LES CAHIERS DE RECHERCHE EN EDUCATION ET FORMATION

The effect of teachers' wages on student achievement: evidence from Brazil.*

Maresa SPRIETSMA[1] *and Fábio D. WALTENBERG*[2]

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L'éducation et la formation constituent des enjeux fondamentaux pour la société contemporaine. Deux équipes de recherche à l'UCL se préoccupent de ces questions : le Groupe interfacultaire de recherche sur les systèmes d'éducation et de formation (GIRSEF) et la Chaire UNESCO de pédagogie universitaire (CPU).

Le GIRSEF est un groupe de recherche pluridisciplinaire fondé en 1998 afin d'étudier les systèmes d'éducation et de formation, réunissant des sociologues, économistes, psychologues et psychopédagogues. L'attention est portée notamment sur l'évaluation des résultats des systèmes éducatifs en termes d'équité et d'efficacité, sur leurs modes de fonctionnement et de régulation, sur les politiques publiques à leur endroit, les logiques des acteurs principaux ou encore sur le fonctionnement local des organisations de formation et l'engagement et la motivation des apprenants. Sur le plan empirique, ses recherches portent essentiellement sur le niveau primaire et secondaire d'enseignement, mais aussi sur l'enseignement supérieur et la formation d'adultes.

La Chaire de Pédagogie Universitaire (CPU) a été créée en mai 2001 et a reçu le label de Chaire UNESCO en septembre 2002. Elle assure également le secrétariat et la coordination du Réseau Européen de Recherche et d'Innovation en Enseignement Supérieur (RERIES), réseau européen des chaires Unesco sur l'Enseignement supérieur. Elle a pour mission de contribuer à la promotion de la qualité de la pédagogie universitaire à l'UCL, en contribuant à la fois à la recherche dans ce domaine et en coordonnant une formation diplômante en pédagogie universitaire (DES en pédagogie universitaire).

Ces équipes se sont associées en 2004 pour proposer les **Cahiers de recherche en Éducation et Formation**, qui font suite aux Cahiers de recherche du Girsef, dont 25 numéros sont parus entre 1999 et 2003 . La série des Cahiers de recherche en Éducation et Formation a pour objectif de diffuser les résultats des travaux menés au sein de la CPU et du GIRSEF auprès d'un large public, tant les chercheurs qui s'intéressent aux questions de l'éducation et de la formation qu'auprès des acteurs et décideurs de ces deux mondes.

La compilation de l'ensemble des onze cahiers parus en 2004 est maintenant disponible dans un volume imprimé qui peut être commandé à partir du site www.i6doc.com, notre partenaire éditorial.

Par ailleurs, chacun des cahiers de la série, depuis le premier numéro, peut être téléchargé gratuitement depuis le site d'I6doc (www.i6doc.com) et depuis les sites du GIRSEF (www.girsef.ucl.ac.be) et de la CPU (www.cpu.psp.ucl.ac.be).

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[2] Economics Department, GIRSEF and Hoover Chair (associate member), Université Catholique de Louvain. I am grateful for the financial support from the Belgian French Community programs 'Action de Recherches Concertée' ARC 02/07-204 (GIRSEF) and ARC 03/08-302 (Economics Department).

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Abstract

We evaluate the effect of teachers' wages on pupils' achievement in a developing country (Brazil), using a good quality micro-dataset (the 2001 wave of SAEB). We estimate education production functions to investigate "whether teachers' wages matter", and we also apply quantile regressions to asses "for whom they matter most". Results show that teachers' wages have a small, positive, average effect on pupils' scores in private, but not in public schools, in both Portuguese and Mathematics tests. In private schools, Portuguese teachers' wages have a greater impact on the scores of low-performing than of high-performing pupils, while in Mathematics no clear pattern is revealed. Main results are maintained when instrumental variables and two-stage least absolute deviation estimations are carried out. Our analysis suggests that there is scope for Brazilian public schools to improve their human resources policies, with potential benefits accruing to low-performing pupils.

1. Introduction

Starting with the seminal works of Shultz (1963) and Becker (1964) economists have recognized that the acquisition of human capital is an important determinant of a wide range of economic outcomes of both individuals and societies (Harmon, Oosterbeek & Walker, 2003; Sianesi & Van Reenen, 2000). Since then, a number of studies have been trying to map the technology for the production of human capital.

It is a much-debated topic whether merely investing in more school resources can improve human capital, as measured by student performance. Starting with the Coleman report (Coleman et al., 1966), a common and persistent finding is that school resources have a small, or even nil, impact on student achievement, and that socio-economic characteristics account for most of the variation in student performance (Hanushek, 1986; 1997; 2002; Woessman, 2001). The evidence of an absence of a school-resource effect has been frequently challenged mostly through methodological and data contestations (Card & Krueger, 1992, Figlio, 1999; Dewey, Husted & Kenny, 2000), but it still remains an open question (Belfield, 2000; Hanushek, Kain & Rivkin, 1999; Vignoles et al, 2000).

Concerning the effects of teacher wages in particular, evidence is similarly mixed. There is some evidence that *a good teacher matters* for pupils' performance. Hanushek (2002), for example, compares pupils within districts in the US and concludes that the performance gap between pupils that had a good teacher and those with a bad one can be substantial. This result seems to be confirmed by some other studies (cf. evidence discussed by Vignoles et al., 2000), although it is contested by others (Pritchett & Filmer, 1999). If teacher quality does matter, increasing teachers' wages would constitute an obvious means for acquiring it.

But there are other good reasons for investigating whether teachers' wages matter for student achievement. In fact, despite of recent technological advances, *schooling remains essentially a labor-intensive sector*, and wages still represent the most important share of educational budgets in many countries. If aiming at the efficacy of public expenditures is of paramount relevance in developed countries, it is all the more important in developing countries where budget constraints faced by governments are typically more binding. For example, in 2001, wages of teachers and school staff together accounted for 77% of total expenditures on primary and secondary education in the country we focus on in this study, Brazil (OECD, 2001).

Assessing whether teachers' wages have an impact on student achievement is therefore of extreme policy relevance in developing countries, but the exercise might also be insightful for shedding light on findings obtained in the estimations of education production functions for developed countries. Indeed, one possible reason why inputs do not seem to have a considerable impact on output in education production functions may be the lack of sufficient variation on the input side. In industrialized countries, school resources in general, and teachers' wages in particular, could have reached a threshold level above which input variation does not affect student performance, or just affects it very slightly. In poor countries, where the wage dispersion is typically large, teachers' wages might have a more significant effect (Case & Deaton, 1999; Belfield, 2000).

This paper assesses the effect of teachers' wages on student performance, exploiting the features of a developing country in which the variation in teacher wages is considerable. We use a unique micro dataset, provided by the Brazilian Ministry of Education, namely the 2001 wave of SAEB (Basic Education Assessment System). Following Eide & Showalter (1998), we try to answer not only whether teachers' wages matter, but also for whom they really matter. Education production function studies typically report average effects of a vector of resources on student achievement. Quantile regression (QR), in turn, allows us to assess the effect of teachers' wages on achievement at different points of the conditional distribution of educational achievement. Clearly, QR can contribute to the debate on the absence of school resources: while the relationship between inputs and performance may be small on average, it may be large for some particular types of students (i. e. specific conditional quantiles of performance). However, the policy implications of findings based on QR estimations go far beyond the debate around the absence of resource effect, as they relate to *equity issues*. Identifying who benefits more from such an important school input is a requirement for the design of accurately targeted policy interventions.

Our paper brings evidence that is not only relevant for the economics of education literature, but also for a broader economic perspective – on whether wages reflect productivity. Wage is often assumed to be a proxy for a worker's productivity in economic analysis when markets function adequately. Specifically in the educational sector, individuals would face choices between working at different schools, or between working in the educational sector and elsewhere. More skilled individuals would be attracted by better compensations offered to teachers relative to those offered by other sectors. Within the teachers' market, better teachers would also be attracted by better rewards (Southwick & Gill, 1997; Dolton & Van der Klaauw, 1999; Angrist & Guryan, 2003). Too low relative wages in the educational sector would create an adverse selection problem, leading less-able graduates to make the choice of becoming teachers and thus lowering the overall level of teacher quality (Hoxby & Leigh, 2003; Lankford & Wyckoff, 1997). The same argument holds for low relative wages within the teachers' profession. Even beyond the strictly selection issue, better teachers would be expected to have higher wages in the presence of some form of reward to merit in the teaching profession. If teachers' labor markets operated just like competitive markets described in economics textbooks suggest, we would expect better teachers to receive higher wages. But this is not realistic in many settings, especially when a considerable fraction of many schooling systems is run by the state. In public schools, teachers' wages are typically determined by age, tenure, political indications and other factors not necessarily related to skills, merit or productivity.

We can sum up by pointing out three hypotheses that we test in this paper: (i) whether teachers' wages matter for students' achievement in a developing country, (ii) whether the conditional correlation of teachers' wages and pupils' scores is stronger in private schools than in public schools, and (iii) whether there are variations in the conditional correlation of teachers' wages with students' test scores along the test scores' distribution, suggesting heterogeneity in the pupil-teacher relationship.

The paper is organized as follows. In section 2 we present the dataset. In section 3, we present the empirical strategy and OLS results. In section 4, we justify the use of QR and discuss the results. Section 5 addresses potential endogeneity. In section 6 we summarize the results and discuss some policy implications. Section 7 contains the conclusions.

2. Data

The data we use come from the 2001 wave of SAEB (Basic Education Assessment System), a survey on pupils' achievement carried out by INEP, a research bureau subordinated to the Brazilian Ministry of Education. While the SAEB is not suitable for international comparisons, its objectives and statistical design, and the procedures employed in the application of the test, have been inspired by, and do not differ very much from, well-known cross-country assessments of pupils' performance, such as PISA, TIMMS/ PIRLS, and LLECE[3].

SAEB consists of countrywide tests that evaluate pupils' cognitive abilities in literacy (Portuguese exam[4]) and numeracy (Mathematics exam). Test score information is coupled with data on relevant features of pupils and their family, as well as teachers', principals' and schools' characteristics. The database consists of repeated cross-sections (not panels) of representative samples of schools and students. Firstly, schools are randomly chosen to take part in the SAEB. Secondly, one class inside each school is randomly selected. All students of a given selected class have to pass the SAEB exam, but only in one of the subjects.

