reported incidence of Severe Dengue in the last 4 months (4M) at municipality level and C. Dengue is the incidence of Classic Dengue at the same level. L.S. Dengue and L.C. Dengue are the lag of Severe and Classic Dengue, respectively. On top of the fixed effects by school and by year, these controls for Inpatient beds and AE positions per 10.000h, Subsidized Health Care registry as a percentage of Population, municipality dependence on central government transfers, municipality per capita income, the incidence rate of influenza-like cases per 1.000h in the municipality during the calendar year, avg. temperature and rainfall for the last 8 months, log-population and the standardized number of people, houses and roads affected by natural disasters. See Table 2 for further details. Clustered standard errors at municipality level in parenthesis. Significance: \* 10%, \*\* 5%, \*\*\* 1%.

One potential explanation is that entire schools closed during the epidemic, and consequently the students did not sit the examination. This could be the case if they had to close because of public health considerations.<sup>13</sup> Columns 5 to 8 in Table 4 consider as an outcome the number of schools per municipality for which at least one student took the test. As a result, there is no evidence of Dengue leading to school closures.

While the discussion of Table 4 above showed that on average an increase in *severe Dengue* implied a decrease in examination attendance, it is interesting to consider whether this impact was non-linear. To explore this, the marginal effects of *severe Dengue* at different levels of *severe Dengue* intensity are plotted in Figure 8 using a polynomial of order 4. The non-linear terms are jointly different from 0, but the difference between the point estimates at intensity level 0 and 5 are not statistically different from one another at the 90% level.



SE clustered at municipality level for 90% confidence intervals. Incidence defined over the last 4 months before SABER 11 test. Incidence restricted to 5 cases per 10.000 h for easiness of exposition

Figure 8: Marginal effect of severe Dengue on the LOG number of Test Takers: non-linear effects

### 4.3 Test Scores

We explore the impact of Dengue incidence (*classic* and *severe*) on mathematics and language scores, conditional on having taken the exam in these subjects. Table 5 indicates very small estimates for the impact at student and school level, respectively. The size of these estimates

for the impact of Dengue is put into perspective if we compare them to the magnitude of the influence of other characteristics that are known to be related to test scores, such as gender for mathematics. While, the gender gap in mathematics is 0.3 standard deviations, an additional case of *severe Dengue* is associated with a decrease of only 0.003 standard deviations in language, and does not have a significant effect on mathematics at all, conditional on examination attendance. A similar pattern is observed when using the mean test scores aggregated at the school level. Therefore, we conclude that the epidemic had a negligent effect on test scores, conditional on participation.

Table 5: Test scores

Variable	Student level				School level			
	Math	Math	Lang	Lang	Math	Math	Lang	Lang
S. Dengue 10000h (4M)	0.0007 (0.0011)		-0.0034** (0.0014)		0 (0.0020)		-0.005* (0.0020)	
S. Dengue 10000h (4M), 1 year ago	0.0014 (0.0013)		-0.0059*** (0.0012)		0.002 (0.0020)		-0.005** (0.0030)	
S. Dengue 10000h (4M), 2 years ago	-0.0008 (0.0012)		-0.0030*** (0.0010)		0 (0.0020)		-0.002 (0.0020)	
C. Dengue 1000h (4M)		0.0031* (0.0017)		0.0074*** (0.0020)		0.006** (0.0020)		0.002 (0.0040)
C. Dengue 1000h (4M), 1 year ago		0.0002 (0.0019)		0.0165*** (0.0024)		0.002 (0.0030)		0.010** (0.0040)
C. Dengue 1000h (4M), 2 years ago		-0.0045** (0.0020)		0.0170*** (0.0022)		-0.005 (0.0040)		0.007 (0.0060)
=1 if student is a girl	-0.3106*** (0.0021)	-0.3106*** (0.0021)	-0.0319*** (0.0017)	-0.0319*** (0.00172)				
N Observations	1501868	1501868	1508018	1508018	30862	30862	30864	30864
N Clusters (Schools)	8746	8746	8743	8743	8746	8746	8746	8746

For the first four columns, reported coefficients come from an OLS over a repeated cross section, with fixed effects at school level (see Equation 2). For the last four columns, the estimated model is a linear fixed effects panel regression at school level (see Equation 1). In each case, the two left-hand columns employ standardised mathematics scores as dependent variables and the two remaining are standardised language scores. S. Dengue is the reported incidence of Severe Dengue in the last 4 months (4M) at municipality level and C. Dengue is the incidence of Classic Dengue at the same level. On top of the fixed effects by school and by year, these controls for Inpatient beds and AE positions per 10.000h, Subsidized Health Care registry as a percentage of Population, municipality dependence on central government transfers, municipality per capita income, the incidence rate of influenza-like cases per 1.000h in the municipality during the calendar year, avg. temperature and rainfall for the last 8 months, log-population and the standardized number of people, houses and roads affected by natural disasters. See Table 2 for further details. Clustered standard errors at municipality level in parenthesis. Significance: \* 10%, \*\* 5%, \*\*\* 1%.



