C.I.R.P.É.E

Centre Interuniversitaire sur le Risque,
les Politiques Économiques et l'Emploi

Cahier de recherche/Working Paper **11-35**

The Distributional Impacts of a Universal School Reform on Mathematical Achievements : a Natural Experiment from Canada

Catherine Haeck

Pierre Lefebvre

Philip Merrigan

Première version/First Version : Novembre/November 2011

Version révisée/revised : Avril/April 2012

Haeck: Katholieke Universiteit Leuven
Catherine.Haeck@econ.kuleuven.be
Lefebvre: Université du Québec à Montréal and CIRPÉE
lefebvre.pierre@uqam.ca
Merrigan: Université du Québec à Montréal and CIRPÉE
merrigan.philip@uqam.ca

We gratefully acknowledge financial support from the Fonds québécois de la recherche sur la société et la culture and from the Belgian Federal Science Policy Office (Interuniversity Attraction Poles P5/26). We thank the Québec Inter-University Cenre for Social Statistics (QICSS) for great support throughout this project. The analysis is based on Statistics Canada's National Longitudinal Survey of Children and Youth (NLSCY) restricted-access Micro Data Files available at the QICSS. All computations on these micro-data were prepared by the authors who assume responsibility for the use an interpretation of these data.

Abstract:
We investigate the impact of an ambitious provincial school reform in Canada on students' mathematical achievements. It is the first paper to exploit a universal school reform of this magnitude to identify the causal effect of a widely supported teaching approach on students' math scores. Our data set allows us to differentiate impacts according to the number of years of treatment and the timing of treatment. Using the changes-in-changes model, we find that the reform had negative effects on students' scores at al points on the skills distribution and that the effects were larger the longer the exposure to the reform.

Keywords: School reform, math achievements, DID and CIC estimators

JEL Classification: I21, I28

Empirical research has shown that measures of educational attainment alone may not be sufficient to capture the extent to which human capital triggers economic growth and impacts individual labor market outcomes. Research shows that concrete measures of academic achievement and cognitive skills, along with educational attainment, are strongly correlated with labor market outcomes, such as earnings and unemployment (Murnane, Willett, and Levy, 1995; Neal and Johnson, 1996; Murnane et al., 2000; Currie and Thomas, 2001; Hanushek and Woessmann, 2008).[1] A number of studies have documented the specific importance of mathematical abilities in adulthood socioeconomic success (e.g. Murnane et al., 1995; Rose and Betts, 2004; Ingram and Neumann, 2006). Evidence suggests that mathematics skills have long lasting effects.[2]

Developing these skills should be of great policy interest, and so should understanding which policy may help (or hinder) the development of these skills. A large body of research in the literature has investigated the impact of different inputs in the educational production function on achievement. Teacher quality has been shown to be of great importance in predicting the success of students.[3] Other types of resources (e.g. per pupil expenditure, school facilities, class size) have generally been shown to be poor predictors of student performance.[4] While the impact of school resources has been widely studied, few studies in economics have addressed the importance of what is being taught and how it is being taught.[5]

In this paper, we estimate the impact of Québec's (the second most populated province in Canada) ambitious and universal school reform implemented in the early 2000's on children's mathematical ability throughout primary (K-6) and secondary (7-11) school. At the time of the reform, Québec was among the top performing countries in international assessments, but

[1] Other recent studies show that non-cognitive skills (i.e. behavioural and social skills) also play an important role in predicting labour market outcomes. Although non-cognitive skills are more difficult to measure, they seem more malleable over the life cycle (Heckman and Rubinstein, 2001; Heckman, Stixrud, and Urzua, 2006).

[2] Murnane et al. (1995) show that math test scores measuring basic knowledge of mathematics (such as the working of fractions and decimals) predict future wages better than reading and vocabulary test scores. They show that reading and vocabulary test scores become insignificant in predicting future wages once the math score is included. They also show that the effect on wages is larger 6 years after graduation than 2 years after.

[3] For example, among many others, Hanushek and Rivkin (2010) show that teacher quality (as well as principals and administrators) can be linked with children test scores, such that better teachers can have significant effects on students' achievements. Chetty, Friedman and Rockoff (2011) show that the quality of teachers has large positive impacts not only on test scores, but also on long-term outcomes (e.g. attending college, future earnings, not having children as teenagers).

[4] In economics, see, for example, Hanushek (2003), Angrist and Lavy (1999), Hoxby (2000), and Rivkin, Hanushek and Kain (2005). In educational research, see Teddlie and Reynolds (2000).

[5] One exception is Machin and McNally (2008) on the impact of a highly-structured hour of literacy on students reading and English skills. Further details are provided in the next section. Other studies related to the teaching approach include, Angrist and Lavy (2002) on the use of Computer Aided Instruction, and Rouse and Krueger (2004) on the impact of instructional computer programs on literacy.

was still subject to severe criticism at home due to its alarmingly large high school dropout rate, especially among male students.[6] To ensure the success of all students, the province decided to implement an ambitious reform introducing a new curriculum in each and every school across the province which drastically changed the way teaching was delivered to all children in primary and secondary schools. The Québec education program (MELS 2001, 2003, and 2007) relied on a competency-based approach. It moved teaching away from the traditional/academic approaches of memorization, repetitions and activity books, to a much more comprehensive approach focused on learning in a contextual setting in which children are expected to find the answers for themselves.

The reform's curriculum content was supported by a number of countries. Evidence from Bulle (2011) suggests that most OECD countries are moving away (or have long moved away) from the traditional (more academic) teaching approach. More specifically, the teaching approach promoted by the Québec reform is comparable to the reform-oriented teaching approach in the United States. As of 2006, this approach was widely spread across the United States (although more traditional approaches remained dominant) and it was supported by leading organizations such as the National Council of Teachers of Mathematics, the National Research Council, and the American Association for the Advancement of Science. Yet few studies in economics have addressed the impact of various teaching approaches, let alone the approach promoted by the Québec reform.

The Québec reform/experiment provides some advantages for the purpose of evaluation. First, Québec's Department of Education implemented the reform and all schools (public and private) were forced to apply the new education program. Combined with a rich data set, this allows us to estimate the impact of a universal reform, on students of different abilities. Second, because teaching in the Rest of Canada (RofC) continued to be delivered in the same way throughout the period, it is possible to estimate the effect of the reform using students from the other provinces, who are in the same grade as Québec students, as controls. Third, because the reform was implemented in steps, starting in September 2000 for grades 1 and 2, ending in September 2008 for grade 11 (i.e. the last grade of high school in Québec), we can compare over time "treated" younger students (newly exposed to the reform) and older students (exposed for many years to the reform) to a comparable group of Québec students observed only a few years before. Fourth, the reform provides a longer treatment period than typically encountered in the literature. This allows us to assess both the impact of the reform on mathematical ability throughout primary and secondary school and the impact of the reform for different lengths of exposure to treatment.

We use the Canadian National Longitudinal Survey of Children and Youth (NLSCY) for

[6] In 1999, the dropout rate was 16.0% in Québec versus 12.0% in Canada, and 19.9% versus 14.7% for malesat age 20 (Bowlby and McMullan, 2002).

the analysis, which provides students' test scores in mathematics. We estimate the effect of the reform on a standardized measure of mathematical ability using two econometric methods. First, we apply the 'Difference-In-Differences' (DID) framework, a method largely used for evaluating the effects of policy changes (Angrist and Krueger, 1999; Blundell and Costa-Dias, 2009). Second, the estimations are conducted with the 'Changes-in-Changes' (CIC) non parametric estimator, developed by Athey and Imbens (2006), which generalizes the DID model. The CIC framework allows us to estimate the impact of the reform at different points on the skills distribution. More specifically, we can investigate whether or not the reform had a positive impact on the least performing students. Using CIC, we also estimate the impact on high achievers.

Studying this reform contributes to the literature by further identifying the determinants of mathematical abilities, and more specifically by identifying the causal impact of an increasingly popular teaching approach. It is the first paper to exploit a universal school reform of this magnitude to identify the causal effect of the teaching approach on the development of the mathematical skills of students. Our results suggest that the reform had negative effects on the development of students' mathematical abilities and that the effects were larger the longer the exposure to the reform and hence to the teaching method.

The outline of the paper is as follows. Section 1 highlights the distinctive features of the education system in Québec compared to the other Canadian provinces, and describes the school reform implemented as of 2000. International research on comparable teaching approaches are also discussed. Section 2 exposes the econometric methodology used to identify the causal effect (treatment on the treated effect) of the school reform on achievement in math. Section 3 describes the data set used and presents descriptive statistics of the key variables. The estimated effects of the reform are presented in Section 4. In section 5, we provide further evidence on the impact of the reform using international assessment data. The last section offers concluding remarks.

1 Québec's school system and curriculum reform

In Canada, education is regulated and administered at the provincial level. The overall structure of the education system is comparable across all ten provinces, except for Québec where it is slightly different (with a K-11 rather than a K-12 system).