SAEB focuses on the evaluation of pupils at three key stages of their formal education: 4th and 8th year of primary school, and 3rd year of secondary school. Each of these grades corresponds to the last year of a stage in the Brazilian schooling system, which are: the end of first half of primary school (during which students have one teacher for all subjects), the end of second half of primary school (during which students have one teacher for each subject), and the end of secondary school (after which students can pass college admission exams). Schooling is mandatory in Brazil for children up to 14 years, regardless of the grade they are attending. The 8th grade sample constitutes the best approximation for the end of compulsory schooling, since most of its students are in fact around 14 years old[5]. Moreover, 8th grade pupils are less likely to have dropped out than 3rd grade of secondary school pupils. Finally, the 8th grade datasets have fewer missing data in key questions (e.g., pupil's age, mother's education, and number of books at home) as compared to the 4th grade. For these reasons, we focus exclusively on the 8th grade sample.

Pupils' test scores correspond to subject-specific pedagogical scales elaborated by INEP staff together with teachers, researchers, and national and international survey experts. Possible scores range from 0 to 500, and are supposed to evaluate skills and abilities of students. The SAEB scale is continuous and hierarchical, which means that a pupil who achieves a certain score – say, 400 in the Portuguese test – has all the literacy skills held by students who scored 150, 300 or 380, plus some additional skills. For example, he might be able to understand and interpret more complex texts than his peers who scored lower. Because of the invariance of the scale, pupils' scores are comparable across years and across grades. Scores are not comparable across subjects, but the distributions of scores do not look very different in Portuguese and in Mathematics[6]. Finally, it should be mentioned that the data used to construct the variable that expresses tax revenues per head for each Brazilian mu-

[3] The INEP website (http://www.inep.gov.br) contains useful information concerning evaluation of students in Brazil, most of which in Portuguese, in the section "Avaliação e Exames". INEP (2002) provides specific information about the 2001 wave of SAEB. INEP (2004) provides information about the SAEB exam in English.

[4] Portuguese is the official language in Brazil and it is the native language of nearly all Brazilians.

[5] In the final samples used in this study, 73% of 8th grade pupils were 15 or less by the time they did the SAEB exams. However, while the recommended age for pupils enrolled in the 8th grade is 14 years, the ages range is actually quite wide (11 to 19), especially because of grade repetition and irregular school attendance.

[6] SAEB scales have been built in such a way that the mean and the dispersion were identical across subjects, for the 8th grade, in the 1997 wave. Averages were set to 250, and standard deviations were set to 50.

nicipality (*TAXPERHEAD*) was obtained from the Brazilian Ministry of Finance[7] and was appended to the SAEB datasets.

2.1. Summary statistics

Tables 1 and 2 and Figure 1 present summary statistics concerning the final samples used in our estimations (28,605 observations in Portuguese and 27,942 in Mathematics).

The variable *SCORE* stands for the score pupils attained in the exam. Figure 1 show histograms and kernel density graphs for this variable. Whereas the distribution of *SCORE* in the Portuguese exam for the pooled samples (i.e. all types of schools) resembles a normal distribution, the Mathematics one is skewed to the left. Tables 1 and 2 show that average scores are 249.31 in Portuguese (standard deviation: 49.85) and 258.02 in Mathematics (s.d.: 53.45). As for the distributions of *SCORE* by type of school, it is clear that, on average, private schools' pupils perform better than public schools' ones. In Portuguese average scores are 279.06 in private schools versus 232.73 in public schools. In Mathematics, we have 295.37 versus 236.89.

The variable *TEACHERWAGE* expresses teachers' gross monthly wage, expressed in "*salários mínimos*" (sm), an index often used in Brazilian administrative data[8]. Figure 2 shows histograms of teachers' wages for both subjects, for the pooled samples. *TEACHERWAGE* is a discrete variable and its values range from 0.5 to 15 sm in all samples[9]. Both means and dispersions of teachers' wages are higher in private than in public schools:

- Portuguese: average is 5.98 (standard deviation: 3.69) in private schools versus 4.57 (2.69) in public ones;
- Mathematics: 6.62 (3.85) in private schools versus 4.69 (2.95) in public ones.

Following Carroll (1963) and subsequent literature[10], we can identify five factors that determine students learning rate: "(i) aptitude, (ii) ability to understand instructions, (iii) perseverance, (iv) opportunity, and (v) quality of instruction". We use these categories as references for the choice of our control variables. Tables 1 (Portuguese) and 2 (Mathematics) contain descriptive statistics of selected variables used in the regressions.

Firstly, to account for observable individual characteristics (potentially related to points i to iv), we include pupil's *AGE*, *GENDER* and race. Gender is a standard control variable. Although the mode is 14 years old in both samples, there is a broad range of ages within the considered grade sample (from 11 to 19). We can expect age to affect motivation, self-confidence and maturity of the pupils. We include dummies for self-reported pupil's race (*BLACK* and *MIXED*). On average, mixed individuals are poorer than whites in Brazil, and blacks are the poorest race group, so this dummy not only plays the role of a control for unobserved variables related to race, but it is also a control for the socio-economic status.

Secondly, we control for pupils' family environment. We use measures of their mother's education (*MISCED*), family wealth (as measured by the number of employees at home: *NMAIDS*), the number of books at home (as a proxy for the family interest in learning and as a home educational resource: *NBOOKS*), and the type of family structure the pupil lives in (with or without both parents: *NONNUCLEAR*). These variables might affect the motivation, level of effort and opportunities of the pupils as well as their ability to understand instructions.

Thirdly, to account specifically for pupil effort (point iii), we use information on the frequency with which pupils do their homework when asked to do it

[7] More precisely, these data have been obtained from a website hosted by the Brazilian Ministry of Finance, which provides regional accounting information: http://www.stn.fazenda.gov.br/estados_municipios/index.asp.

[8] Literally "salários mínimos" mean minimum wages. Actually, more than defining the value of the minimum wage, it is used as an economic index. In October 2001, when SAEB exams took place, one unit of sm was equivalent to 180.00 *reais*, the Brazilian currency, or approximately, US $68.00 (source: Brazilian Central Bank).

[9] The range is the same across samples because this variable was composed out of the same categorical question asked to all teachers about their wages. We inputted to each teacher the midpoint of his wage category.

[10] E.g., Creemer (1994); Scheerens (1997); Creemer, Scheerens & Reynolds (2000).

(*HMWK*)[11]. We also have information about whether the pupil repeated grades (*RETENTION*) and how often. We use that as an imperfect control for past effort[12].

Fourthly, we include measures of the quality of schooling (point v) received by pupils. We have information on class size (student/teacher ratio: *STRATIO*), a dummy for the availability of a library at the school (*LIBRARY*), the quality of the air (*AIR*) and light (*LIGHT*) in classrooms, and the number of computers available for pupil use (*NCOMP*). Moreover, we include the gross monthly wage of the principal as a control for her overall level of competence (*PRINCWAGE*).

Finally, we add controls for regional specificities, first by means of indicator variables for the 27 Brazilian states (from *UF1* to *UF27*), aimed at capturing state-specific heterogeneity. We also include a control for more local characteristics, namely data on tax revenues per head by municipality (*TAXPERHEAD*), in order to account for variations in economic resources that could affect both scores and teachers' wages, independently of the actual productivity level of teachers[13].

As for teachers' characteristics, we assume that, conditional on having or not a university degree (*TCHCOLLEGE*), all other unobservable characteristics related to teachers' quality are subsumed in their wages. The observed teacher variables that are used as predetermined instruments in IV and two-stage least absolute deviation estimations (section 5) are assumed not to affect teacher quality on average. They include: teachers' gender (*TCHGENDER*), teachers' experience in teaching the tested discipline (*TCHEXP*), monthly hours of work (*TCHHOURS*) and a dummy indicating whether the teacher has another job besides teaching (*TCHJOB*).

In all estimations we use as dependent variable a standardized version of *SCORE*, with its mean set to 500, and its standard deviation set to 100 (labeled *STDSCORE*). The explanatory variable is a standardized version of *TEACHERWAGE*, with mean 0, and standard deviation 1 (labeled *STDTEACHERWAGE*). These standardizations were carried out in order to make the interpretation of the coefficients clearer. We do not report these standardized variables in Tables 1 and 2, since by definition their means and standard deviations are the same across samples.

[11].One could fear that the quantity of homework given by the teacher is either endogenous (unobserved characteristics influence both pupils homework records and their scores, simultaneously), or even an outcome variable (well-paid teachers possibly have an impact, not only the score of pupils, but also on their homework activities). It should be noted that the variable used here measures the frequency with which pupils *do* their homework, and not simply the frequency with which they are *given* homework. That is, the value this variable assumes depends primarily on a choice made by pupils. Simultaneous determination might be of concern, but we kept this variable essentially because it is the only variable indicating current effort which is available.

[12] We are aware that *RETENTION* is a complex variable, which also reflects innate talent and family background. Brazilian researchers have been trying to determine the causes and implications of grade retention in Brazil, as well as the effect of policies on the grade retention record. A useful reference (in Portuguese) on that is Ferrão, Beltrão & Santos (2002).

[13] For instance, wealthier municipalities could give pupils and teachers access to public libraries, health services, or other aid to families, and on average parents' earnings would tend to be higher than in poorer municipalities.

3. The baseline model (OLS): Do teachers' wages matter ?

As mentioned before, scores have been standardized such that the mean for this variable is 500, with a standard deviation of 100 (*STDSCORE*), and teachers' wages have been set to have mean 0 and standard deviation 1 (*STDTEACHERWAGE*). Thanks to these transformations, estimated effects of teacher wages on scores can be interpreted in an intuitive way. For example, when we run simple OLS regressions, having *STDSCORE* as the dependent variable and *STDTEACHERWAGE* as explanatory variable, plus a constant, we obtain the following uncontrolled or *gross effects of teachers' wages on scores*:

- Portuguese – pooled sample: 22.67; private schools: 23.57; public schools: 8.64.
- Mathematics – pooled sample: 28.60; private schools: 25.88; public schools: 10.31. [14]

Hence, in private schools, a change of 1 unit of Portuguese teachers' wages (that is, 1 standard deviation of teachers' wages) corresponds with a change of 23.57 points of pupils score (that is, 23.57% of standard deviation of pupils' scores). In public schools, in turn, a change of 1 standard deviation of Portuguese teachers' wages corresponds with a change of only 8.64 points of score. Note that the results for Mathematics are not essentially different from those for Portuguese, although coefficients are systematically larger in the former.

We would like to understand how these *gross* coefficients are affected when we include covariates. Does the relationship between scores and teachers' wages remain positive and significant? Do differences between public and private schools coefficients persist? Are Mathematics coefficients systematically higher than Portuguese ones? Our baseline strategy consists of *controlling for observable variables*. We estimate by OLS an education production function for SAEB scores obtained by 8th grade pupils, in each subject (Portuguese and Mathematics), where test scores are a function of teachers' gross monthly wages:

$$(STDSCORE)_i = \alpha + \beta(STDTEACHERWAGE)_i + \gamma X_i + \delta X^2_i + \varepsilon_i \qquad (1)$$

where: X is a vector of *control variables*, and ε is the error term.