These results are comparable to those of Goulas and Megalokonomou (2016), who found that the swine flu outbreak (2009-10) in Greece triggered an increase in high school students' absenteeism. However, in their case this behavioural change resulted in an increase in average test scores, indicating a stronger pattern of selection (i.e. it suggests that in their context weaker students selected into absenteeism).

#### 4.4 Heterogeneous effects

In this section, firstly, we examine whether the impact of *severe Dengue* varied according to the prior incidence of the disease. More specifically, we consider the impact in municipalities which had no cases of *severe Dengue* in 2007 and 2008 separately from municipalities that were already afflicted in these previous years. Secondly, we assess whether the characteristics of the municipalities and the school affected the impact of Dengue on students who attended that school.

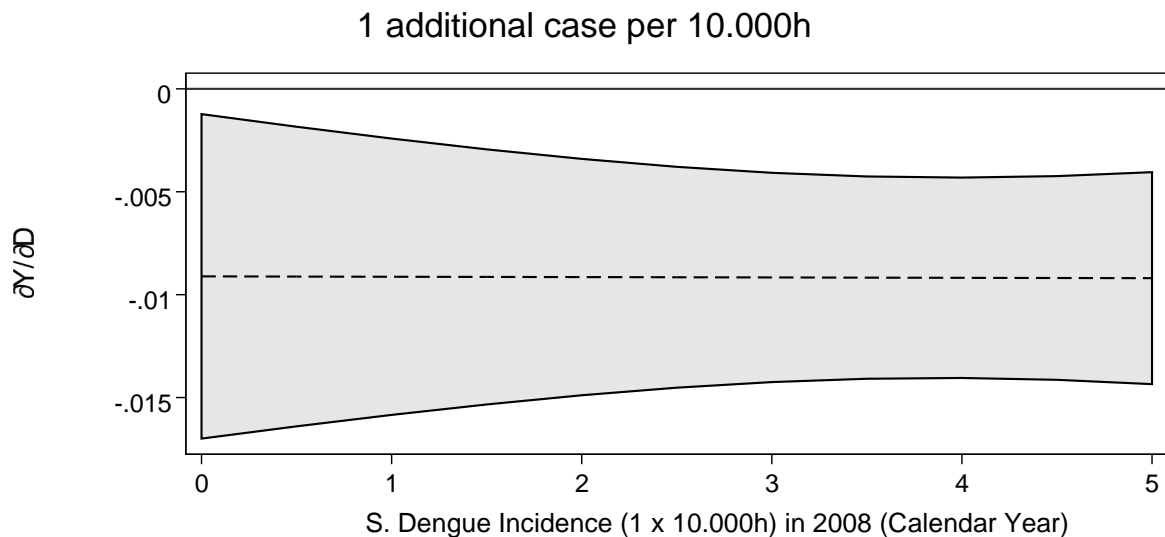
Table 6 compares the behavioural response to *severe Dengue* in municipalities that were not affected by *severe Dengue* prior to the epidemic (i.e. in 2007, 2008) to endemic municipalities. This is done by interacting the intensity variable with an 'endemicity' indicator. While the coefficient for those places that normally do not have severe Dengue seems to be larger, these coefficients are not statistically different from one another. Furthermore, Figure 9 shows that for those municipalities with at least 1 case of *severe Dengue* in 2008, there was no differential effect according to prior intensity level.