In all of Canada, children start school in kindergarten at age 5 in most cases, but sometimes as early as age 4 depending on the provincial rules concerning entry age in kindergarten. Children then move on to primary school, where they complete six years of education from grades 1 to 6. Children then pursue their education in high school. In Québec, high school consists of five years of education, grades 7 to 11, while in the RofC children must complete six years of education, grades 7 to 12, to obtain their high school diploma. Grades 7 to 11 in the RofC are comparable to those in Québec.[7]

Québec teachers prior to and after the reform have the same level of qualifications when entering the profession. The 4 year long bachelor's degree in education is a necessary condition to access the teaching profession in Québec since 1994.[8] Findings of this paper relates to the reform itself and the teaching method, and not to the teacher's level of training, or even more generally to teacher quality.

We first provide a detailed overview of the reform and then discuss its implementation, and also discuss quantitative research studying comparable reforms in other countries.

1.1 The reform

As of 2000, a comprehensive school reform impacting both primary and secondary schools was deployed all across the province of Québec. The reform aimed at making schools more responsive to the changing needs of children in order to improve their chances of success. Cross-curricular competencies and broad areas of learning[9] were introduced into the new program and formed the key elements of this new approach centering the teaching and learning environment around the students. More specifically, this approach was designed to enable students to "find answers to questions arising out of everyday experience, to develop a personal and social value system, and to adopt responsible and increasingly autonomous behaviors" (MELS, 2005).

In the classroom, what should be different? Students were expected to be more actively involved in their own learning and take responsibility for it. Critical to this aspect was the need to relate their learning activities to their prior knowledge and transfer their newly acquired knowledge to new situations in their daily lives. "Instead of passively listening to teachers, students will take in active, hands-on learning. They will spend more time working on projects, doing research and solving problems based on their areas of interest and their concerns. They will more often take part in workshops or team learning to develop a broad range of competencies." (MELS, 1999). This centralized approach in providing the program and training with a school-based execution is in many ways comparable to the current approach taken within the comprehensive school reform (CSR) models at the national level in the United States (Borman et al., 2003). The main differences are that in Québec, implementation is mandatory in each and every school, funding is not tied to the implementation, and training packages and support is centralized in many ways.

[7] Our data set, further detailed in Section 5, covers grade 2 to 10 students.

[8] The bachelor's degree in education is among the few programs that requires more than 3 years of training at the University level.

[9] A complete list of the competencies and areas of learning is provided in Table 9 of the Appendix.

The allocation of time per subject was also modified.[10] More time was spent on learning the language of instruction (French or English) and mathematics, while less time was spent on all other subjects. More specifically, in high school some subjects were completely dropped (e.g. home economics), while others were integrated in the curriculum of other broader subjects (e.g. economics with citizenship education, human biology with science and technology).

In sum, active competencies such as problem solving, strong communication skills, use of creativity, cooperation with others and teaching strategies based on the active participation of students were central to the reform, while more passive learning approaches such as memorization, repetitions and traditional lectures in which teachers provide the content to be learned appears to have been put aside.

1.2 The implementation

Figure 1 shows the implementation schedule of the reform. Students in grades 1 and 2 (Elementary Cycle 1) were introduced to the reform in September 2000. The changes were phased in for other cycles over time: September 2001 - grades 3 and 4 (Elementary Cycle 2); September 2003 - grades 5 and 6 (Elementary Cycle 3); September 2005 and 2006 - grades 7 and 8 respectively (Secondary Cycle 1); September 2007, 2008 and 2009 - grades 9, 10 and 11 respectively (Secondary Cycle 2). The original plan for grades 5-6 and secondary school was delayed by one year. While training for grade 5 and 6 teachers began as early as 2001, the implementation was delayed, from 2002 to 2003. Whether private or public, English speaking or French speaking, all schools across the province were mandated to follow the reform according to the implementation schedule. This implies that all children in Québec were treated according to the above timeline, and that parents were not able to self-select their children into or out of the reform, except by moving out of the province.

Extensive training was provided to support the new program. The year prior to the implementation in Elementary Cycle 1, teachers, principals and government officials began the task of preparing the implementation of the reform. Sixteen pilot schools along with several other Lead schools in the English sector experimented with the key concepts of the program of study, as well as school organizational approaches that could be best suited to the strategies required to maximize the effectiveness of the learning environment.

In June 2000, principals in conjunction with teachers began developing their implementation plans for September 2000. Each school was allowed to develop its own approach to

[10] The main areas and subjects of the curriculum are: 1. Languages (French or English as a teaching language, and French/English as a second language). 2. Mathematics, science, technology. 3. Arts education (art, music, drama or dance). 4. Physical education and health. 5. Moral education, or Catholic religious and moral instruction or Protestant moral and religious education.

deal with the implementation since no single approach was believed to meet the needs of each school across Québec. Teaching was organized by cycle. Some schools chose to organize teacher teams by cycle. Others opted for a "looping" model in which each teacher was assigned to one group of students for the entire cycle (e.g. grades 1 and 2). Some schools spent a lot of effort in developing themes and projects that actively involved the students, while others piloted a new reporting method to evaluate students that would be in tune with the new program. In 2000, all schools, both elementary and secondary, participated in some way to the development of the implementation of the reformed curriculum despite the fact that it did not affect all levels of schooling at the time.

The NLSCY does not provide any information on the extent to which the reform was implemented in the school attended by the child.[11] Since the reform was mandatory, we assume that at least part of the reform was enacted in each and every school.

1.3 International comparability

Although the Québec reform is not unique (see for example the 1989 NCTM Standards in California, and the 1997 reform in Belgium's French Community) and the importance of mathematical skills is well documented, we are not aware of any study in the economics literature estimating the impact of the teaching approach promoted by these reforms on the development of students mathematical abilities.[12] Bailey and Borooah (2010) provide a glimpse into what the effects may be. Using a multivariate approach, they estimate the influence of different factors (e.g. family type, education of the parent, minutes of instruction, etc.) on the mathematical skills of students. They use the OECD's Program for International Student Assessment (PISA) 2003 data on students from 41 countries. Their results suggest that relative to elaboration learning (the strategy promoted by the Québec reform), memorization/rehearsal and control learning are positively correlated with the mathematics test score, but the coefficients are small.

Studies from education research also provide some insights. In the United States, Com-

[11] Research by the Evaluation of the Reform at the Secondary School Level group (ERES, 2011a) on students starting high school in 2006-2007 revealed that students post-reform (relative to pre-reform students) perceived less favourably the classroom climate and some of the teaching practices.

[12] Machin and McNally (2008) have studied the impact of a highly structured hour of literacy on primary school students' reading and English skills. The number of hours of teaching did not change, but the content became much more structured. In practice, it was felt that the literacy hour raised the standards to be met and increased the time spent on whole class teaching (about 40 minutes out of 60). The literacy hour was generally (but not exclusively) implemented in schools with lower student performance. Using a difference-in-differences approach comparing students subject to the literacy hour (for up to two years) with students who were not, the authors find that the literacy hour generated a singificant improvement in students' reading and English skills. In contrast to the literacy hour, the Québec reform was based on a much less structured approach in which teachers were provided much more responsability and students were expected to create their own learning opportunities out of their daily experiences.

prehensive School Reforms (CSR) have been implemented by schools and districts for almost two decades to improve the country's many low-performing public schools. Although the CSR model developers are many and their designs differ, they typically employ similar strategies to achieve better student performance (American Institutes for Research - AIR, 2005): organizing the school to facilitate transformed teaching and learning, transforming curriculum and instruction, providing students with the necessary academic and social support, increasing teacher and principal effectiveness, as well as parental involvement. A meta-analysis of over 230 evaluations on 29 leading CSR models across the country found that their overall effects are positive, but small[13] (Borman et al., 2003).

Of the few experimental studies cited by Borman et al. (2003), one clearly relates to the Québec reform curriculum. Crawford and Snider (2000) study two curricula. The first one explicitly teaches mathematical concepts and focuses on the mastery of mathematical concepts through drill and repetition. The second one uses a more implicit approach in which the teacher sets up a situation in which the students have to learn and discover concepts through reasoning and discussions, but provides no explicit opportunities to review or practice. The latter shares similarities to the Québec reform. The authors find that the former approach (i.e. the more explicit approach) is more successful in producing mathematical knowledge.

In parallel with CSR, other reforms closely related to the Québec reform were conducted in the United States. Le et al. (2006) evaluate the impact of a more targeted approach, reform-oriented teaching, on students' achievements in mathematics and sciences in three school districts in the United States. Reform-oriented teaching promotes the active participation of students in their own learning. In this approach, inquiry-based activities are central: students are expected to ask questions, discuss alternative solutions, make connections between knowledge acquired in different subject areas and present the reasoning that led them to a preferred solution. Using multivariate analysis, the authors find that the relationship between reform-oriented teaching and achievement in mathematics and sciences is either nonsignificant or at best weakly positively significant.