Note that by including in (1) a vector (X^2) containing the squares of the continuously-valued right-hand side variables, we avoid imposing linearity in the relationship between right-hand side variables and the outcome variable (score), a procedure inspired by the work of Figlio (1999). We do not claim that the inclusion of X^2 provides some particular economic intuition; however, we prefer not to restrict arbitrarily our education production function to a linear form. In the presentation of results (section 3.2) we explain why we use the specification stated in Equation 1 and not a more general one, which would include the square of *STDTEACHERWAGE*.

3.1. Partitioning public and private schools samples

In Brazil, a private schooling system co-exists with a public one. In addition to the estimations for the pooled samples, we also estimate our models separately for private and public schools. There are several reasons for doing so. First of all, our data reveals the existence of important differences between public and private schools. In the summary statistics, we observe that average scores of private schools students are between 20 to 25% higher than those of public schools. We also notice that, on average, private schools teachers earn 30 to 40% more than their public school counterparts. When we turn to control variables, the differences are also striking. For example, pupils in private schools live much less often in non-nuclear families (about 26%, against about 40% in public schools), have highly educated mothers (on average, they have a college degree, while pupils' mothers in public schools do not), live in

[14] These 6 coefficients are significant at the 1% level, but the R^2 varies considerably from one regression to another. Portuguese: 0.051, 0.056 and 0.008; Mathematics: 0.082, 0.067 and 0.011.

wealthier families with more books and do more homework. Private school infrastructure is also much better than that of the public sector (attested by variables *LIBRARY*, *NCOMP* and *STRATIO*). School principals earn, on average, around 45% more in private than in public schools.

Of course, these differences in average values of dependent, explanatory and control variables do not make the case for partitioning the sample – indeed these differences are controlled for in our estimations. However, based on the data and on our own knowledge of the Brazilian educational sector, we believe there might be heterogeneity of pupil's and teachers' characteristics from one type of school to another, which go beyond observable variables. If this is true, we can suspect that private and public schools operate in very different environments, and are allocated extremely different mixes of inputs. The technological setting for the production of education is potentially different from one type of school to another. For example, by means of the payment of expensive tuition fees, parents supply Brazilian private schools with resources that allow some of these schools to operate in an environment that resembles that of good schools in developed countries. Public schools, in turn, must cope with much more constrained budget sets.

In addition to that, studying in public schools is socially stigmatizing. All the parents who can afford it prefer to enroll their children in private schools, generally identified as "good schools"[15].

Another reason why it is interesting to look at private and public schools separately relates to their respective funding and managing characteristics. Private schools are neither funded nor managed by the public authority, which significantly modifies their decision-making environment and the nature of their budget constraints as compared to public schools[16]. Private schools are put in competition with other schools in the educational market, whereas public schools are managed by the state and respond to bureaucratic rules.

Finally - and probably more importantly given the topic of the paper - there are striking differences between the private and the public systems concerning the functioning of teachers' labor market. In private schools, there is almost a free teachers' labor market: recruitment procedures and wage settings are decided on a decentralized basis, subject to some constraints imposed by unions and collective bargaining rules. Each school is considerably free to make decisions related to teacher hiring and performance rewarding. In the public system, in turn, there is no free market for teachers. Recruitment should in principle be done by means of public contests, but many teachers are allocated to their jobs by politicians or by other, non-competitive, means. Wages are determined according to general guidelines stated by the federal authority (ministry of education), but mainly by state-level and/or municipal-level decision-makers. Public schools cannot decide autonomously to pay higher salaries in order to attract better teachers, nor to reward such teachers, who are supposedly the ones who could lead pupils to attain better performance.

As a consequence of all that, we believe that the effect on student scores of an important input like teachers' wages should not be estimated (only) by taking the pooled sample and assuming a constant coefficient for all types of schools. Although we always report and comment the results concerning the pooled sample for each subject, it seems meaningful to estimate private and public schools' coefficients separately. In order to keep results comparable when we use partitioned samples, we standardize the dependent variable (*STDSCORE*) and the explanatory variable (*STDTEACHERWAGE*) *by subset*, such that means and standard deviations are adjusted, respectively, to 500 and 100, and to 0 and 1, in every subsample.

[15] Oliveira & Schwartzman (2002) provide figures obtained from a survey that documents the perception Brazilians have about the quality of each type of school. When asked in what type of school they would prefer to enrol their children, 94.3% of private school teachers said they would choose private schools. What is striking, however, is that a great fraction of *municipal* (*public) schools* teachers would choose private schools (69.9%).

[16] Part of the money spent with tuition fees returns to parents by means of tax credits (Ioschpe, 2004). So the Brazilian state indirectly subsidizes private schools expenditures (by a kind of implicit voucher system) and granted after tax, which is different, in nature, from the direct funding of public schools.

3.2. OLS results

Tests of structural change (F- or Chow-tests)[17] inform us that we can reasonably reject the null hypothesis that the coefficient δ, associated with the vector of squared control variables, is equal to zero, a conclusion that holds for both subjects. However, we cannot reject the null hypotheses that the coefficients associated with the square of *STDTEACHERWAGE* are equal to zero. These tests suggest that the specification we use here (linear in *STDTEACHERWAGE* and nonlinear in X) is more adequate than the linear functional form usually employed in education production functions, a result which is in line with those obtained by Figlio (1999). In the remaining of the paper, we make use of this specification, stated in Equation 1.

Tables 3 (Portuguese) and 4 (Mathematics) contain coefficients and standard deviations for the pooled sample in each subject. Control variables yield significant coefficients, whose signs are in line with standard results found in the literature.[18]

According to this baseline OLS estimation, teachers' wages maintain a *small but positive and significant (at 1% level) correlation with student test scores* in the pooled samples, even after controlling for a great number of covariates. In Portuguese, the coefficient is 3.36, which means that a change of 1 unit in teacher's wage (i.e., 1 standard deviation of teacher's wage) corresponds to a change of 3.36 points of pupils score (that is, 3.36% of standard deviation of pupils' scores). A similar result is obtained in Mathematics, although the coefficient is smaller (2.38). So the pooled sample results suggest that teachers' wages do matter for students' achievement in Brazil. After including an extensive set of controlling variables, the relationship between scores and teachers' wages remains positive and statistically significant in both subjects. However, it drops substantially in comparison to the *gross* coefficients: in Portuguese, it drops from 22.67 (uncontrolled) to 3.36 (controlled); in Mathematics, it drops even further – from 28.60 to 2.38.

How large are these coefficients? How much do teachers' wages matter for students' achievement in Brazil? Turning back to the non-standardized versions of our explanatory and dependent variables (*TEACHERWAGE* and *SCORE*), we can see that conditional on all covariates, an increase in Portuguese teachers' gross monthly wages of 1 standard deviation (that is, 3.16 sm, or about US$215) is associated with an increase of 3.36% of standard deviation of scores (that is, 1.67 points in the test). In Mathematics, an increase of 1 standard deviation of teachers' gross monthly wages (that is, 3.43 sm, or about US$233) is associated with an increase of 2.38% of standard deviation of scores (that is, 1.27 points in the test). Such conditional correlations between scores and teachers' wages look very small. If they reflected causality between teacher's wages and pupils' scores, then, in order to obtain very modest increases in students' performances, it would be necessary to increase teachers' wages by more than US$2400 dollars per year – a substantial amount, in a country where the GNP per capita is not much higher than US$3000 dollars, and given that teachers' wages already represent a substantial fraction of the educational budget.

However, it is important to qualify the conclusion of a small coefficient in two dimensions. First, it should be emphasized that *STDTEACHERWAGE* coefficient remains *positive* and *significant*, even after the inclusion of an extensive amount of controlling variables in the regression. Although small in absolute terms, the coefficients obtained can be considered to be relatively "large" as compared to a series of findings

[17] Not reported here, but available upon request.

[18] Boys perform better than girls in Mathematics and the reverse is true in Portuguese. Grade retention affects test scores negatively as well as living in a municipality with low tax revenues. Black and mixed pupils perform worse on average, as well as individuals coming from non-nuclear families, and those who have few books at home. Many variables show a non-linear correlation with *SCORE*, such as MISCED2 (positive in both subjects): the total marginal effect of mother's education on *SCORE* becomes increasingly positive as the level of education goes up. The availability of a school library affects scores positively in public schools whereas the number of computers has a positive impact in private schools. These differences probably result from difference in average endowments of each type of schools. Indeed, only 75% of public schools have a library (against 90% of private schools) whereas public schools have on average only 4 computers (against 22 in private schools).

in the economics of education literature, suggesting that school inputs in general, and teachers' wages in particular do not matter for students' learning, at least in developed countries (cf. introduction). Moreover, part of our covariates accounts for pupils' family and social environment, which are usually pointed as the essential determinants of pupils' performance, but still a typical and important school input such as teachers' wages turns out to be significant in our estimations.

The second qualification to the small-coefficient conclusion is that for the moment we have overlooked an important characteristic of the Brazilian schooling system, namely its division into two types of school: private and public. Indeed, the coefficients associated with the private-school dummy (*PRIVATE*) are positive and very high in both subjects (39.05 and 45.58 respectively). It is useful to check whether the differences between public and private schools *gross* coefficients remain after the inclusion of control variables. Tables 3 and 4 also show the results for the partitioned samples. The picture obtained is quite different depending on the type of school. For both subjects, the *STDTEACHERWAGE* coefficient in private schools is larger than that of the pooled sample (7.21 in Portuguese and 3.94 in Mathematics) and both are significant at the 1% level. For public schools, in both subjects, coefficients of teachers' wages are very small, and, indeed, can not be considered statistically different from zero. So the hypothesis that in private schools the conditional effects of teachers' wages on scores are stronger than in public schools is largely supported by our OLS results, even after controlling extensively for many different types of factors. The effect is more pronounced in Portuguese than in Mathematics.

How much do teachers' wages matter for students' achievement in Brazilian private schools? Turning back, once again, to the non-standardized versions of our explanatory and dependent variables (*TEACHERWAGE* and *SCORE*), we can see that conditional on all covariates, an increase in Portuguese teachers' gross monthly wages of 1 standard deviation (that is, 3.69 sm, or about US$250) is associated with an increase of 7.21% of standard deviation of scores (that is, 3.26 points in the test). In Mathematics, an increase of 1 standard deviation of teachers' wages (that is, 3.85 sm, or a little more than US$260) is associated with an increase of 3.94% of standard deviation of scores (that is, 1.99 points in the test). The marginal increase in pupils' scores is larger in private schools as compared to the pooled sample, but the correspondent increase in wages also has to be larger for private school teachers. So once again we conclude that these conditional correlations are not extremely large. The increases in tuition fees that would be necessary to finance such an increment in wages would be substantial, with modest results in terms of increase in scores.