Table 6: S. Dengue Impact by Prior Intensity

	LOG(Takers) (1)	Maths (2)	Lang (3)
S. Dengue x No Cases 2007, 2008	-0.011** (0.005)	0.001 (0.004)	-0.003 (0.004)
S. Dengue x At least 1 Case 2007-2008	-0.006** (0.003)	0.000 (0.002)	(0.003) (0.002)
Observations	37299	37299	37301
Schools	8839	8839	8839
Avg. periods per school	4.22	4.22	4.22
Municipalities	837	837	837
Adj. R squared	0.02	0.02	0.01
H0: impact is the same	0.4561	0.868	0.959

Linear fixed effects panel regression at school level (see Equation 1). In Column 1, the dependent variable LOG(Takers) is the logarithm of the number of students who presented the test per school. In Columns 2 and 3, the dependent variables are the standardised test result in mathematics (Maths) and language (Lang). S. Dengue is the reported incidence of Severe Dengue in the last 4 months (4M) at municipality level, and it is interacted with a couple of dummies that indicates the presence or not of Dengue cases in the past. On top of the fixed effects by school and by year, these controls for Inpatient beds and AE positions per 10.000h, Subsidized Health Care registry as a percentage of Population, municipality dependence on central government transfers, municipality per capita income, the incidence rate of influenza-like cases per 1.000h in the municipality during the calendar year, avg. temperature and rainfall for the last 8 months, log-population and the standardized number of people, houses and roads affected by natural disasters. See Table 2 for further details. Clustered standard errors at municipality level in parenthesis. Significance: \* 10%, \*\* 5%, \*\*\* 1%.

Using the same specification from equation 3, we estimate the heterogeneous effects of *severe Dengue* by school and municipality characteristics. Figure 10 presents these estimates of heterogeneous effects for an indicator of the capacity of the health system in the municipality, the size of the municipality given by its population, as well as for a school level measure of average household income of the families of children in that school, relative to the municipality average.<sup>14</sup>



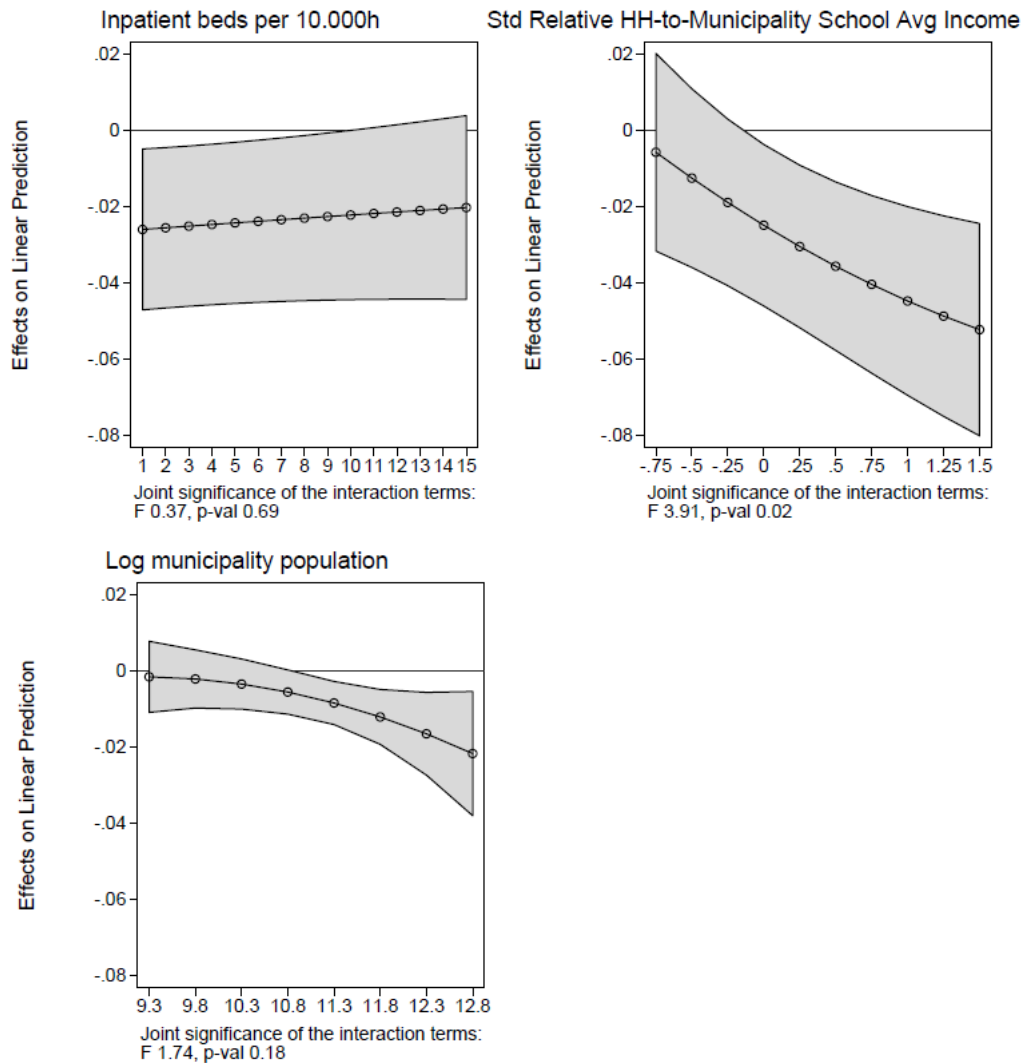
Linear interaction term between outbreak (2010) and pre-outbreak (2008) incidence was not different from 0 (p-val: 0.99). SE clustered at municipality level for 90% confidence intervals. Incidence of the vertical axis is defined over the last 4 months before SABER 11 test. Incidence restricted to 5 cases per 10.000 h for easiness of exposition