Although extensive work was deployed to gather classroom data revealing the implemented teaching approach, the data collected and the contextual setting pose a number of limitations. First, since students were not randomly assigned to teachers, most students experienced a mix of teaching approaches during the three year observation period. Second, teachers self-selected into the reform-oriented approach, such that the estimated impact cannot reveal the impact of the reform if applied to all teachers. Third, the teaching approach was mainly self-reported by teachers, and somewhat conflicting evidence was found through observation of a few of the sampled teachers. Fourth, teachers admitted to being influenced

[13] The estimated effects are about one tenth to one seventh of a standard deviation.

by the testing environment. Given the push forward for similar teaching approaches in the United States, combined with limited empirical evidence concerning the effectiveness of these approaches in raising students' achievements, further research is required.

In sum, the few studies listed above suggest that a more structured approach leads to increased students' performance. Compared to these studies, the evaluation of the Québec reform has some methodological advantages. First, the reform was mandated to each and every school across the province by the Ministry of Education, such that every school and teacher had to embrace the reform (at least to some degree) and students from all background were treated. The impact of the reform can be estimated on students with different abilities. Second, since teaching in the Rest of Canada (RofC) continued to be delivered in the same way throughout the period, students from the other provinces may be used as controls. Third, the reform combined with our data set allows us to observe students treated for up to nine years (as opposed to three and less in the studies cited above). This longer observation period, also allows us to estimate (to some extent) the long term effects of the reform.[14] Fourth, although the treatment period is long, because the reform was implemented in steps, all of our estimates are derived from a comparison of students in the same grade close by in time, which reduces the possible bias induced by other reforms taking place at the same time.

2 Empirical strategy

In economics, difference-in-differences (DID) methods have often been used to estimate the effects of policy reforms. Angrist and Krueger (1999) and Blundell and Costas Dias (2009) describe applications and give an overview of the methodology. This approach can be used in settings where some individuals of a population are subject to a policy reform (or a treatment) while others are not, and comparable groups of individuals are observed prior to the policy intervention. The standard DID has raised a number of concerns in the literature (e.g. Bertrand, Duflo, and Mullainathan, 2004; Donald and Lang, 2007; and Besley and Case, 2000). As a result, in addition to standard DID, we also use the changes-in-changes (CIC) model developed by Athey and Imbens (2006).

The CIC model relaxes some of the assumptions of the standard DID.[15] Standard DID assumes outcomes are additive in time period, group and unobservable characteristics of the individual, while the CIC model is nonparametrically identified. Standard DID often assumes that the treatment effect is constant across individuals, or more generally assumes

[14] Borman et al. (2003) found that greater impacts were estimated when the school reform evaluated had been in place for a greater number of years (more than 5 years).

[15] Note that the standard DID is a special case of the CIC model.

that the effect might differ across individuals but that the distribution of outcomes without treatment is common across groups. In the CIC approach, the distribution of the unobservable characteristics of individuals may differ across groups and the treatment effect may also differ according to the unobservable characteristics of the individual. In contrast to DID, the more general CIC model can accommodate the possibility that treated individuals may benefit more from the treatment than untreated individuals, and that the policy may have been implemented because greater benefits were expected in the treatment group (see Besley and Case (2000) on endogenous policy reform). Using CIC, one can estimate the entire counterfactual distribution of outcomes in the absence of treatment for treated individuals, and in the presence of treatment for non-treated individuals. It is thus possible to evaluate the mean effect of a policy intervention, and also the effect at different points on the distribution.[16] This feature is particularly attractive in the present application, as knowing whether lower performing students benefited more or less, compared to middle to top performing students, is of great policy interest.[17]

The CIC model relies on two main assumptions. First, the underlying production function for treated individuals and non-treated individuals, mapping the relationship between the outcomes and the unobservable characteristics at a given point in time, does not vary across groups. Second, the distribution of the unobservable component of the math score should stay the same within a group over time. As long as these hold true, CIC provides consistent estimates of the effect of treatment on both treated and untreated individuals.

In sum, CIC allows the possibility of time and treatment effect heterogeneity. It accommodates the possibility of selection into treatment due to expected larger benefits from treatment. It provides consistent estimates of the entire counterfactual distribution of outcomes of treated and non-treated individuals, and allows the two distributions to differ. As such, CIC permits policy evaluations in terms of mean-variance trade-off.

In our setting, repeated cross-sections of students are observed in a treatment and a control group, before and after the treatment. Each child i is observed once, in time period $T_i \in \{0, 1\}$, where period 0 is prior to the school reform and period 1 is after the implementation of the school reform. Each student i also belongs to a group, $G_i \in \{0, 1\}$, where group 0 is the RofC (the control group) and group 1 is Québec (the treatment group). Effectively, we implement the following CIC estimator:

[16] Quantile DID, which applies DID to each quantile as opposed to the mean, can also look into the distributional effects of the treatment. While individuals are compared across time according to their quantile in both QDID and CIC, they are compared according to their outcome in CIC and their quantile again in QDID. QDID assumes that the underlying distributions of unobservable characteristics of the individuals is the same in both groups, while CIC allows for heterogenity across groups. See Athey and Imbens (2006) for the benefits of CIC over quantile DID.

[17] Gender effects would also be of policy interest, but our sample size does not allow subgroup analysis.

$$\tau^{CIC} \equiv E\left[Y_{11}^{I}\right] - E\left[Y_{11}^{N}\right] = E\left[Y_{11}^{I}\right] - E\left[F_{Y,01}^{-1}\left(F_{Y,00}\left(Y_{10}\right)\right)\right], \tag{1}$$

where Y_{gt}^{I} is the outcome of students receiving treatment in group g in time period t and Y_{gt}^{N} is the outcome of students not receiving treatment in group g in time period t. In equation 1, Y_{11}^{I} is the outcome of students receiving treatment in Québec after the implementation of the school reform and Y_{11}^{N} is the outcome of students not receiving treatment in Québec after the implementation of the school reform. Y_{11}^{N} is not observed, but can be inferred using $E\left[F_{Y,01}^{-1}\left(F_{Y,00}\left(Y_{10}\right)\right)\right]$. $F_{Y,01}$ and $F_{Y,00}$ are the outcome distribution functions $F_{Y,gt}$ of students in the RofC after and before the implementation of the school reform respectively, and Y_{10} is the outcomes of students in Québec prior to the reform. Since the math score in a given grade takes on twenty different values, we implement the discrete CIC model with conditional independence, and also provide the discrete CIC model lower and upper bounds.

The main identification condition for the estimation of the reform effect is that, aside from the Québec school reform, there are no other province-specific transitory shocks during the period pertinent to the performance of students in mathematics.[18] While we recognize that outcome variables related to the labor market (e.g. earnings, probability of employment) are subject to aggregate transitory shocks impacting the business cycle, we argue this is unlikely to be the case for test scores. The robustness of our results to this condition is further discussed in Section 4. Identification further requires that students did not self-select into or out of the reform (i.e. there were no compositional changes). First, since the reform was implemented across all schools in Québec, parents were not able to self-select their children into (or out of) the reform. Furthermore, Québec being mainly French speaking, mobility between Québec and the RofC, following a school reform, is unlikely. Second, since students were already born at the time the reform was being designed, even if public discussions pertaining to the reform started a few years prior to its implementation, parents could not have altered their fertility decision to self-select into or out of the reform. As such, we can safely assume that students did not self-select into or out of the reform.

Deke and Haimson (2006) show that some students are more likely to benefit from an improvement in academic competencies, and that the gains are greater the weaker the student is in this area. In this spirit, one could expect the reform to have a greater impact on students weaker in mathematics than on highly performing students. As mentioned above, CIC allows us to estimate the impact of the reform at different points in the skill distribution. More specifically, the counterfactual distribution is obtained using the observed distributions of outcomes of the treated before treatment, the control before treatment and the control after treatment. In our setting, each point on the distribution is inferred as follows. First,

[18] Bertrand et al. (2004) and Donald and Lang (2007) raise concerns related to the computation of standard errors. As pointed out by Athey and Imbens, their proposed solution relies on linearity and additivity.

treated students before treatment with a given score corresponding to a certain percentile, are associated with control students before the reform with the same score, but possibly located at a different percentile in the score distribution. Second, these control students prior to the reform are associated with control students after the reform located at the same percentile on the score distribution. The control students' change in score post reform is the inferred change in score of the treated students post reform had they not been treated located at the same percentile as treated students prior to the reform.[19] Comparing the score distribution of the treated individuals after treatment with the counterfactual distribution of the treated individuals had they not received treatment at different points on the distribution allows us to estimate the impact of the reform for lower skilled students as well as highly skilled students.