The first qualification mentioned for the pooled sample coefficients also holds in the case of private schools samples coefficients. In fact, coefficients remain positive and significant even after the inclusion of a great number of control variables, which makes our results somewhat different from usual findings in the literature. More importantly, we have provided evidence that there is a clear difference between private and public schools with respect to the conditional effects of teachers' wages on scores. Finally, we have seen that the conditional correlation between teachers' wages and scores resists more strongly to the inclusion of covariates in Portuguese than in Mathematics, in all the samples. We will come back to this issue in following sections.

4. Quantile Regression (QR) : To whom do teachers' wages matter?

Education production function studies typically report average effects on some outcome variable (typically, student achievement) of school resources, family resources, or other relevant inputs. However, a major drawback of methods such as OLS and IV is that they estimate only a constant coefficient, the conditional mean. Quantile regression (QR), on the contrary, allows us to assess the effect of resources (here: teachers' wages) on achievement (here: scores) at different points of the conditional distribution of educational achievement.

Understanding the effect of an educational input, such as teachers' wages, *along the distribution of scores* may be relevant for various reasons. Firstly, there is no reason to impose the coefficients associated with the explanatory variable to be constant along the distribution of scores. The impact of a given educational input on students' performance might be different according to the type of student. Low-performing students could benefit from an increased quality of teachers to obtain careful explanations and helpful support, which would eventually improve their skills, while for high-performing pupils such increased quality would be useless (they would have learned anyway). Inversely, high-performing students could gain more than low-performing ones from an increase in teacher quality, if the low-performing pupils were not able to benefit from the extra knowledge brought about by the teacher. We did not have a clear expectation with regards to the relationship between teachers' wages and scores – whether it is larger for low- or for high-performing students –but we would not be surprised if the coefficient actually varied from one quantile to another.

A second reason for studying the effect of teachers' wages along the distribution of score is closely related to a long-lasting debate in economics of education, about whether school inputs affect student performance (cf. introduction). While the relationship between a particular input and student performance may in fact be negative, nil, or small on average, as reported by a great number of studies, such relationship may be positive or large for particular types of students, that is, for particular quantiles. Therefore, many results found in the literature showing a "no resource-effect" may in fact be hiding interesting "resource-effects" for specific types of student. The same is true for the small (nil) OLS coefficients reported in the last section of this paper.

Thirdly QR evidence may be very helpful from a policy perspective. The effects of a reform are possibly non-neutral, and identifying who benefits more from each input is a requirement for designing accurately targeted policy interventions. For example, if inequalities of scores, or a very low educational performance of some students, are of concern, then QR allows the policymaker to understand what inputs matter for the low-performing students who are its main target. If, instead, the policymaker prefers to boost the performance of high-performing students (say, for efficiency reasons), he should focus on coefficients associated with this sort of student.

A fourth reason for using QR is related to the heterogeneity of students. If a given student population is homogeneous with respect to all that matters for learning, we do not expect to find great differences in the effects of inputs on their performances. However, the more heterogeneous is the population, the more likely are the coefficients to vary along the distribution of scores (when control variables are not enough to drive out the existing heterogeneity). As mentioned before, we believe that in the SAEB data, there might be unobservable heterogeneity of pupil's characteristics that go beyond available controls.[19]

[19] Indeed, Brazilian students (and teachers) are heterogeneous in various respects, some of which go far beyond the schooling sector and the covariates available in SAEB dataset. Brazil presents one of the most unequal income distributions in the world; its Gini coefficient is very high and stable around 0.59 since the 1980s (Barros, Henriques & Mendonça, 2000). Moreover, inequality of student achievement is particularly strong in Brazil, in comparison with developed countries and even some developing countries. According to usual measures of inequality, Brazil ranks last (i.e. most unequal country) in an international student assessment exam, the so-called 'PISA 2000', recently organized by OECD (according to our own calculations).

To sum up, QR allows us to map the technology for the production of education more precisely, with relevant policy implications. In our case, we study whether the performance returns to teachers' wages are the same for different types of students. Eide & Showalter (1998) advocated the use of QR by saying that they "not only addressed the question 'does money matter?' ", but also "for whom does money matter?". Accordingly, in this paper QR allows us to determine for whom teachers' wages really matter.

Technically, QR consist of a generalization of the conditional *median* (or least absolute deviation) estimation, which is in fact an old statistical technique, for a long time presented merely as a curiosity in statistical textbooks because of computational difficulties, among other reasons (Koenker, 2000). It was then "rediscovered", developed and introduced in the economic literature by Koenker & Bassett (1978). It has been generalized as a method of estimation of conditional quantile functions for any quantile θ of the dependent variable. A very interesting feature of QR is that all the observations are employed in the estimations, but different weights are assigned to them. When estimating quantiles, absolute deviations are given positive and negative weights, in such a way that a fraction θ of the observations lies below the fitted line while a fraction (1 – θ) lies above it. As θ goes from 0 to 1, the entire distribution of test scores, conditional on teachers wages (*STDTEACHERWAGE*) and covariates (X and X^2), is described. θ^{th} quantile coefficients are obtained as a solution to the expression below:

$$\underset{\beta \in R^k}{Min}\left\{ \sum_{i:Score \geq x_i\beta} \theta \left| Score_i - x_i\beta_\theta \right| + \sum_{i:Score < x_i\beta} (1-\theta) \left| Score_i - x_i\beta_\theta \right| \right\} \quad (2)$$

We thus estimate Equation 2 for each quantile we are interested in, so as to obtain a set of coefficients for each quantile:.β_θ

4.1. Related literature and the procedure we adopted

Some recent papers have used QR to assess the effect of resources on student achievement. Eide & Showalter (1998) estimate the effect of different types of school resources on the conditional distribution of performance (test score gains) in the US, both by OLS and QR. Most of the coefficients are not statistically significant *on average* (i.e. by OLS estimation). However, some of them turn out to be statistically significant for specific quantiles when the QR method is used. Levin (2001) studies mainly the effect of class size, but also of peer effects, on achievement of Dutch pupils. His results show a strong downward trend in the effect of having more pupils of the same IQ in one's class on achievement as one moves up the achievement distribution. That is, low performing pupils benefit more from ability grouping than average or high performing ones.

Rangvid (2003) estimates peer effects along the conditional distribution of scores for Danish pupils, finding that peer effects are stronger for weak students, and that they decrease over the distribution of scores. In a setting not far from ours, Billger (2002) first uses OLS and QR separately, and then combines IV with QR, in order to estimate the effect of teacher pay on student performance in private schools in the US. In the latter formulation, she finds that higher maximum salaries have no significant impact on the measure of student performance she uses.

To our knowledge, our paper is the first to estimate education production functions applying the QR technique using Brazilian educational data, and probably one of the first ones to do so for a developing country. In order to obtain a clearer picture of the changing pattern of the effect of wage variables on the distribution of scores, we estimated Equation 2 for a number of quantiles of the test score distribution: 0.05, 0.10, 0.15, …, 0.90, 0.95, and the extremes quantiles 0.01 and 0.99.

4.2. QR results

Figures 3 to 5 show QR estimations results for all estimated quantiles, with OLS coefficients and their confidence intervals, for comparison. The pooled samples (Figure 3) show quite different results according to the subject. In Portuguese, we observe a clear overall decreasing pattern of the effect of teachers' wages on the performance of students. The coefficient of *STDTEACHERWAGE* drops from a positive and significant level for the lowest end of the test scores distribution (5.75, for quantile θ=0.10), to a small but still statistically significant coefficient for higher quantiles (1.94, for θ=0.85). Then the coefficient drops further and the conditional relationship between *STDTEACHERWAGE* and *SCORE* ceases to exist for the three upper quantiles (θ=0.90, 0.95, 0.99). In fact, all coefficients are positive and statistically different from zero, except for the three upper quantiles. Eight out of the 21 estimated coefficients fall out of the band defined by confidence intervals around the OLS coefficient (95% level): these are exactly those corresponding with the four bottom quantiles and with the four upper quantiles.

According to these results, Portuguese teachers' wages are conditionally correlated to a higher extent with the scores of low-performing students than with those of high-performing students. The highest coefficient obtained (5.75, for θ=0.10), is 71.13% higher than the mean coefficient obtained in the OLS estimation (3.36). Moreover, that highest coefficient is almost three times larger than the lowest significant coefficient obtained (1.94, for θ=0.85) and a Wald test reveals they are indeed different (see end notes 24 to 26). To sum up, an increase of 1 unit of Portuguese teacher's wage (1 standard deviation of teacher's wage) corresponds with a change of 5.75 points of standardized score of pupils situated around the 15^{th} quantile of the conditional distribution of score, but only with a change of 1.94 points of conditional standardized score of pupils situated around the 85^{th} quantile.

In Mathematics, such decreasing pattern is not observed. Almost all the coefficients are small, positive, and significant, with four exceptions (θ=0.01, 0.15, 0.20, 0.99), and they all oscillate around the correspondent OLS coefficient, without any clear increasing or decreasing trend. The largest coefficient (3.15, for θ=0.60) is only 32.35% larger than the correspondent OLS coefficient, and it falls inside the OLS confidence interval band. The smallest significant coefficient (1.49, for θ=0.80) is 37.39% smaller than the correspondent OLS coefficient, and also lies within the boundaries of the confidence interval. These results suggest that Mathematics teachers' wages are virtually uniformly correlated to scores of students, regardless of their conditional performance[20].

[20] Variable *TCHCOLLEGE* reveals that, in Portuguese, having more qualified teachers improves pupil performance, especially of better students. This result seems to indicate that highly skilled students are more able to extract benefits from a highly qualified teacher. These results do not hold for Mathematics test scores, which do not seem to be affected by the teacher's education.

When we turn to different types of school, an interesting result is found for private schools (Figure 4) in Portuguese. With the exception of three extreme quantiles (θ=0.01, 0.95, 0.99), all coefficients are positive and statistically different from zero. The overall decreasing pattern verified for the pooled sample is reproduced in private schools: Portuguese teachers' wages are once again correlated to a higher extent with the scores of low-performing students than with those of high-performing students. However, the effect is considerably intensified. For example, the largest coefficient obtained now refers to very low-performing students (14.43, for θ=0.05), which is precisely twice as large as the mean coefficient from the OLS estimation (7.21), and it is more than 3,5 times larger than the lowest significant coefficient obtained (4.06, for θ=0.90). Moreover, QR coefficients for private schools are on average two times larger than those for the pooled sample.