Figure 9: Marginal effect of severe Dengue on the LOG number of Test Takers: by S. Dengue Incidence in 2008

The rationale for examining the influence of the health capacity of the municipality is that one might expect the public's perception of the ability of the municipality to contain an epidemic may affect the beliefs of members of the community regarding their mortality risk due to the epidemic. This could then affect their behaviour in response to the epidemic. Furthermore, one would expect that the public's perceptions regarding the efficacy of the health system would be related to measures of the true efficacy. The upper left panel of Figure 10 does not provide much evidence in favour of a heterogeneous impact due to variation in the number of inpatient beds per 10.000 inhabitants, one of the main infrastructure indicators of the health system. While the point estimates for the coefficients are negative everywhere, these interactions terms are not jointly different from 0.

Interestingly, in the right upper panel, there appears to be a clear pattern when considering heterogeneity in the self-reported income index. The impact is not significantly different from 0 when considering schools with low average income levels, but the point estimate of the impact decreases to around -5 pp for schools with high average income levels.

Avg Marginal Effects of S. Dengue incidence  
with 95% CIs



Domain of Z: 5%-95%. Polynomial of order 3 on Z.  
Std Relative HH-to-Municipality School Avg Income refers to the standard deviations of the average HH. income index of a school from the value of the municipality

Figure 10: Marginal effect of severe Dengue on the LOG number of Test Takers:  
heterogeneous effects

Importantly, our income measurement considers the school level average household income level, relative to the municipality average.<sup>15</sup> This relative measure is employed to ensure that we remove municipality level effects related to income (e.g. the influence of the relevant

municipality being urban or rural). As discussed above, Dengue tends to be more prevalent in urban environments due to the high population density assisting reproduction. Since urban areas tend to be wealthier, using a measurement of absolute income levels, without controlling for municipality effects, might confound these two effects (i.e. the influence of income, and population density). This last effect, the influence of population size, is captured in the lower panel which shows that the magnitude of the behavioural impact of Dengue was increasing in the population size of the municipality (i.e. the behavioural response was stronger in cities as opposed to towns).

The previous exercise was also carried on the average mathematics and language test scores and is available in Appendix D (available in Supplementary Materials). For mathematics, marginal effects are statistically equal to zero across all three variables. For language tests, the shapes of the effects are the same as the shapes observed for student attendance, but still the size of the coefficients is small.

#### 4.5 Robustness Checks

In order to test our identification assumptions, we conducted several robustness exercises. The main results of these exercises are summarised in Table 7, while we also provide a more detailed discussion of the exercises and results in Section B of the Supplementary Material associated with the paper.

First, we conducted a placebo test in which we assessed the impact of future Dengue shocks (two years leads of incidence rate) on current outcomes. It showed no evidence of any anticipatory effects. Secondly, we varied the incidence window used in our estimation to ensure that was not driving our results. Thirdly, we estimated our specifications for the restricted sample of municipalities with non-zero *severe Dengue* incidence. Fourth, we restricted the sample to only use variation from the period between 2008 and 2010 in order to avoid a potential recovery effect.<sup>16</sup> The estimates from this exercise suggest a lower point estimate of 0.4 pp. instead of 1 pp, consistent with double counting due to individuals postponing the exam by one year as opposed to never taking it (see footnote 16). Finally, we performed a matching exercise in which we use a synthetic control strategy to approximate an experiment in which some municipalities are randomly treated with additional cases of *severe Dengue*.