Individual characteristics (denoted X) need not be stable over time or across subpopulations, as long as the changing characteristics are observed. In our approach to CIC, we control for X through a linear specification. Standard DID also assumes that Y_{gt} is linear in X, such that the estimated response to the reform is also linear in X. To address the possibility of non linearity of response with respect to X, we also implement the matching difference-in-differences (MDID) (Heckman, Ishimura and Todd, 1997 and 1998). This estimator also allows the possibility of selection into treatment.[20] With repeated-cross sections, the MDID estimator is (Blundell and Costa Dias, 2009):

$$\tau^{MDID} = \sum_{i \in S_{11}} \left\{ \left[y_{it_1} - \sum_{j \in S_{10}} \tilde{w}_{ijt_0} y_{jt_0} \right] - \left[\sum_{j \in S_{01}} \tilde{w}_{ijt_1} y_{jt_1} - \sum_{j \in S_{00}} \tilde{w}_{ijt_0} y_{jt_0} \right] \right\} w_i \qquad (2)$$

where student i is in the treatment group after the reform and student j is part of a subpopulation S_{gt}, and can either be part of the treatment group prior to the reform S_{10}, the control group prior to the reform S_{00} or the control group after the reform S_{01}. The outcome variables are measured at time t_0 (prior to the reform) for students in S_{10} and S_{00}. The outcome variables are measured at time t_1 (after the reform) for students in S_{11} and S_{01}. Each student j when compared to student i is attributed a new weight $\tilde{w}_{ijt}$ that depends on the matching technique used. The sampling weight of student i is denoted w_i. The MDID estimator controls for X non-parametrically by ensuring that students in each group (control prior to treatment, control after treatment and treated prior to treatment) all share the treated group after treatment distribution for each of the characteristics contained in X.

Effectively, we first estimate a probit model in which the dependent variable equals one

[19] See Figure 1 in Athey and Imbens (2006) for a graphical representation.

[20] As mentioned above, in the present application, selection into treatment is extremely unlikely, since the only way to self-select out of (or into) treatment is to change the family's province of residence. However, variations in response rates across survey waves may create a selection bias.

if the student lives in Québec and equals zero otherwise. Using this model, we predict the propensity score of each student and perform matching using these scores. We implement kernel matching, local linear regression matching and nearest neighbor matching. Bootstrap standard errors are calculated to account for the underlying matching procedure. Rosenbaum and Rubin (1983) show that if observations in the treated and control groups have the same propensity score distribution, the underlying characteristics used to calculate the propensity score are also distributed equally. We include the following covariates: maternal education dummies, gender, area of residence, household income quartile, and a maternal work dummy. To assess the importance of non-parametrically controlling for X, we compare the estimated impacts using standard DID with those of MDID.

3 Data set

The data set used for our empirical analysis is Statistics Canada's National Longitudinal Survey of Children and Youth (NLSCY),[21] a long-term biennial survey designed to provide information about the development and well-being of Canadian children and youth. The survey covers a comprehensive range of topics including child care, schooling, physical development, cognitive skills and behavior of the child as well as data on the demographic situation and the social environment of the child (family, friends, schools and community). The NLSCY began in 1994-1995 (wave 1), and the last collection period to have been released by Statistics Canada covered 2008-2009 (wave 8). The sampling unit is the child (or youth). The NLSCY is designed to provide estimates representative of the population of Canadian children aged 0 to 11 years old, first selected in wave 1 (1994-1995) of the survey.[22] For simplicity, from here on, we refer to the first year only to identify data in a particular wave. For example, data from wave 1 will be referred to as data from 1994.

In 1994, a sample of 22,831 children was selected. This sample constitutes the main longitudinal sample of the NLSCY. To reduce the response burden on families with several eligible children, the number of children selected per family was limited to two in 1996. As a result, some children were dropped from the original sample and 16,903 children remained in the longitudinal sample. The rule changed again to one child per household in 2002. Given the timeline of the reform, this change implies that a sibling fixed effects method cannot be used to evaluate the impact of the reform using the NLSCY. At the time the NLSCY survey was last conducted (year 2008) longitudinal children were aged 14 to 25. This longitudinal sample is central to our study as it provides information on primary and secondary school

[21] Many studies in economics have used this data set (e.g. Baker, Gruber and Milligan, 2005).

[22] Weights, adjusted for total non-response matching known population count, are provided in each wave of the survey.

students from academic years 1994-95 (grades 1 to 6, or 6 to 11 year olds) to 2008-09 (grades 9 to 11, or 14 to 17 year olds). Later on, a new initiative providing additional observations on primary school students in grades 1 to 4 in academic year 2006-07, and in grades 1 and 2 in academic year 2008-09, was added to the main longitudinal survey.

In sum, the NLSCY provides three cohorts of children of primary and secondary school age: (1) students in grades 1 to 6 in academic year 1994-95 up to grades 9 to 11 in academic year 2008-09, (2) students in grades 1 to 4 in academic year 2006-07, and (3) students in grades 1 and 2 in academic year 2008-09.

The next four subsections are organized as follow. First, we describe the measure of mathematical ability used in this study and relate it to later outcomes, such as total personal income. Second, we present the school grades for which we observed students passing comparable math tests, by year and by treatment status. Third, we show the summary statistics for these students by treatment group (Québec vs RofC). Fourth, we provide an overview of the trends in math score by treatment group, and also discuss the number of years of treatment and the response rate to the test for each subgroup.

3.1 Measure of mathematical ability

The NLSCY provides one measure of cognitive development for school age children: the CAT/2 mathematics test.[23] The CAT/2 test is a shorter version of the Mathematics Computation Test taken from the Canadian Achievement Tests, 2^{nd} edition. This test was developed by the Canadian Test Centre after careful consideration of the differences among the main school curricula across Canada. The CAT/2 is designed to measure procedural skills in mathematics. The test consists of 20 questions on four binary operations (i.e. addition, subtraction, multiplication, and division) on integers, decimals, fractions, negatives, exponents and percentages, and on simple linear algebra. The test is administered to students enrolled in grades 2 to 10, aged 7 to 15. The difficulty of the test varies with the school grade of the child. Thus, there are different tests depending on the school level of the child. Grade 2 students passed the level 2 test, grade 3 students the level 3 test, and so on. The master files of the NLSCY provide both the raw scores and the standardized scores. The raw score is simply the number of correct answers to the test. The standardized scores are obtained using sub-samples (by schooling-grade) of the normative sample.[24] The standardized scores are designed to numerically represent the relative level of mathematics a child has attained and to track the progress of a child in mathematics throughout the years. The range of

[23] In 1996 and 1998, a reading test was also administered (in addition to the CAT/2 mathematics test). However, as of 2000, the reading test was discontinued because of time constraints.

[24] More specifically, Statistics Canada standardizes the raw scores using a sample of Canadian children from the ten provinces called “the normative sample”. This sample received the complete Mathematics Computation Test.

scores for grade 2 students is thus much lower than the range for grade 10 students, but overlaps with the range of grade 3 students such that particularly strong 2^{nd} graders may be as proficient in mathematics as some lower performing 3^{rd} graders. Since the level depends on the school grade and not the age of the child, it is possible that students of different ages passed the same test in a particular survey wave, and that students of the same age passed different tests.

The CAT/2 test is comparable to the test used in Murnane et al. (1995), where elementary mathematical concepts such as the working of fractions and decimals are measured using a multiple choice test of 25 questions. It is also aligned with the definition of mathematical development in Ingram and Neumann (2003) used to assess the importance of mathematics in different types of occupations. To further validate the relevance of the test used in this study, we estimate the influence of the CAT/2 score on a variety of adulthood outcomes. Using the oldest cohort of the NLSCY, youth aged 24-25, we regress a high school dropout dummy, the highest level of education completed, and the total personal income on the CAT/2 score at age 12-13.[25] Results are shown in Table 1. If we assume that the marginal effects are constant, we find that the dropout rate would decrease by 0.07 of one percentage point if the math score increases by 1, the probability of having a University degree (as opposed to a community college degree) would increase by 0.12 of one percentage point and the total personal income would increase by 25$. We later quantify the effect of the reform in terms of these three adulthood outcomes.

Over the years, there has been some changes in the test and in the administration of the test. In 1994, a large fraction of students obtained perfect scores, making it impossible to distinguish the true top performers from the others. Because of this ceiling effect, the difficulty level of the tests for comparable students was adjusted as of 1996.[26] As a result, we decided to exclude the 1994 sample from our analysis.[27]

In 1996 and 1998, the test was administered by the student's teacher. The student's parent had to sign a consent form, and the School Board and the teacher had to agree on taking the time to administer the tests. The response rates for these waves were uncharacteristically low: 74% in 1996, and 54% in 1998. From 2000 onward, to avoid disrupting class activities at the end of the school year, the math test was administered at home by

[25] Youth aged 24-25 are observed in 2008 only, and approximatively 1,400 observations are available. These youth passed the CAT/2 test in 1994, 1996 and 1998, but we use the CAT/2 score at age 12-13 in 1996 (grades 5-6). Scores from 1994 are excluded because of the ceiling effect detected in the 1994 tests (see below for further details). Scores from 1998 are excluded because of the low response rate (see below for further details).