In Mathematics, the extreme quantiles coefficients from each side of the distribution are not statistically different from zero, but apart from that, the overall pattern observed in private schools' QR coefficients is very similar to that of the pooled sample ones. QR coefficients oscillate around the correspondent OLS coefficient, without a clear increasing or decreasing trend. Largest and smallest coefficients fall within the confidence interval. These results suggest once again that Mathematics teachers' wages are virtually uniformly correlated to scores of students, regardless of their performance. The only relevant difference with respect to the pooled sample result is that the coefficients for private schools are, on average, 1.5 times larger than those for the pooled sample.

Public schools results (Figure 5) are similar across subjects at least in two respects: none of the estimated coefficients is statistically different from zero; and virtually all coefficients fall within the confidence interval. These results suggest that the nil correlation of teachers' wages with pupils' performance, found in the OLS estimations, are maintained across the whole conditional distribution of scores. Teachers' wages are not conditionally correlated to a larger extent with any particular type of student. Thus, for public schools, QR estimations provide evidence supporting the absence of “resource-effect” mentioned in the introduction.

5. Endogeneity

Until now we have based our analysis of the effect of teachers' wages on scores on an empirical strategy which consists essentially of controlling for covariates. We are well aware of the limits of such method, since one may fear the presence of selection bias or endogeneity in the relationship between teachers' wages and students' scores. For different reasons, one may suspect that *teachers' wages are not randomly assigned to different types of students*, even after all the efforts made to condition on available covariates. Our data being cross-sectional, we were somewhat limited in the task of designing a causal model. Trying to account for potential endogeneity of teachers' wages, we estimated an instrumental variable (IV) model. In the first stage, we estimate teachers' wages as a function of the same set of variables used in OLS and QR estimations, but also with a set of instruments excluded from the main, second-stage, equation. The first step is the following:

$$(STDTEACHERWAGE)_i = \eta + \theta X_i + \kappa X^2_i + \lambda I + \mu_i \quad (3)$$

where: X is a vector of control variables, I represents the set of instrumental variables that are excluded in the second step (assumed to be orthogonal to scores) and μ is the error term.

In the main equation, we exclude the instruments assumed to be predetermined with respect to students' score, especially the gender of the teacher (*TCHGENDER*) and his or her years of experience as a teacher (*EXPPROF*). We assume that whether a teacher is a man or a woman is not a factor that is likely to influence students' score directly on average. However, there is typically a gender gap in wages, even when experience, age and other factors are controlled for, so that, on average, gender is correlated with wages[21]. Secondly, education production functions frequently provide evidence that a teacher's experience, conditional on covariates, has no systematic significant impact on scores[22]. And experience can be expected to be strongly correlated with wages, especially in the public sector. So, in principle, these two variables seem to be good candidates to be valid instruments: they are correlated with the variable we suspect to be endogenous and they are correlated with the dependent variable of the main equation only through the channel of the endogenous variable. In the set of instruments we also include the monthly hours of work of a teacher (*TCHHOURS*), whether he or she has another job (*TCHJOB*), and the squares of *EXPPROF* and *TCHHOURS*. We use the same specification for the two subjects, with all these six instruments being used as predetermined variables.

The second step is exactly the same as in the OLS specification, except for the fact that we replace the potentially endogenous variable (*STDTEACHERWAGE*) by its predicted value from the first stage (*WAGEHAT*).

$$(STDSCORE)_i = \alpha + \beta(WAGEHAT)_i + \delta X_i + \zeta X^2_i + \varepsilon_i \qquad (4)$$

where: *WAGEHAT* stands for the predicted value of teacher's wage (based on the first stage), X is a vector of control variables and ε is the error term.

5.1. IV results

Selected results from the second stage of IV estimations for the complete sample are reported in Tables 5 and 6, and they can be compared with OLS results for both subjects (Tables 3 and 4). As a first check of the validity of our instruments, we look at the results of first stage estimations. First-stage results show

[21] About gender wage inequality, see, for example, Altonji & Blank (1999).

[22] Vignoles et al. (2000). Because some authors do find a correlation between experience and test scores either in the first (Hanushek et al., 1999) or the last years of a teacher's career, we estimated our model without the least or without the most experienced teachers. Our results remain when we exclude either of these subgroups.

that, in both subjects and for all samples, most coefficients of predetermined instruments are statistically significant at the 1% level. More interesting, though, is to look at partial R-squared, as well as the F tests of the excluded instruments (variables we assume to be predetermined) of the first stage regressions. The R-squared is reasonably high for all subjects and samples (ranging from 0.12 to 0.18) and all F tests allow us to reject the hypotheses that the coefficients of predetermined variables are zero. As a second check of the validity of the instruments, we have computed Sargan's statistic for a test of over-identification. The test yields good results in Portuguese, both for the pooled and for the private schools sample (p-values are, respectively, 0.40 and 0.28), but not so good a result for public schools sample (0.09). In Mathematics, p-values are much lower for all the samples (0.09, 0.04, 0.03, for the pooled, private schools, and public schools samples, respectively), casting doubt on the validity of the set of instruments. Indeed, in Mathematics, none of the coefficients is significant, the standard errors are remarkably large, and there is even a sign reversal (private schools' coefficient becomes negative). Given the doubts placed on the set of instruments, we refrain from drawing any further conclusion for Mathematics, and we concentrate our analysis on Portuguese.

In Portuguese, for the pooled sample, second-stage estimation yields a positive and significant coefficient of teacher wages on test scores, as in OLS. The coefficient is larger than its OLS counterpart (4.33 vs. 3.36) and both are significant at the 1% level. The same pattern is verified for private schools (8.56 vs. 7.21), and here both coefficients are also statistically significant at the 1% level. Standard errors are considerably larger in the IV as compared to the OLS estimations. In public schools the coefficient is small (0.34) and not statistically different from zero, just as in OLS. The main qualitative conclusions we had drawn in the OLS section are thus preserved when we instrument teacher's wage. The coefficients obtained for the pooled and for the private schools samples are larger than the correspondent OLS ones, suggesting that OLS coefficients underestimated the effect of teachers' wages on scores, possibly because of a selection problem[23].

5.2. Combining QR with IV: two-stage least absolute deviation

Just as we extended the estimation of conditional means (OLS) to the estimation of coefficients that vary along the distribution of conditional scores (QR), it is natural to proceed in an analogous way extending the IV model in a similar manner. The idea underlying this combination of two techniques (QR and IV) is to cope simultaneously with both problems that are likely to bias our OLS coefficients, namely the heterogeneity of students' response to variation in teachers' wages and the possible endogeneity of teachers' wages. This combination of QR with IV has been called two-stage least absolute deviation (2SLAD). Levin (2001) and Billger (2002) have recently applied it in education production functions. Consistency and asymptotic normality of the 2SLAD estimator have been shown by Amemiya (1982), Powell (1983) and Chen & Portney (1996).

The procedure consists of regressing the endogenous variable (*STDTEACHERWAGE*) on all instruments (including predetermined ones) in the first stage through OLS, and then using the fitted values from the first stage (*WAGEHAT*) as the explanatory variable in the second stage (in the QR). So the second step consists of estimating the effects of the instrumented variable (*WAGEHAT*) on student achievement (*STDSCORE*) at different points in the conditional test score distribution.

The overall preciseness of the estimations is reduced when we apply 2SLAD, instead of plain QR estimations, which translates into a greater number of non-significant coefficients in 2SLAD regressions.

[23] It may be the case that rich parents whose children are not brilliant at school enrol them in expensive private schools so that well-paid teachers working there could help them in the acquisition of a good level of academic skills. Since they are not very talented, however, these students might obtain low test scores even though their teachers earn a relatively high wage (and have a high level of skills). In this case, teachers' wages coefficients would be underestimated because of a selection problem, regardless of the quality of teaching that is provided.

The preciseness of IV estimations is also reduced with respect to OLS, and the IV confidence bands (Figure 6) are larger than the OLS ones.

Results for Mathematics are not quite reliable for the reasons outlined before. Indeed, very few coefficients are statistically different from zero at usual levels of confidence.

Nevertheless, for Portuguese, a considerable number of coefficients still remain statistically significant[24] and, more importantly, the main qualitative results obtained using QR remain when we turn to 2SLAD. The effect of teachers' wages on pupils' scores decreases with the performance of students, both in the pooled sample (Figure 6A) and in the private schools sample (Figure 6B). In both cases, the coefficients for low quantiles (θ=0.05 and 0.10) are the largest significant ones, and exactly those which lie outside IV coefficients confidence interval. In the pooled sample, they are, respectively, 11.19 and 10.06, while in the private schools sample they are, respectively, 18.45 and 17.30. In public schools, although we can observe a slightly decreasing pattern (Figure 6C), teachers' wages are not correlated to a large extent with any particular type of student, since there are no significant coefficients, and almost all of them lie inside IV confidence band.

6. Discussion

All our results using the Portuguese sample support the three hypotheses tested in the paper: (i) on average, teachers' wages do have a significant positive effect on students test scores, although the coefficients are small – it should be emphasized, however, that coefficients are small here, but not nil, possibly because we are dealing with a developing country data with a substantial variability in teachers' wages; (ii) in private schools, which are typically funded and managed in a decentralized fashion, and in which richer families enroll their children, coefficients for teachers' wages are positive, significant, and higher than those of the public schools sample and of the pooled sample; (iii) the achievement impact of an additional unit of teacher wage is not the same for all types of student: the positive effect of teacher quality (as measured by his wage) is more important for low-performing pupils. The credibility of our results is reinforced, since they are preserved in qualitative terms when we correct for potential endogeneity of teacher wages using IV and 2SLAD. Not surprisingly, the coefficients of IV and 2SLAD are less precise than their OLS and QR counterparts.

In Mathematics, OLS results suggest that teachers' wages do matter for student performance, and they are more pronounced in private schools. QR results also provide evidence of heterogeneity, since some estimated coefficients are different across quantiles. So, there is also evidence in support of hypotheses (i), (ii) and (iii). However, we can not identify a decreasing pattern as clear as in Portuguese and some key coefficients are not different across quantiles[25]. Moreover, OLS and QR results are not reproduced in IV and 2SLAD estimations.

A puzzling issue is why the results we obtain for teachers' wages are so different from one subject to the other. Of course, when we instrument teachers' wages (IV and 2SLAD models), the differences could be due to the weakness of the instruments in Mathematics. For example, while an instrument such as teachers' gender was likely to be endogenous in Mathematics, it was more likely to be exogenous in Portuguese. This could be explained by differences in the nature of pupil-teacher relationship (gender-sensitive only in one subject) or due to different labor market characteristics, such as the gender composition of teachers' population. A male teacher seems to have a *direct* negative impact on scores in the Mathematics exam (not through the channel of wages), meaning the few female mathematics teachers perform better than their male counterparts.

[24] Most of them are significantly different from zero at 10 or 5%, but some are significant even at the 1% level.