Table 7: Robustness checks exercises

	MAIN	PLACEBO	NZI	2008/10	SYNC
	(1)	(2)	(3)	(4)	(5)
S. Dengue 10000h (4M)	-0.011**	0.005	-0.011**	-0.004*	-0.008**
	(0.005)	(0.006)	(0.005)	(0.002)	(0.003)
L.S. Dengue 10000h (4M)	-0.005	-0.003	-0.010*		-0.001
	(0.004)	(0.003)	(0.006)		(0.003)
L2.S. Dengue 10000h (4M)	0	0.004	-0.001		-0.002
	(0.003)	(0.003)	(0.004)		(0.003)
Observations	30862	26956	12682	20799	13108
Municipalities	836	836	363	837	3721

In all columns the dependent variable LOG(Takers) is the logarithm of the number of students who presented the test per school. MAIN: This column reproduces the main result discussed above. PLACEBO: In this exercise, future variation on dengue incidence is used in order to explain the variation on the number of students who present the test. It includes variation of incidence rates from 2009 to 2012, and on SABER 11 participation from 2007 to 2010. NZI: The exercise was restricted municipalities with at least one case of severe dengue. 2008/10: Sample restricted to years 2008 to 2010 SYNC: A synthetic control strategy was used in this specification in order to obtain a more balanced control group.

Linear fixed effects panel regression at school level (see Equation 1). S. Dengue is the reported incidence of Severe Dengue in the last 4 months (4M) at municipality level. L.S. Dengue is the lag of Severe Dengue. On top of the fixed effects by school and by year, these controls for Inpatient beds and AE positions per 10.000h, Subsidized Health Care registry as a percentage of Population, municipality dependence on central government transfers, municipality per capita income, the incidence rate of influenza-like cases per 1.000h in the municipality during the calendar year, avg. temperature and rainfall for the last 8 months, log-population and the standardized number of people, houses and roads affected by natural disasters. See Table 2 for further details. Clustered standard errors at school level in parenthesis. Significance: \* 10%, \*\* 5%, \*\*\* 1%.

## 5 Discussion

Our results show that the Dengue outbreak had a strong impact on the number of students who took the SABER 11 test. To put the size of the estimates into perspective, consider an average school with a cohort of 47 students in an average municipality (which has around 7.7 schools). The estimated impact of 1pp implies that for each additional case of *severe Dengue* per 10 000 inhabitants during the 4 months prior to the examination, 0.47 fewer students took the examination per school.

Since the average increase in incidence between 2009 and 2010 was 0.37, the mean impact of the outbreak on test taking was a reduction of around 1.34 students per municipality. If we consider only municipalities affected by the epidemic (i.e. non-zero cases), the average change in *severe Dengue* incidence was 2.11, implying a substantial reduction of 7.63 students. However, we should bear in mind that in some municipalities the epidemic was even more harmful, with the incidence increasing by more than 10.

Overall, it does not appear that the epidemic had a relevant impact on the scores that students achieved in the examinations. In order to have an impact of a similar magnitude, there would need to be an unrealistic increase of over 100 cases per 10 000 inhabitants in severe Dengue.<sup>17</sup> Therefore, we conclude that the estimated short-run effect of Dengue incidence on test scores, conditional on exam attendance, should be treated as being zero, for practical purposes. It is important to qualify this statement by mentioning that this observed zero effect may be driven by the fact that severe Dengue causes some students not to attend the exam. If these students tend to be poorly prepared students, then this selection effect would imply an underestimation of the effect of Dengue on test scores.

The impact of Dengue on examination attendance seems to be an indirect effect due to a behavioural response to the epidemic: given the magnitude of the estimates, the number of students affected could be up to 100 times larger than the number of individuals who contracted *severe Dengue* if we compare the 1/100 impact with the 1/10.000 change in the incidence rate.<sup>18</sup>

However, it is worth mentioning a few caveats to this interpretation. Firstly, the impact on students is likely to be smaller than this as the incidence rate for students could have been underestimated in this exercise. This is because the age-group incidence for students tends to be larger than the entire municipality average (Padilla et al., 2012). Secondly, there is the possibility that underreporting and misclassification between *severe* and *classic* Dengue might also be an issue. However, underreporting of *severe Dengue* is unlikely to be substantial due to the severity of the disease. Lastly, our main estimates might overestimate the true effect due to the potential presence of a recovery effect - an increase on cohort size in 2011 because of students postponing taking the exam from 2010 to 2011 in Dengue-prone areas. Taking this into consideration, our robustness exercises suggest that the true magnitude of the effect lies between 0.4 pp. and 1 pp.