[26] In 1994, only 3 levels of the test were available: one for students in grades 2 and 3, one for grades 4 and 5, and one for grades 6 and 7. In this first wave of the NLSCY, a significant number of students had a perfect score on the CAT/2 test (e.g. 38% for grade 3 students). In 1996, to reduce the ceiling effects observed in the first wave of the survey, separate versions of the test were created for each school grade.

[27] Also note that the response rate in 1994 for the mathematical component was relatively low (51%).

the interviewer rather than at school, and almost all eligible students (approximately 90 percent) responded. In most of our empirical work, we rely on test scores taken from year 2000 onwards, which covers pre- and post-reform students in most instances (except grade 2). Results using samples from 1996 and 1998 are to be interpreted with caution.

In 1996, students in grades 9 and 10 were observed for the first time. At the time, a single test was administered to these students. In 2002, to better assess the development of students in grades 9 and 10, Statistics Canada decided to produce separate tests for grades 9 and 10. Scores obtained in year 2002 and above cannot be compared with scores obtained between 1996 and 2000. As a result, we do not estimate the impact of the reform using test scores prior to 2002 for grades 9 and 10.

Given the specificity of the test and the changes mentioned above, from here on, we restrict our attention to grade 2 to 10 students and exclude students observed in 1994 and those observed in grades 9 and 10 prior to 2002.

3.2 Students observed and the incidence of the reform

Table 2 provides a more detailed overview of the grades and academic years observed using the NLSCY CAT/2 test. The table covers academic year 1996 to academic year 2008. Table 2 shows that students entering grade 1 in academic year 1989 or 1990 are later observed in the same school cycle (i.e. grades 7-8)[28] during the same academic year. This is also true for students entering grade 1 in academic year 1991 or 1992, and so on. Since the school curriculum was designed by cycle, this grouping comes by naturally.[29] In Table 2, boxed grades are under the reform, while unboxed grades are prior to the reform. One exception is unboxed grades in bold with an asterisk "*". Students in those grades are not under the reform, but they were treated by the reform while in grade 4 of academic year 2001.

These students are the first students observed in the NLSCY to be treated by the reform. They entered grade 1 in 1998 and were only treated while in grade 4 of academic year 2001. As such, this group is only partially treated and for a period of one year only. This allows us to assess the impact of the reform on older children when first implemented for one year only. Looking at their test scores later, we can also determine whether the effect persists or not. The second group of treated students observed entered grade 1 in 1999 or 2000. Students entering grade 1 in 1999 were treated as of grade 2 in academic year 2000, while students entering grade 1 in 2000 were treated from the start. This group constitutes our

[28] As mentioned above, the reform in primary school was implemented by cycle: with cycle 1 comprised of grades 1 and 2, cycle 2 grades 3 and 4, and cycle 3 grades 5 and 6. We extend this grouping to secondary school and regroup grade 7 and 8 students together, and grade 9 and 10 students together.

[29] As previously mentioned, the entire school curriculum was generally designed by cycle. In practice, some schools implemented multi-grade classrooms using the same grouping structure by cycle. Some schools also assigned teachers to one group of students for two years, such that students only had one teacher per cycle.

main longitudinal sample, as they are observed from grades 2 to 10 after the reform was implemented. It allows us to estimate the cumulative effect of the reform. We also observe three other groups of students: students entering grade 1 in year 2003 and 2004, students entering grade 1 in 2005, and students entering grade 1 in 2007. The first group is observed in grades 3-4, while the second and third groups are only observed in grade 2. Since these three groups contain observations on a different sample of students entering the reform at a later point, estimates using these alternative groups allow us to further validate the results obtained from our main longitudinal sample.

3.3 Student and family characteristics

There is no reason to believe that students from Québec differ in a meaningful way from students in the RofC. Nonetheless, since the NLSCY contains information on a fraction of all students in the population, in Table 3, students attending school in Québec (first two columns) are compared with students attending school in the RofC (last two columns) across a number of student and family characteristics. The NLSCY provides a total of 7,745 observations for the Québec sample and 33,390 observations for the RofC. The mean and standard deviations reported in Table 3 are weighted using the population weights provided by Statistics Canada.

Table 3 shows that an equal proportion of male and female students are observed in both groups. These students also have comparable scores on the Peabody Picture Vocabulary test (PPVT) taken at age 4 and 5. The PPVT is widely used in the literature related to early childhood cognitive development to assess receptive and hearing vocabulary and may serve as a measure of early childhood ability. The proportions of students per school cycle (grade 2, grades 3 and 4, and so on) are also comparable.

Students from Québec are similar to RofC students in terms of family characteristics. Most students live in a two-parent household and have a mother who works, but students in the RofC have mothers who are slightly more educated, their family income is generally higher and they are less likely to live in a highly populated urban area. Since the cost of living varies both by province and in time, in our empirical approach we use household income quartile by province and by year when controlling for confounders.

Although students observed in both groups share similar characteristics, we control for all of these characteristics in our empirical approach to ensure that our estimated effects are not a mere reflection of differential changes in X over time.

3.4 Mathematics scores over time and grades

Mathematical scores over time are presented in Table 4. This table provides a detailed overview of the test scores by subgroups over time. We first discuss the statistics presented in Table 4. Then, we highlight the evolution of the differences in mean scores between the treatment and control group using Figure 2 and discuss the stability of the trends prior to the reform.

Table 4 shows the mathematical assessment summary statistics for the different groups of treated versus non-treated students by school grade and academic year. The first panel shows the summary statistics for grade 2 students, the second panel grades 3-4, the third grades 5-6, the fourth grades 7-8, and the fifth and last panel grades 9-10. The left panel shows the summary statistics for students residing in Québec (treatment group), while the right panel includes only students residing in the RofC (control group). For each grade (or combined grades) we show first the number of years of treatment (always equal to zero in the RofC as the reform was implemented in Québec only). This allows the reader to better understand which groups can be compared and what is the intensity of treatment for that group. Second, we show the summary statistics related to the CAT/2 test: first the mean score, second the standard deviation, third the number of observations, and fourth the response rate to the test. The response rate is calculated using the population weight and thus provides a representative percentage of students in the population who completed the test.

From grade 2 to grades 9-10, we find that the mean score is increasing in both groups in each year. As mentioned above, the CAT/2 test is designed to numerically represent the progression of students in mathematics throughout the years. Comparing Québec and the RofC year by year, we find that Québec students consistently score higher than comparable students in the RofC,[30] but trends over time are different. We now characterize these differences.

In grade 2 (top panel), looking at the response rate, we decided to exclude 1998 observations from our main analysis. The response rate in 1998 is 49% in Québec and 52% in the RofC. As a result, for grade 2 observations, we use 1996 as the base year (prior to the reform), and 2000, 2006, and 2008 as the treatment years.[31] In 1996, the response rate was below 80%, while it was generally above 90% in 2000, 2006, and 2008. As mentioned above, in 1996, the tests were still being administered in schools at the end of the school year. If schools with lower performing students were more likely to not administer the tests due to time constraints days before the final exams, then mean score values in 1996 (and

[30] One exception is grades 5-6 in 2004.

[31] Grade 2 students are not observed in 2002 and 2004 in the NLSCY (see Table 2). Results using 1998 are presented in the Appendix.

1998) are overestimated, in both Québec and the RofC. If they are overestimated by the same magnitude, our estimates should be unbiased. Nonetheless, we specifically address the possibility of a bias due to the variation in non response in the empirical section. The summary statistics over time suggest that the scores have been downward trending in both groups (Québec and RofC), but the decrease has been more striking in Québec.

In both grades 3-4 and grades 5-6, we use results from 2000 as the base year prior to the reform given the lower response rate in 1996 and 1998 in both groups. Looking at the results between 2000 and 2006, we find that the results are decreasing in Québec post reform (for the academic year in which the number of years in the reform is greater than zero for all students),[32] while no clear pattern can be identify in the RofC. Focusing again on results from 2000 and beyond, the fourth panel on grades 7-8 students reveals that the results in Québec pre-reform (before 2004) were largely above the post reform (in 2006) results, while they were generally stable in the RofC, decreasing slightly in 2004. Finally, for grade 9-10 students (last panel), the mean values suggest an important decrease in Québec when comparing 2002 and 2008 outcomes, and a more modest decrease for 2004 and 2006 versus 2008. Grade 9-10 students in the RofC generally perform better in 2008 (compared to 2002, 2004 and 2006).

In sum, focusing on years where the response rate is high, students in Québec generally perform better than students in the RofC across all grades and across all time periods, but the mean score generally decreases more sharply in Québec post reform in all grades, while the pattern in the RofC is generally stable (or at least shows no precise trend). Figure 2 further highlights these findings by showing the differences in mean score between Québec and the RofC over time. The vertical line in each quadrant marks the first school year during which the reform was implemented. Since their treatment differs, the mean score differences for grades 5 and 6 students are presented separately. Students in grade 5 in academic year 2002 were impacted by the reform while in grade 4 in 2001. Students in grade 6 in 2002 were never impacted by the reform. The dashed line in the grade 5 figure marks this unique cohort. In grades 7-8 (bottom left Figure 2), there are two solid lines because the reform was first implemented in grade 7 in 2005, followed by grade 8 in 2006. The same logic holds true for grades 9-10 (bottom right).