[25] Cf. test results shown on endnotes 24 to 26

However, there are striking differences in the results across subjects, which are not related to the use of instruments. When we compare the QR results, we observe that, while in Portuguese there is a decreasing effect of teachers' wages on scores, in Mathematics the QR line is a flat one, indicating a more similar effect of teachers' wages on good and bad pupils. This is true both in the pooled samples and in the private samples. We don't have a good explanation for those different patterns. Understanding what explains that difference and what that implies in terms of educational policies are topics that would require further research.

Some policy implications are more transparent, though. It seems clear that public schools have scope for improving their human resources policies. The most important policy objective related to the management of teacher hiring and teacher payment would be to introduce some form of reward to performance. This could be achieved through the assignment of higher salaries to better candidates, fostering competition for new (good) teachers with the private schools and other sectors of the economy. Alternatively, some form of merit pay (through a bonus system for instance) could be introduced. The latter is however likely to face opposition from a sector where, traditionally, pay is only related to seniority. In the US, resistance to the use of merit pay in the public sector appears to be caused by specific circumstances such as the opposition of teacher unions (Ballou, 2001). According to our results, it would be all the more relevant to attract and reward teacher quality in the public sector as the lowest achieving pupils seem to benefit most from this resource – to be sure, in the literacy exam.

7. Conclusion

Using a good-quality dataset coming from a developing country and employing a more flexible functional form than the ones that are commonly used in the economics of education literature, we estimated education production functions in order to evaluate the magnitude of the cross-sectional correlation between teachers' wages and students' achievement, conditional on an extensive set of covariates. We used OLS (IV) methods to asses whether teachers' wages matter for pupils' scores, and we employed QR (2SLAD) to determine for whom teachers' wages matter. To our knowledge, this paper is the first to estimate education production functions applying the QR technique using Brazilian educational data, and probably one of the first ones to do so for a developing country.

We do not claim our results provide a strong causal relationship between teachers' wages and students' scores. But they do contain insightful evidence of the intricate relationship between these variables, since we used a great number of controls across the estimations; we examined teachers' wages effects for all schools, but also separately for private and public schools; we used different econometric techniques; and we found contrasting results in different subjects. A possible path for further research is to test our three hypotheses again by using different strategies of identification.

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Annex 1 : Tables

Table 1: Selected descriptive statistics, Portuguese exam, by type of school

Variable	All schools (pooled sample)		Private schools		Public schools	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
SCORE	249.31	49.85	279.06	45.27	232.73	44.26
TEACHERWAGE	5.08	3.16	5.98	3.69	4.57	2.69
GENDER	0.46	0.50				
AGE	14.92	1.58	14.12	0.94	15.37	1.68
BLACK	0.07	0.25	0.03	0.17	0.09	0.28
MIXED	0.37	0.48	0.28	0.45	0.43	0.49
MISCED	3.27	1.21	4.17	0.92	2.77	1.05
NONNUCLEAR	0.35	0.48	0.26	0.44	0.39	0.49
NMAIDS	0.60	1.01	1.24	1.13	0.24	0.71
NBOOKS	1.50	0.68				
RETENTION	0.55	0.84	0.23	0.56	0.73	0.92
HMWK	1.95	0.97				
PRINCWAGE	0.00	1.00				
LIBRARY	0.82	0.39	0.90	0.29	0.77	0.42
AIR	0.84	0.37				
LIGHT	0.92	0.26				
NCOMP	10.14	16.01	21.07	20.93	4.05	7.15
STRATIO	35.28	9.81				
TAXPERHEAD	103.17	101.79	116.73	107.49	95.62	97.65
TCHGENDER	0.18	0.38				
TCHHOURS	117.07	46.08				
TCHEXP	3.35	1.18				
TCHJOB	0.16	0.36				
tchcollege	0.91	0.28				
Number of obs.	28,605		10,238		18,367	

Short description of variables:

- *SCORE*: pupil's test scores, *TEACHERWAGE* gross monthly teacher's wages;
- *GENDER*: pupil's gender, *AGE*: pupil's age in years, *BLACK* and *MIXED*: self-declared race;
- *MISCED*: mother's level of education, *NONNUCLEAR*: dummy of value 1 if family if either parent does not live with pupil, *NMAIDS*: number of maids at home (as proxy for household wealth), *NBOOKS*: number of books at home;
- *RETENTION*: number of times pupil repeated a grade, *HMWK*: frequency with which the pupil does his homework, *PRINCWAGE*: wage of school principal, *LIBRARY*: dummy indicating presence of a library in school, *AIR* and *LIGHT*: dummies indicating whether classroom has enough air and light, *NCOMP*: number of computers available for pupil use, *STRATIO*: student/teacher ratio; *PRIVATE*: dummy indicating that schools are privately (funded and managed).
- *TAXPERHEAD*: tax revenues per head at the municipality
- *TCHGENDER*: teacher's gender, *TCHHOURS*: number of hours working as a teacher per month, *TCHEXP*: number of years of experience, *TCHJOB*: dummy variable which assumes value 1 if teacher has another job; *TCHCOLLEGE*: dummy indicating whether teacher went to university or not.

Table 2: Selected descriptive statistics, Mathematics exam, by type of school.

Variable	All schools (pooled sample)		Private schools		Public schools	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
SCORE	258.02	53,45	295.37	50.54	236.89	42.34
TEACHERWAGE	5.39	3.43	6.62	3.85	4.69	2.95
GENDER	0.47	0.50				
AGE	14.91	1.58	14.12	0.95	15.36	1.68
BLACK	0.07	0.26	0.03	0.18	0.09	0.29
MIXED	0.37	0.48	0.28	0.45	0.42	0.49
MISCED	3.28	1.20	4.16	0.92	2.78	1.05
NONNUCLEAR	0.34	0.47	0.26	0.44	0.39	0.49
NMAIDS	0.60	1.01	1.24	1.12	0.24	0.71
NBOOKS	1.50	0.68				
RETENTION	0.55	0.84	0.22	0.55	0.73	0.92
HMWK	1.90	0.98				
PRINCWAGE	0.00	1.00				
LIBRARY	0.82	0.38	0.91	0.29	0.77	0.42
AIR	0.84	0.37				
LIGHT	0.93	0.26				
NCOMP	10.32	16.51	21.33	21.80	4.09	7.10
STRATIO	35.31	9.81				
TAXPERHEAD	104.35	102.76	118.10	108.72	96.58	98.38
TCHGENDER	0.55	0.50	0.61	0.49	0.52	0.50
TCHHOURS	123.93	45.76	128.47	47.09	121.36	44.79
TCHEXP	3.29	1.20				
TCHJOB	0.23	0.42				
TCHCOLLEGE	0.88	0.32				
Number of obs.	27,942		10,095		17,847	

Table 3: OLS results, Portuguese exam, by type of school.

Dependent variable: Standardized test scores (*STDSCORE*)

	All Schools			**Private**			**Public**		
	Coef.		**Std.Dev.**	**Coef.**		**Std.Dev.**	**Coef.**		**Std.Dev.**
STDTEACHERWAGE	3.36	***	0.61	7.21	***	1.17	0.41		0.82
GENDER	-15.67	***	0.99	-21.51	***	1.79	-15.20	***	1.39
AGE	16.13	***	5.73	70.46	***	14.37	8.82		7.78
AGE^2	-0.75	***	0.18	-2.60	***	0.48	-0.57	**	0.24
BLACK	-16.26	***	2.01	-23.75	***	5.10	-16.08	***	2.52
MIXED	-4.25	***	1.07	-5.70	***	2.06	-3.43	**	1.46
RETENTION	-32.28	***	1.83	-51.95	***	4.49	-28.96	***	2.33
RETENTION^2	8.80	***	0.70	11.35	***	2.01	8.12	***	0.86
HMWK	24.24	***	1.98	22.20	***	3.95	27.37	***	2.66
HMWK^2	-4.83	***	0.55	-4.37	***	1.06	-5.39	***	0.75
MISCED	-1.59		2.34	5.68		6.23	-0.44		3.29
MISCED^2	1.32	***	0.36	0.39		0.84	1.22	**	0.55
NONNUCLEAR	-14.19	***	1.03	-18.41	***	2.03	-13.85	***	1.40
NMAIDS	-1.82		2.13	5.07	*	2.87	-20.63	***	4.34
NMAIDS^2	1.78	**	0.80	-0.03		1.05	8.00	***	1.69
NBOOKS	24.92	***	4.57	22.78	***	7.10	40.27	***	8.03
NBOOKS^2	-3.97	***	1.21	-3.14	*	1.78	-8.26	***	2.25
PRINCWAGE	4.06	***	0.72	5.95	***	1.25	3.09	***	1.17
PRINCWAGE^2	-0.47		0.59	-0.09		1.02	-2.12	**	0.95
LIBRARY	3.37	**	1.33	2.02		3.17	5.51	***	1.71
PRIVATE	39.05	***	1.59						
AIR	-1.84		1.50	1.21		3.86	-1.92		1.91
LIGHT	3.77	*	2.04	3.12		6.32	4.03		2.48
NCOMP	0.50	***	0.08	0.35	***	0.12	0.31		0.24
NCOMP^2	0.00	***	0.00	0.00	**	0.00	0.01		0.01
STRATIO	-0.09		0.24	-0.09		0.37	0.16		0.39
STRATIO ^{2}	0.00		0.00	0.00		0.01	0.00		0.01
TAXPERHEAD	0.16	***	0.02	0.18	***	0.04	0.18	***	0.02
TAXPERHEAD^2	0.00	***	0.00	0.00	***	0.00	0.00	***	0.00
TCHCOLLEGE	8.30	***	1.85	12.49	***	4.42	9.74	***	2.38
STATE DUMMIES (UF1 – UF27)	yes			yes			yes		
Constant	345.74	***	45.88	-55.69		110.32	428.72	***	62.95
R squared	0.34			0.22			0.17		
Number of Obs.	28,605			10,238			18,367		

Table 4: OLS results, Mathematics exam, by type of school.