Nevertheless, our results indicate that the observed behavioural response is not due to a direct effect of illness: we do not find any impact of *classic Dengue*, even with much higher incidence rates of nearly 1/1000 inhabitants. While it is true that it is milder than the *severe* version, it is still debilitating. In some areas, the disease is known as the '*bone breaker fever*'

(Fajardo et al., 2001), which gives an idea of the temporary debilitating effect that it generates.

Our behavioural explanation relies on the assumption that households considered it to be riskier to send their children to school than for them to stay at home. This is consistent with the high degree of uncertainty and fear that is often generated when there is a sudden and severe new epidemic. Support for this argument comes from web searches for Dengue that coincided with the epidemic.<sup>19</sup>

The effect of *severe Dengue* in a municipality extended far beyond its direct influence on the afflicted households. Furthermore, the fact that the effect had a strong income gradient is striking. The following are potential explanations for this finding. Firstly, it is likely that the children of wealthier households face a lower baseline risk of contracting the disease at home if they remain away from public areas in contrast to the children of poorer families, who live in more densely populated areas and face a higher risk of contracting the disease in their local neighbourhood. This difference in the relative risk between home and public areas may make rich families less inclined to send their children to public spaces. Secondly, wealthier families are likely to have greater savings and be able to afford to delay the school leaving examination in order to reduce the perceived risk of being exposed to the epidemic by staying out of school. Thirdly, the examination is more likely to be pivotal for wealthier students, in the sense of being on the borderline between being accepted into tertiary education and not being accepted. These pivotal students might be more likely to delay the examinations by a year if they think the disease will negatively influence their performance.

## 6 Conclusion

This paper provides new evidence regarding the behavioural response to a short, sharp, unexpected increase in the incidence of both *classic* and *severe* Dengue fever in Colombia on students' outcomes. The striking finding is that the likelihood that final year secondary students attend their school leaving examination is reduced on average by between 0.4 to 1 pp if the incidence of *severe Dengue* increases by 1 case per 10,000 inhabitants in the 4 months prior to the exam. This is not the case for *classic Dengue*, which has no impact. These results are estimated using the geographic and temporal variation in *severe Dengue* incidence between 2008 and 2012.

These results suggest a behavioural risk-prevention response to the high degree of uncertainty generated by a sudden and severe epidemic. It does not seem plausible that the results are driven by either the direct or indirect consequences of illness of family members.



This conclusion is drawn from the fact that while *classic Dengue* is far more prevalent, it had no impact, and furthermore, the estimated reduction in the number of students who missed or delayed their school leaving examination was larger than the number of individuals afflicted by *severe Dengue*. The behavioural response may be explained by the fact that contracting *severe Dengue* resulted in death in 2 percent of cases in 2010. Furthermore, the fact that it had mortality rates of up to 40 percent during the preceding two decades in Colombia would have contributed to the fear and uncertainty generated by the 2010 epidemic.

The results, in conjunction with those from the preceding literature, suggest that in addition to addressing the direct health concerns generated by an epidemic, substantial benefit may be obtained from ensuring that the public is well-informed regarding the facts pertaining to the channels of transmission and good practices for reducing the development and spread of the disease.

## Endnotes

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<sup>1</sup> This finding is consistent with a large body of evidence from the non-expected utility literature, which argues that individuals tend to behave as if they overweight the probabilities associated with the 'best' and 'worst' outcomes from the feasible set of outcomes, such as Choquet-expected utility (CEU) and cumulative prospect theory (CPT) (Schmeidler, 1989; Tversky and Kahneman, 1992; Wakker and Tversky, 1993).

<sup>2</sup> These results are robust to alternative specifications, and a placebo test shows that they are not driven by the empirical strategy.

<sup>3</sup> In the average municipality, there are 41 000 inhabitants. Of these, 21 percent are enrolled in primary or secondary school. The school leaving examinations are taken by students in the last year of secondary school - in the average municipality, there are 464 students enrolled in this final year of school, and 363 of them took the SABER 11 examination. Therefore, 4.1 extra cases 4 months before the exam of *severe Dengue* in the entire municipality (i.e. one additional case per 10 000 gives  $41\,000 / 10\,000 = 4.1$ ) would imply that 3.6 fewer students sat their SABER 11 examination in the municipality (i.e. one percent of 363 is approximately 3.6).