The upper left quadrant shows the results for grade 2. The difference is clearly decreasing post reform, but possibly returns to the pre-reform level eight years after the implementation of the reform. In grades 3-4, the pattern is also fairly stable pre-reform and well above the post-reform mean difference. In grade 5, the pattern pre-reform is less stable, but reaches lower levels post reform. While the official implementation date in grade 5 was academic year

[32] As mentioned above, students in grades 5-6 in 2002 were only partially treated. The number of years for this group is denoted "1-0" because grade 5 students were treated for one year, while in grade 4, and grade 6 students were never treated.

2003, Figure 2 shows that mean differences drop as early as 2002 in grade 5. As mentioned above, these students were treated by the reform while in grade 4. In grade 6, the pattern is extremely stable pre-reform, but the mean difference immediately starts to decrease as of 2002. This may be in part due to the fact that grade 5-6 teachers had already started their training as of 2001 as the implementation was originally scheduled for 2002, and were surrounded by colleagues who were teaching following the reform curriculum in all other primary school grades. In grades 7-8 and 9-10, the differences pre-reform are above the post-reform difference, but the pre-reform pattern is fairly unstable.

To determine whether the instability in the difference in mean outcomes pre-reform in grades 5, 7-8 and 9-10 is due to a change in students' characteristics and/or the proportion of students in each grade within the group, matched samples of students were created. Within each school grade, Québec students in each academic year were matched to Québec students in academic year 2000. The same procedure was applied to students in the RofC. The following matching covariates were included: maternal education dummies, gender, area of residence dummies, household income quartile dummies, and a maternal work dummy. Figure 3 shows the average score differences between Québec and the RofC over time for these matched samples. The trend over time becomes much more stable for grades 5, 7-8 and 9-10 students, suggesting that students' characteristics were driving the instability. For grade 5 and grades 7-8 students, this may also be in part attributed to the fairly high rate of non response in academic years 1996 and 1998.

In sum, Figure 3 highlights two attractive features of the data: (1) differences between Québec and the RofC were fairly stable prior to the reform, and (2) in each grade, mean differences drop following the reform. Pre-reform, students in Québec had higher scores in mathematics than students in the RofC. Post-reform, this difference had almost completely vanished. It appears that the reform had negative impacts on the development of mathematical abilities for students in Québec. Section 4 further validates these results by computing the statistical significance of those differences using standard DID and MDID. Distributional (and mean) effects are computed using CIC approach.

4 Effects of the reform on math scores

Table 5 presents the empirical results using DID and MDID. Estimated impacts using DID and MDID with three matching techniques, suggest that the reform had significant negative effects on mathematical abilities. Given the complex sampling design of the NLSCY, all estimations are performed using the sampling weights provided by Statistics Canada. To account for the clustering and stratification of the NLSCY, the standard errors are estimated using the 1,000 bootstrapped weights provided by Statistics Canada. We first present the results on our benchmark specification using standard DID. Then we assess the robustness of our results to students' heterogeneity, non response, other reforms in the RofC, and the linearity assumption using MDID. We then confirm the results from standard DID using CIC and discuss the distributional effects. Finally, we present a number of falsification exercises to further validate our results and discuss the materiality of the estimated impacts.

4.1 Benchmark specifications

We first focus on results presented in the first two columns of Table 5. The first specification (column 1) does not control for any covariates, while the second specification (column 2) controls for gender, school grade, maternal education, household income quartile, a dummy indicating whether the mother works or not and the area of residence.[33]

Across all grades, the estimated impacts of the reform are negative and statistically significant. Looking at the first specification, in grade 2, the estimated impacts, all negative, range from 6.1 to 22.3 (1.8% to 6.6% of the mean score pre-reform). In grades 3-4, they range from 22.0 to 27.6 (5.6% to 7.1% of mean score), while in grades 5-6 they range from 13.4 to 20.3 (2.9% to 4.3% of the mean score). Finally, in grades 7-8, the estimated effects range from 22.5 to 36.9 (4.3% to 6.8% of the mean score) and in grades 9-10 they range from 24.0 to 51.5 (4.0% to 8.1% of the mean score).

Results from the second specification (column 2), DID with covariates, are generally comparable: 11.1 to 24.3 (grade 2), 16.7 to 19.6 (grades 3-4), 13.4 to 20.1 (grades 5-6), 23.1 to 33.8 (grades 7-8), and 28.6 to 45.1 (grades 9-10). This suggests that, the magnitude of the estimated effects are larger the higher the school grade (both in absolute value and in % of the mean score pre-reform), but are of comparable magnitude from grade 7 to 10 (in units of a standard deviation). As students in higher grades have been exposed to the reform for a longer period, this finding suggests that the reform consistently limits the development of students in mathematics compared to the pre-reform approach. One exception are students in grades 5-6 in academic year 2002. Students in grade 5 had only been in the reform for one year (in grade 4 in 2001) and students in grade 6 had not been in the reform (see years in Table 4). It is therefore not surprising to find that the estimated effect is smaller in magnitude for this cohort. More surprising are the large effects estimated for grade 2 students (of about 25% to 50% of a standard deviation).

[33] Results are robust to the inclusion of age in month at the time of test, and province of residence. Because entry age regulations are different across provinces, the support for the age at the time of test in Québec is different from that of the RofC. Since age and province do not alter our results but cannot be included when estimating MDID (common support issue), we generally do not include these variables.

4.2 Students' heterogeneity

The estimated effects of the reform reported above do not account for students' unobserved heterogeneity. We do not have any reason to believe that the distributions of students' unobserved ability differ across provinces (or more specifically between Québec and the RofC). However, given the relatively small sample size used in this study compared to the overall Canadian population of students, we address this possibility. To control for unobserved students heterogeneity, we use a widely used measure of early childhood cognitive development, the PPVT score. This score is completely unaffected by the Québec school reform, since students complete the PPVT at age 4 and 5 prior to entering primary school (i.e. grade 1).

Estimated impacts are reported in the third column of Table 5. This specification controls for the same set of covariates as specification 2, but also controls for the PPVT score. Comparing the number of observations in column 1 and 3, we observe that the PPVT is generally available for about 82% to 94% of the students in our sample depending on the groups being compared. However, for students in grades 7-8 in 2000 (observed again in grades 9-10 in 2002) the PPVT score is completely missing. These students never took the test as they were first surveyed at age 6 and 7 (in 1994). Estimated effects controlling for the PPVT scores (column 3) are slightly smaller in magnitude for grade 2 students. This is also true in grades 3-4 and 5-6, but in grades 7-8 and 9-10, the estimated impacts are slightly larger. This reinforces our earlier statement on the growing effect of the reform with increased exposure.

4.3 Non response bias

Students' unobserved heterogeneity is not the only source of potential bias. The pattern of non response documented in Table 4 may also influence our results. So far, we have assumed that if scores were overestimated (or underestimated) they were overestimated (or underestimated) by the same magnitude in both groups. This may not be true, especially in cases where the non response rate did not change in one group over time, but did in the other (e.g. grade 2, years 1996 versus 2000).

Since changing patterns in non response may influence the results, we imputed the missing math scores using multiple imputation by chained equations, and re-estimated the impact of the reform using the same covariates. The following variables were included in the imputation procedure: gender, school grade, maternal education, household income quartile, a dummy indicating whether the mother works or not, area of residence, province and year. The scores were imputed a total of 10 times ($M = 10$). The estimated coefficient $\bar{b}$ was obtained using:

$$\bar{b} = \frac{\sum_1^M b_m}{M},$$

where b_m is the regression coefficient of the m imputed data set (Schafer, 1997). The standard error was obtained using:

$$SE_{\bar{b}} = sqrt\left(\frac{\sum_1^M (SE_{b_m})^2}{M} + \left(1 + \frac{1}{M}\right)\left(\frac{1}{M-1}\right)\sum_1^M \left(b_m - \bar{b}\right)^2\right),$$

where SE_{b_m} is the standard error of the regression coefficient of the imputed data set m. Results are reported in the fourth column of Table 5. Across all grades, estimated effects $\bar{b}$ are generally slightly smaller, but again the confidence intervals overlap with that of the DID estimates with covariates (column 2).

4.4 Reforms in the Rest of Canada

Specifications accounting for students heterogeneity and non response patterns have been shown to produce comparable results. These are, however, not the only sources of potential bias. In Canada, primary and secondary school education is generally within provincial jurisdiction. Other school reforms taking place in other provinces could bias our results. So far we have assumed that teaching in the RofC continued to be delivered in the same way.