Dependent variable: Standardized test scores (*STDSCORE*)

	All Schools			Private Schools			Public Schools		
	Coef.		Std.Dev.	Coef.		Std.Dev.	Coef.		Std.Dev.
STDTEACHERWAGE	2.38	***	0.59	3.94	***	1.12	0.20		0.84
GENDER	26.52	***	0.92	24.87	***	1.72	36.29	***	1.36
AGE	-10.66	**	5.38	33.42	**	13.75	-17.46	**	7.73
AGE²	0.08		0.17	-1.47	***	0.46	0.20		0.24
BLACK	-21.19	***	1.83	-28.95	***	4.86	-23.84	***	2.42
MIXED	-7.86	***	0.99	-8.76	***	1.96	-8.64	***	1.44
RETENTION	-29.88	***	1.71	-53.59	***	4.32	-27.65	***	2.30
RETENTION²	8.20	***	0.65	12.20	***	1.92	7.82	***	0.85
HMWK	17.77	***	1.82	13.30	***	3.65	21.69	***	2.63
HMWK²	-3.23	***	0.51	-1.68	*	1.00	-4.15	***	0.74
MISCED	-8.06	***	2.19	2.55		6.11	-2.09		3.27
MISCED²	2.42	***	0.34	1.14		0.83	1.50	***	0.55
NONNUCLEAR	-16.13	***	0.97	-23.12	***	1.95	-15.59	***	1.39
NMAIDS	8.84	***	1.99	13.59	***	2.78	-4.90		4.25
NMAIDS²	-1.84	**	0.75	-3.44	***	1.02	3.21	*	1.66
NBOOKS	30.16	***	4.26	32.65	***	6.82	48.93	***	7.97
NBOOKS²	-5.39	***	1.13	-5.75	***	1.72	-10.47	***	2.24
PRINCWAGE	4.83	***	0.68	8.26	***	1.18	2.19	*	1.17
PRINCWAGE²	0.27		0.56	-0.23		0.98	-1.18		0.96
LIBRARY	2.35	*	1.25	2.48		3.13	5.17	***	1.70
PRIVATE	45.58	***	1.47						
AIR	-3.13	**	1.42	-7.81	**	3.79	-0.40		1.91
LIGHT	5.79	***	1.96	17.75	***	6.23	4.69	*	2.52
NCOMP	0.76	***	0.07	0.77	***	0.11	-0.29		0.24
NCOMP²	0.00	***	0.00	-0.01	***	0.00	0.04	***	0.01
STRATIO	-0.51	**	0.22	-1.10	***	0.34	-0.05		0.39
STRATIO ²	0.01	*	0.00	0.01	***	0.00	0.00		0.01
TAXPERHEAD	0.09	***	0.02	0.15	***	0.04	0.12	***	0.02
TAXPERHEAD²	0.00	***	0.00	0.00	***	0.00	0.00	***	0.00
TCHCOLLEGE	1.66		1.55	8.85	**	3.57	1.31		2.15
STATE DUMMIES (UF1 – UF27)	yes			yes			yes		
Constant	548.06	***	43.04	213.10	**	104.30	618.02	***	62.71
R squared	0.44			0.29			0.22		
Number of Obs.	27,942			10,095			17,847		

Table 5: IV results, Portuguese exam, by type of school.

1st stage	All schools			Private schools			Public schools		
	Coef.		Std.Dev.	Coef.		Std.Dev.	Coef.		Std.Dev.
TCHGENDER	0.18	***	0.01	0.19	***	0.19	0.15	***	0.02
TCHHOURS	0.01	***	4.90E-04	0.01	***	7.50E-04	-4.48E-04		6.70E-04
TCHHOURS²	-1.21E-05	***	2.13E-06	3.09E-05	***	3.28E-06	2.02E-05	***	2.92E-06
TCHEXP	0.15	***	0.02	0.02		0.03	0.24	***	0.03
TCHEXP²	4.90E-03		3.16E-03	0.02	**	5.20E-03	-1.50E-03		4.00E-03
TCHJOB	-0.09	***	0.01	-0.14	***	0.019	-0.11	***	0.02
R2	0.15			0.16			0.16		
Number of Obs	28,605			10,238			18,367		
Sargan	0.401			0.283			0.089		

2nd stage	All schools			Private schools			Public schools		
	Coef.		Std.Dev.	Coef.		Std.Dev.	Coef.		Std.Dev.
STDTEACHERWAGE	4.33	***	1.57	8.56	***	2.90	0.34		2.03
R2	0.34			0.22			0.43		
Number of Obs	28,605			10,238			18,367		

Table 6: IV results. Mathematics exam, by type of school.

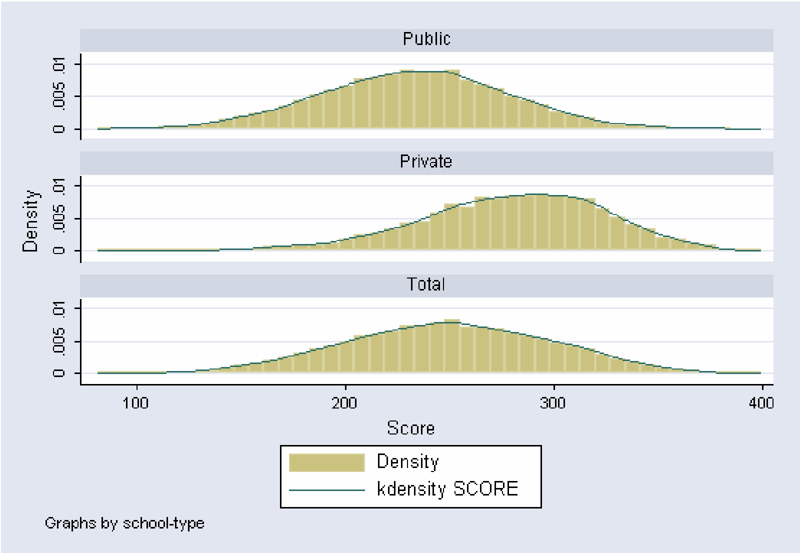
1st stage	All schools			Private schools			Public Schools		
	Coef.		Std.Dev.	Coef.		Std.Dev.	Coef.		Std.Dev.
TCHGENDER	0.11	***	0.01	0.17	***	0.02	0.08	***	0.01
TCHHOURS	3.70E-03	***	5.20E-04	4.00E-03	***	8.80E-04	4.00E-03	***	6.95E-04
TCHHOURS²	3.65E-06	*	2.21E-06	2.730E-06		3.66E-06	2.92E-06		2.96E-06
TCHEXP	0.03	*	0.02	0.07	*	0.04	-0.0031		0.03
TCHEXP²	0.02	***	3.00E-03	6.00E-03		0.01	0.032	***	3.85E-03
TCHJOB	-0.12	***	0.01	-0.05	**	0.02	-0.17	***	0.01
R2	0.15			0.12			0.18		
Number of Obs	27,942			10,095			17,847		
Sargan	0.086			0.042			0.03		

2nd stage	All schools			Private schools			Public schools		
	Coef.		Std.Dev.	Coef.		Std.Dev.	Coef.		Std.Dev.
STDTEACHERWAGE	0.30		1.52	-2.63		3.16	0.02		1.98
R2	0.44			0.29			0.22		
Number of Obs	27,942			10,095			17,847		

Annex 2 : Figures

Figure 1: Distributions of *SCORE* for each type of schools.

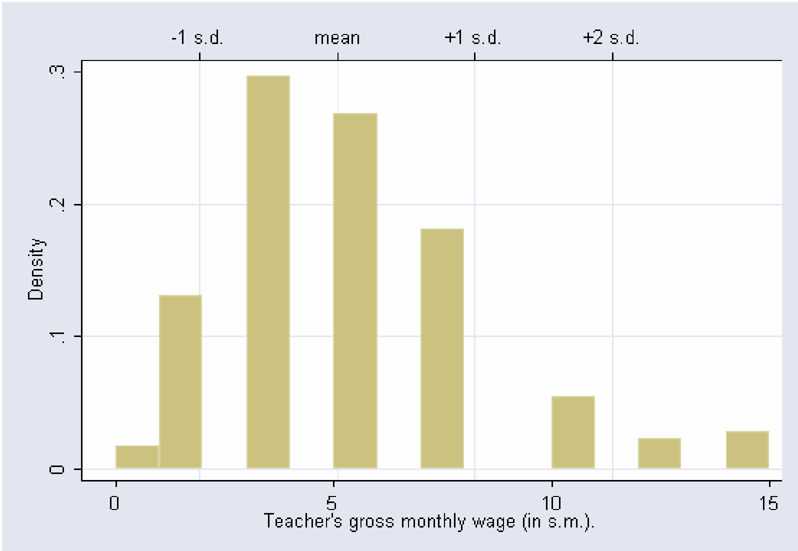
Panel A: Portuguese.



Panel B: Mathematics

Figure 2: Distribution of *TEACHERWAGE* for the pooled samples.

Panel A: Portuguese.



Panel B: Mathematics

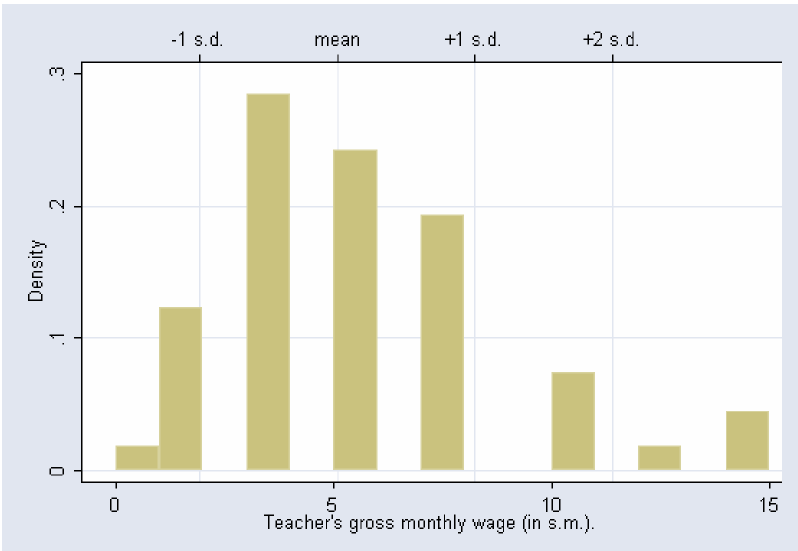
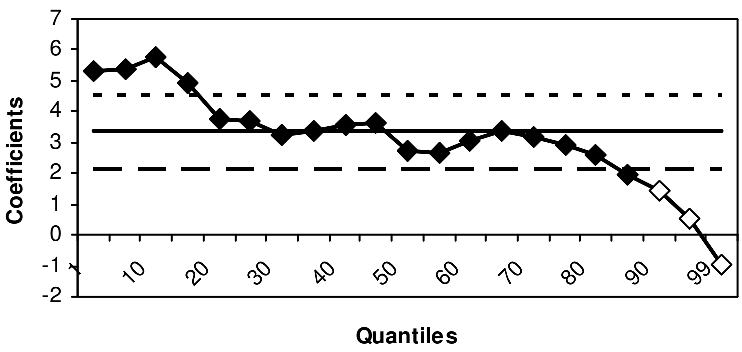
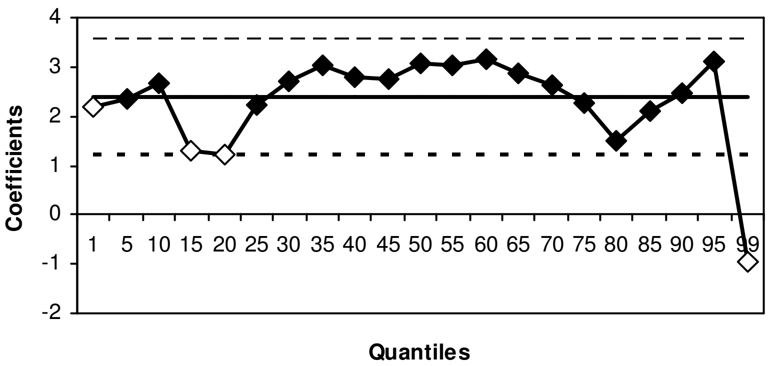


Figure 3: Quantile regression results. Pooled samples.[26]

Panel A: Portuguese.