<sup>4</sup> For detailed reviews, particularly in relation to Colombia and the Americas, see Dick et al. (2012), Villar et al. (2015), Teixeira et al. (2013) and WHO (2009).

<sup>5</sup> Water tanks provide *Aedes aegypti* with a place to lay its eggs during dry periods and keep the baseline population level high while waiting for more favourable conditions. The average lifespan of the *Aedes aegypti* mosquito is two weeks, however, the eggs of the mosquito can lie dormant in dry conditions for up to nine months. They can then hatch if they are exposed to favourable conditions. *Aedes Aegypti* benefits from the existence of stagnant water tanks and is active at the beginning and end of the day. Previously, the areas in which this mosquito could be found were limited to the tropical and subtropical regions of the Americas, between the latitudes of 35° north and 35° south (Organizacion Panamericana de la Salud', 1995). The WHO notes that due to rapid geographical expansion dengue now ranks as the most harmful mosquito-borne viral disease in the world, affecting different geographic areas in the Americas, South-East Asia, the Eastern Mediterranean as well as the Western Pacific.

<sup>6</sup> The evidence provided by Figures 4 and 5 is supported by Table 1, which shows that this rapid expansion was not only due to an increase in incidence in endemic municipalities. Rather, for *severe Dengue*, 2010 was the only year in which the 75th percentile municipality was affected; while for *classic Dengue*, the incidence per 1 000 inhabitants for the municipality at the 75th percentile jumped dramatically from 0.15 to 1.1.

<sup>7</sup> ICFES is a government institution for the assessment of quality in education.

<sup>8</sup> These schools are concentrated in a few cities, especially in the capital which was unaffected by the outbreak because of its location.

<sup>9</sup> The general municipal characteristics data is sourced predominantly from the 2005 National Census. Data regarding natural disasters was compiled from the *Sistema Nacional de Informacion y Gestion del Riesgo* (SNIGRD) webpage, a government institution.

<sup>10</sup> Specifications at the school level include school fixed effects, while specifications at the municipality level include municipality fixed effects.

<sup>11</sup> We also considered municipality level estimates. These results are reported in Appendix A (available in Supplementary Materials). Results do not differ from the findings shown at school level.

<sup>12</sup> Certified municipalities are those who are able to determine how they spend part of their education and/or health care resources. This classification depends on previous performance assessments by the national government. For those that are non-certified, such expenses are controlled directly by the departmental authorities. This classification depends on population size and some administrative quality indicators.

<sup>13</sup> We are not aware of any such closure in Colombia, but it is a real possibility. In a Dengue outbreak in Paraguay (2009), at least one school was temporarily closed in the Bugaba district because of the high incidence of classic Dengue and the occurrence of two severe cases Vasquez' (2009).

<sup>14</sup> The rationale for the former is to consider whether people respond more in avoiding public spaces when there is a weaker health system that they might perceive as providing protection. The latter considers whether the wealthy respond to the epidemic differently to the poor.

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<sup>15</sup> While this variable does not reflect the relationship between absolute income levels and the behavioural response, it shows that, within a municipality, the households with a higher income responded more to the epidemic, controlling for regional-specific differences. The variable is measured in standard deviations of the income index.

<sup>16</sup> If it is the case that some of the students who did not take the test in 2010 decide to take it in 2011, the size of the 2011 cohort would increase beyond its usual non-epidemic times (especially in areas with favourable conditions for Dengue). As our estimates are based on yearly variation, the reduction in incidence in 2011 relative to 2010 would imply that students who postponed taking the test from 2010 to 2011 could potentially be double counted in our main estimates.

<sup>17</sup> Similarly, the effects for *classic Dengue* are also small but positive.

<sup>18</sup> If one student in 10,000 contracts *severe Dengue*, the results suggest that this implies that 100 fewer students in 10,000 sit their examination, which is an incredibly large effect. As discussed below, the true effect size is likely to be smaller than this, but still strikingly large.

<sup>19</sup> In Appendix C (available in Supplementary Materials), using an additional dataset, the 2010 DHS, we present estimates for the impact of Classic Dengue on household activity using an instrumental variables approach. In this exercise, we do not find any effect on general health perceptions or demand for health care services in affected communities apart from higher hospitalization rates of children aged 5 or younger.

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