Our review of events around the time of the implementation of the Québec school reform does not suggest that other major reforms took place in the RofC, except in Ontario (Canada's largest province). In a recent report on the world's most improved school systems (Mourshed, Chijioke, and Barber, 2010), the province of Ontario is identified has having undertaken a whole system school reform (started in 2003), and having registered significant and sustained student outcome gains (based on 2003-2009 assessment data). The reform, mainly in the form of additional funds allocated to schools, encouraged schools to set their own objectives and to decide how to best address the needs of the least advantaged students. Schools were, for example, allowed to increase the number of working hours, to reduce the number of students per class, and to obtain help from education specialists.

Our reading of the evolution of Ontario's math scores on the CAT/2 test and PISA's scores on comparable assessments (reading, math and science) between 2000 and 2009 does not suggest any progress (results are generally flat), but the Trends in International Mathematics and Science Study (TIMSS) results in science (but not math) suggest a potential gain. Nonetheless, we decided to exclude the scores for Ontario's students to assess the robustness of our results. Estimated impacts excluding Ontario are reported in the fifth column of Table 5. Estimated effects are some times slightly above that of our benchmark specification (column 2), and sometimes slightly below. In all cases, confidence intervals strongly overlap.

4.5 Linearity assumption

All of the estimated impacts presented above rely on the assumption that X influences the outcome linearly. To ensure that our results are not dependant on this assumption, we also implemented MDID. Comparing the MDID (columns 6 to 8, Table 5) estimates with the DID estimates (column 2, Table 5), we find that the MDID estimates generally have confidence intervals that considerably overlap with those of the DID estimates using all three techniques (at 5%). Two main differences are noteworthy. First, in grades 3-4, the MDID estimators are smaller in magnitude and some times not significant. Second, in grades 9-10, for academic year 2006 compared to 2008, some of the MDID estimates are not significant, while the DID estimates are.

4.6 The CIC approach

The mean effects documented so far suggest that the reform had negative effects and that these effects are larger the longer a student was treated by the reform. These findings are in line with Crawford and Snider (2000) on the impact of a more academic approach against a more contextual approach on math scores. Results from our benchmark specification are robust to a variety of alternatives, but all rely on the more restrictive assumptions of standard DID discussed above. To investigate the robustness of our results if some of these assumptions are relaxed and to assess the distributional effects of the reform, we now discuss the results obtained using the CIC model. In our CIC model, we linearly control for the set of covariates included in our benchmark specification.[34] Effectively we first regress the covariates on the math scores using ordinary least squares. Then, using the residuals, we estimate the effects of the reform using the CIC approach. Since DID with covariates and MDID mainly lead to statistically equivalent results, we assume that controlling for X linearly is not crucial for the results.[35]

Table 6, four estimators are presented: (1) the DID model, (2) the discrete CIC model with conditional independence, (3) the discrete CIC model lower bound, and (4) the discrete CIC model upper bound.[36] The first column shows the mean effect. Columns 3, 5, 7 and 9 present the effects at the 25^{th}, 50^{th}, 75^{th} and 90^{th} percentile and thereby provide an overview of the distributional effect of the reform. Table 6 shows the empirical results for grade 2 (top

[34] We decided not to control for the PPVT score for two reasons: (1) the results controlling for the PPVT scores are comparable, and (2) the PPVT score is missing for about 80% of all our observations, which would greatly reduce our ability to detect distributional effects.

[35] Also, note that CIC estimates without covariates (not provided here, but available on request) are comparable to those with covariates.

[36] We modified the MATLAB program provided by Athey and Imbens to include the bootstrap weights provided by Statistics Canada to account for the sampling design of the NLSCY. We assume full responsibility for the computation of the estimates presented in this paper.

panel), grades 3-4 (second panel), grades 5-6 (third panel), grades 7-8 (fourth panel) and grades 9-10 (bottom panel). All standard errors are bootstrapped to account for the clusters and stratifications of the NLSCY. The mean effects assuming conditional independence using CIC are generally comparable to the DID estimates and the estimated bounds are fairly tight. Before we discuss the distributional effects, a few points on mean effects using CIC versus DID are worth mentioning.

4.6.1 Mean effects

First, estimated impacts on our main longitudinal cohort (students entering grade 1 in 1999 and 2000, denoted using "$\star$" besides year) again suggest that the effect of the reform is increasing with exposure (except from grade 2 to grades 3-4). In grade 2, the mean effect is 17.0. It increases from 15.2 in grades 3-4, to 19.5 in grades 5-6, to 23.7 to 34.5 in grades 7-8, to 26.9 to 43.5 in grades 9-10.[37]

Second, in grades 5-6, for year 2000 versus 2002, the CIC estimator is small and negative, but not statistically different from zero (while the DID estimator is significant). As mentioned above, only grade 5 students were exposed to the reform and for only one year (grade 4, 2001). Comparison of the estimated impact of treatment on years 2000, 2002 versus 2000, 2004 for students in grades 5-6 also support the idea that longer exposure results in higher impact. Students in grades 5-6 in 2004 have been exposed to the reform 5 years. The estimated impact on these students is negative and significant (on the order of 33.7% of a std. dev.). A similar pattern can be observed when comparing the impact of the reform on grade 2 students in 2000 (exposed 1 year) with those of 2006 (exposed 2 years).

Third, age at first exposure may be important. Comparing grades 5-6 students spending 0 to 1 year in the reform (years 2000, 2002) with those in grade 2 (years 1996, 2000), it appears that the reform had a significant negative impact on grade 2 students, but no impact on grade 5-6 students. Age at first exposure appears important, with younger children being more impacted than older children. This finding needs to be interpreted with caution, as estimated effects on grade 2 students rely on observations with higher non response and only half of the students in grades 5-6 were treated.

Fourth, both CIC and DID support the idea that long term effects may differ from short term effects. We find that grade 2 students, 8 years after the implementation of the reform, no longer seem to experience a significant negative effect (the CIC and DID estimators for years 1998 versus 2008 is small and not different from zero).[38] The reform being ambitious, it is possible that it took a fair number of years for teachers to develop the necessary skills

[37] Table 10 in Appendix present the CIC estimates for grade 2 students using the 1998 observations. Results are generally smaller but remain comparable to those using 1996 observations.

[38] This can also be observed from Figure 2.

to fully deploy all aspects of the reform. It may also be the case that, observing the decline in students' academic performance, teachers informally decided to reintroduce some of their pre-reform teaching approaches, and set aside in part or in totality the reform approach. The NLSCY does not provide information on the actual teaching approaches, therefore we are unable to identify which of these two explanations is dominant. In any case, this finding implies that at best the provincial reform had no long run effects on the development of procedural mathematics skills. This conclusion is derived from one set of grade 2 students at one point in time and although math achievement is an important predictor of socioeconomic success, it is not the only one.

4.6.2 Distributional effects

Looking across the entire math score distribution, we find that the results discussed above hold true for both lower performing students, and middle to top performing students.

In grade 2, only students in the 75th percentile appear to be significantly impacted by the reform. However as we move from grade 2 to grades 9-10, the effect also becomes significant for lower and middle performing students. In grades 9-10, the magnitude of the coefficients is the largest for students in the 25th percentile, and slowly decreases as one moves toward the upper tail of the distribution. Looking at the top of the distribution (90th percentile), we also find negative effects across all grades, but the estimates are generally not significant.[39] It is possible that the reform did not harm top performers. It is also possible that the reform did impact top performers, but that the number of observations at this mass point is too small to obtain precise estimates. Figure 4 shows the observed and counterfactual math score cumulative distribution function for Québec students post reform. This figure clearly shows that the effect is consistently negative across the entire distribution, and more so at the bottom of the distribution.

In sum, CIC suggests that the effects were negative on average and across the distribution. Lower performing students were impacted more severely, and the effects grew larger as students progressed from primary to secondary school. These large negative effects are worrying, and suggest that the reform may have harmed those most in needs. Long term effects may be neutral. Further research is needed to fully understand the long term effects of the reform on a larger diversity of skills to get a better picture of the net benefit (or loss).

[39] From the findings in Deke and Haimson (2006) discussed above, we were expecting top performers to not perform better as they were already at the high end of the distribution and further improving their skills was marginally more costly.

4.7 Falsification exercises

We ran a number of falsification tests to further validate our results. Table 7 presents these results. We estimate the effects on all possible combinations of groups that are exclusively pre-reform (labeled "before" in the last column), and groups that are exclusively post-reform (labeled "after" in the last column). Generally, we find no significant effects on all group combinations, but a few exceptions are worth discussing.

In grade 2, the effect is positive between 2006 and 2008. This relates to our earlier discussion on a possible neutral effect in the long run, as teachers further react to the reform by either mastering the reform content better, or by putting aside some of the reform content in favor of other teaching approaches. In grades 5-6, there is a weak negative effect when comparing 2002 and 2004 scores. As mentioned above, grade 5-6 students in 2002, were only partially treated (grade 5 students only, while in grade 4). As such, it is not surprising to find a negative effect.

Overall, the falsification exercises support our earlier findings.