Panel B: Mathematics.

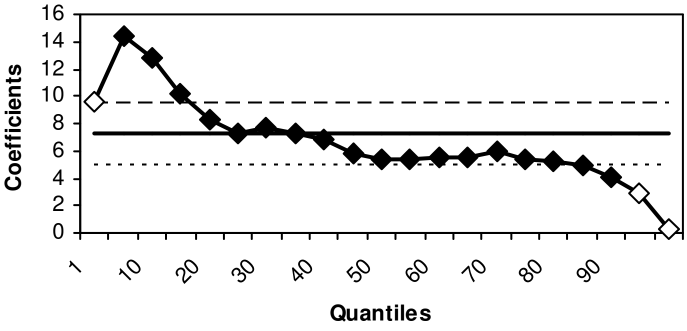


Significant QR coefficients: —▲—   Non-significant QR coefficients: —Δ—   OLS coefficient: ———   Dotted lines: OLS confidence bands.

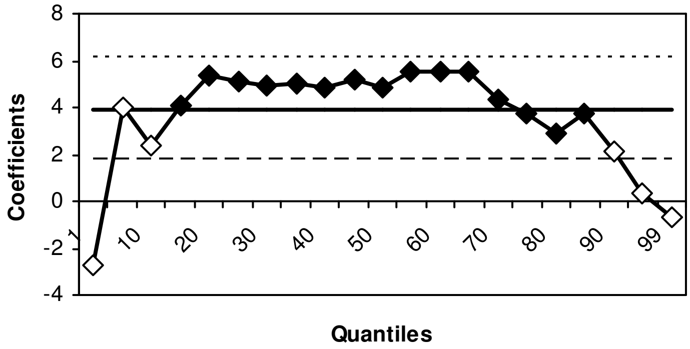
[26] Figure 3. Wald tests for Panel A: H_0: $\beta_{(\theta=0.10)} = \beta_{(\theta=0.85)}$: F-statistic: 4.96; p-value: 0.0260. H_0: $\beta_{(\theta=0.15)} = \beta_{(\theta=0.85)}$: F-statistic: 7.02 ; p-value: 0.0081. We can reasonably reject both null hypotheses, concluding that $\beta_{(\theta=0.10)} \neq \beta_{(\theta=0.85)}$ and $\beta_{(\theta=0.15)} \neq \beta_{(\theta=0.85)}$. Wald tests for panel B: H_0: $\beta_{(\theta=0.20)} = \beta_{(\theta=0.60)}$: F-statistic: 4.05; p-value:0.0442. H_0: $\beta_{(\theta=0.20)} = \beta_{(\theta=0.95)}$: F-statistic: 1.62; p-value:0.2026. We can reasonably reject the first null hypotheses, concluding that $\beta_{(\theta=0.20)} \neq \beta_{(\theta=0.60)}$. However, we can not exclude the possibility that $\beta_{(\theta=0.20)} = \beta_{(\theta=0.95)}$.

Figure 4: Quantile regression results. Private schools.[27]

Panel A: Portuguese.



Panel B: Mathematics.



Significant QR coefficients: ━▲━ Non-significant QR coefficients: ━Δ━ OLS coefficient: ━━━ Dotted lines: OLS confidence bands.

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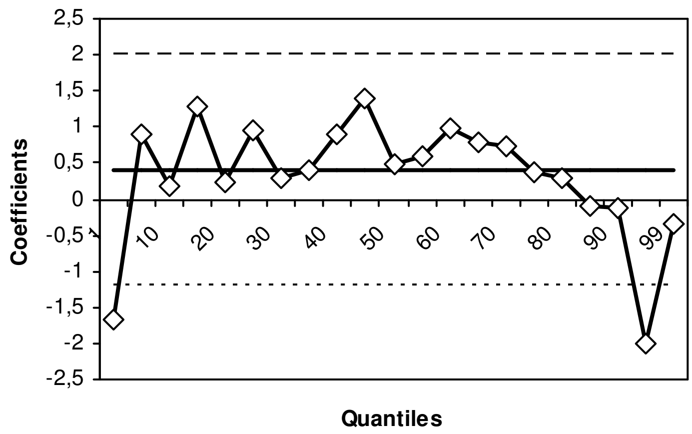
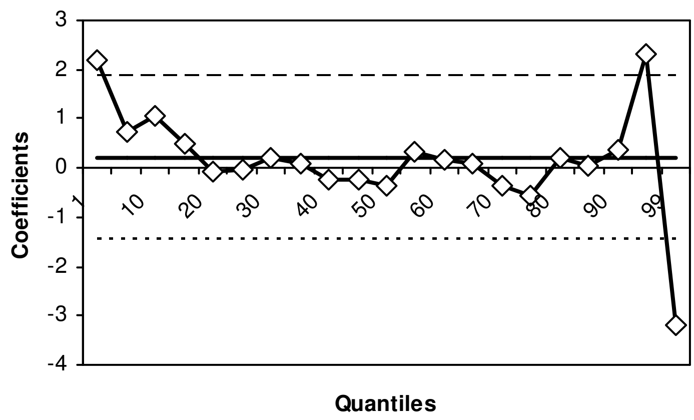
[27] Figure 4. Wald tests for Panel A: H_0: $\beta_{(\theta=0.05)} = \beta_{(\theta=0.90)}$: F-statistic: 7.03; p-value: 0.0080. H_0: $\beta_{(\theta=0.15)} = \beta_{(\theta=0.90)}$: F-statistic: 5.40; p-value:0.0201. We can reasonably reject both null hypotheses, concluding that $\beta_{(\theta=0.05)} \neq \beta_{(\theta=0.90)}$ and $\beta_{(\theta=0.15)} \neq \beta_{(\theta=0.90)}$. Wald tests for Panel B: H_0: $\beta_{(\theta=0.20)} = \beta_{(\theta=0.80)}$: F-statistic: 0.01; p-value: 0.9107. H_0: $\beta_{(\theta=0.20)} = \beta_{(\theta=0.60)}$: F-statistic: 1.48; p-value: 0.2243. We cannot reject any of the null hypotheses, concluding that $\beta_{(\theta=0.20)} = \beta_{(\theta=0.80)}$ and $\beta_{(\theta=0.20)} = \beta_{(\theta=0.60)}$.

Figure 5: Quantile regression results. Public schools.

Panel A: Portuguese.



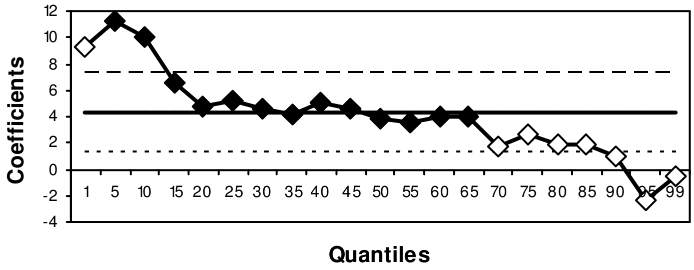
Panel B: Mathematics.



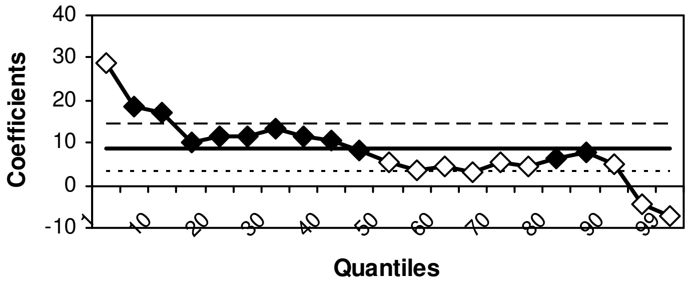
Significant QR coefficients: —▲—
Non-significant QR coefficients: —∆—
OLS coefficient: ——
Dotted lines: OLS confidence bands.

Figure 6: 2SLAD regression results. Portuguese[28].

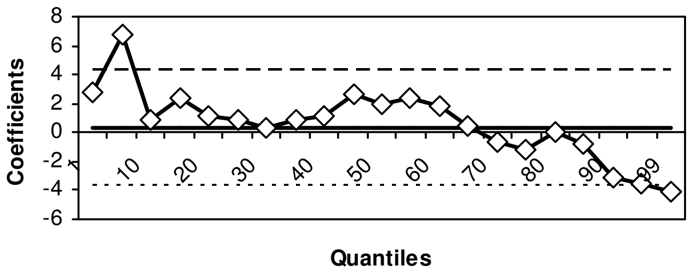
Panel A: Pooled samples**.**



Panel B: Private schools samples.



Panel C: Public schools samples.



Significant 2SLAD coefficients: ▬▲▬ Non-significant 2SLAD coefficients: ▬Δ▬
IV coefficient: ▬▬ Dotted lines: IV confidence bands.

[28] Figure 6. Wald tests for Panel A: H_0: $\beta_{(\theta=0.05)} = \beta_{(\theta=0.55)}$: F-statistic: 2.25; p-value: 0.1339. H_0: $\beta_{(\theta=0.05)} = \beta_{(\theta=0.95)}$: F-statistic: 7.63; p-value: 0.0058. We can reject the second null, concluding that $\beta_{(\theta=0.05)} \neq \beta_{(\theta=0.95)}$. However, we can not exclude that $\beta_{(\theta=0.05)} = \beta_{(\theta=0.55)}$. Wald tests for Panel B: H_0: $\beta_{(\theta=0.05)} = \beta_{(\theta=0.80)}$: F-statistic: 1.98; p-value: 0.1598. H_0: $\beta_{(\theta=0.80)} = \beta_{(\theta=0.99)}$: F-statistic: 3.03; p-value: 0.0816. We can reasonably reject the second null hypotheses, concluding that $\beta_{(\theta=0.80)} \neq \beta_{(\theta=0.99)}$. However, we can not exclude the possibility that $\beta_{(\theta=0.05)} = \beta_{(\theta=0.80)}$.

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