4.8 How material are these effects?

When discussing the CAT/2 test, we documented the influence of the test on later outcomes. We found that the CAT/2 score in grades 5-6 had a marginal effect of -0.06% on the probability of dropping out of high school, a marginal effect of 0.12% on the probability of having a University degree (as opposed to a community college degree), and a 25$ effect on total personal income at age 24-25. Going back to Table 6, we found that the mean effect on grades 5-6 scores (comparing years 2000 and 2004) was about -19.46. Assuming the marginal rate is constant, this decrease in the average math score would correspond to a 1.29% increase in the probability of dropping out of high school, a 2.39% decrease in the probability of having a University degree, and a 494$ decrease in total personal income at age 24-25.[40]

One of the reform's objectives was to raise the proportion of students who successfully complete their high school education, which indirectly implies that the reform aimed at raising the achievement of lower performing students. Since mathematical ability (as measured by the CAT/2 test) is strongly related to school attainment and total personal income, the evidence presented above does not suggest that the reform achieved this objective. The effect of the reform on math scores is negative, but the net effect of the reform depends on the overall impact of the reform on the development of a variety of skills. Although this is well beyond the scope of this paper, we provide some guidance on what the net effect might

[40] Murnane et al. (2006) show that basic skills in mathematics between the 1970s and 1980s have become increasingly important in predicting future wages. As mentioned above, they also show that basic mathematic skills predict wages better than other cognitive measures such as reading and vocabulary skills.

be by (1) presenting the impact of the reform on other measures of achievement in the next subsection, and (2) discussing the overall trends in dropout rate in the conclusion.

5 Further evidence from TIMSS

The NLSCY is not the only source of information providing evidence on the reform. International assessments in which Canada participated can also be used for the analysis. Only a few of the ten provinces participated in the TIMSS.[41] This survey collects data on mathematical and science literacy and is administered to students in grades 4 and 8. The TIMSS mathematics test is broader than the CAT/2 test. In addition to procedural skills, the test also assesses ability in, for example, geometry, problem solving, reasoning and graphical representation.

The global scores by province are presented in Table 8. Grade 4 students are post-reform in years 2003 and 2007, and pre-reform in years 1995 and 1999, while grade 8 students are post-reform in year 2007 only, and pre-reform otherwise. In mathematics and sciences, grade 4 students in Québec had a lower performance post-reform (year 2003) compared to their performance in 1995. Scores in Ontario (Québec's neighboring province to the west) had in contrast increased over the same period. As of 2007, the overall performance of Québec's 4^{th} graders remained under its 1995 level, but had slightly increased compared to 2003. The performance in Ontario remained stable. Grade 8 students' performance shows a similar pattern when results from 2007 are compared with results from all previous years: Québec's performance in both mathematics and sciences is trending downwards, while the performance in Ontario is increasing or stable.

Using the average scores by province, we estimated the DID estimator. This estimator is comparable to the estimator proposed by Donald and Lang (2007) and Wooldridge (2003). Estimated effects are large and negative in all cases. They are significant in mathematics, but not significant in science.[42] The standard errors obtained using this approach account for the possibility of aggregate random group-time specific effects. We argued before that this concern was unlikely to apply when looking at mathematical test scores of children. As such, the estimated effects using TIMSS may be more significant than they appear here.

[41] Although all provinces in Canada have participated in the PISA since 2000, for the purpose of this analysis average results presented in official documents may not be easily compared. The only year post reform is 2009, which is also the year in which the response rate for the province of Québec (71%) was well below the international satisfactory threshold of 80% set by PISA (Knighton, Brochu, and Gluszynski, 2010,Table A.2). A non-response bias analysis conducted by Statistics Canada showed that students in less favourable socioeconomic environments were less likely to participate in PISA and that these students had a statistically lower performance on the provincial reading test.

[42] The same exercise using PISA data (with a 71% response rate post-reform) leads to insignificant results in Reading, Mathemathics, and Science.

Overall, the evidence from TIMSS suggests a worsening of Québec's students performance post-reform in mathematics and at best a stand still in science. These results are in line with the more detailed results estimated using the NLSCY.

6 Conclusion

We estimated the impact of the Québec school reform, based on a complete revision of teaching methods, on grade 2 to 10 students using math scores provided by the NLSCY. To our knowledge, no formal evidence-based evaluation of the reform has been conducted to date.[43] We find strong evidence of negative effects of the reform on the development of students' mathematical abilities. More specifically, using the changes-in-changes estimator, we show that the impact of the reform increases with exposure, and that it impacts negatively students at all points on the skills distribution. Results based on grade 2 students, suggest that long run effects may have been null. As such, the reform seems to have failed to meet one of its primary objectives (at least in the short to medium run). Students from the lower end of the distribution do not seem to be in a better position to successfully complete their schooling. Mathematical abilities are strongly related to school attainment and labor market outcomes, and for lower performing students they are at best equivalent post-reform, but most likely lower.

The teaching approach dictated by the reform is based on constructivism. According to Pinker (1997), proponents of this method believe that children must construct mathematical knowledge for themselves with the teacher only guiding the discussion on the topics and that repetitions and practice are seen as detrimental to learning. He argues that constructivism is not appropriate for mathematics. For him, "...without the practice that compiles a halting sequence of steps into a mental reflex, a learner will always be building mathematical structures out of the tiniest nuts and bolts". Certain skills for mathematics may be very difficult to "construct" at a young age and can possibly be better attained by old-fashioned practice and a more mechanical approach. Pinker suggests that the poor performance of the United States in mathematics could be linked to the teaching approach, which is mainly contextual with no teaching of mathematical concepts. The evidence presented in this paper supports this argument.

Mathematical skills are, however, not the only valuable skills that a student must develop in school. Although the debate is still ongoing on which skills should be developed in school, a consensus seems to have emerged on the importance of non-cognitive skills, or in other

[43] A research group from Laval University (ERES) has been mandated by Québec's Department of Education to report on the implementation (of cross-curricular competencies), teaching practices and outcomes of high school students. The report is due in 2013.

words, behavioral skills. Constructivism being heavily focused on communication and group interactions, it may be the case that the reform was better able to foster these skills. As pointed out by Deke and Haimson (2006), already high achieving students may have limited room to improve further in mathematics, but they may benefit from developing non-cognitive skills. The reform studied in this paper implemented a teaching approach that had a strong focus on non-cognitive skills such as communication, creativity and cooperation.[44] We do not measure the impact of the reform on non-cognitive skills, and may be missing part of the benefits (or losses) generated by the reform.

However, preliminary research by ERES (2011b) found no effect on social adjustment, personal and emotional adjustment and intrinsic motivation. They found that post-reform students felt less well-adapted to secondary school, male students were found to have lower self-esteem, and at risk students[45] were less engaged in school work. Furthermore, trends in dropout rates in Québec between 1996 and 2009 suggest that the situation has not improved on that front either (MELS, 2011). For students aged 17, 18 and 19, dropout rate has remained stable over the period (around 9% at age 17, 15% at 18, and 17% at 19). Students aged 17 and 18 are generally post-reform as of 2009. Clearly, even if social skills (not measured by ERES) were improved, they did not help achieve one of the reform's objectives which was to ensure the success of each and every student.

This paper highlights two important aspects of policy reforms. First, reforms of this magnitude have impacts beyond the scope of the original plan, and these effects should also be accounted for. While this may appear obvious to economists trained to think about general equilibrium effects, this is not always the case in other fields. In the present application, the reform's main target was to improve students' cross-curricular competencies, but it impacted at the same time the acquisition of specific skills in mathematics, and negatively so. Second, even if mastering the reform content may have taken some time, the impact on students during the transition period will always remain and should be taken into consideration when implementing large scaled reforms. While improving non-academic skills may be well placed and still require further analysis, we argue that the negative effects on mathematical skills remain worrying.

7 References

AIR. (2005). "Report on Elementary School Comprehensive School Reform Models." Comprehensive School Reform Quality Center. Washington, D.C.: American Institutes

[44] As mentioned above, Table 9 in Appendix provides the complete list of competencies and areas of learning.

[45] Student risk status is determined by the parent and relates to aggressiveness, attention deficit and the level of prosociability.

for Research.

Angrist, Joshua D., and Alan D. Krueger. (1999): “Empirical Strategies in Labor Economics.” *Handbook of Labor Economics*, O. Ashenfelter and D. Card, eds. North Holland: Elsevier, chapter 23: 1277-1366.

Angrist, Joshua D., and Victor Lavy. (1999). “Using Maimonides’ rule to estimate the effect of class size on scholastic achievement.” *Quaterly Journal of Economics* 114: 533-75.

Angrist, Joshua D., and Victor Lavy. (2002). “New evidence on classroom computers and pupil learning.” *Economic Journal* 112: 735-65.

Athey, Susan, and Guido W. Imben. (2006): “Identification and Inference in Nonlinear Difference-In-Differences Models.” *Econometrica* 74, no. 2: 431-97.

Bailey, Mark, and Vani K. Borooah. (2010). “What enhances mathematical ability? A cross-country analysis based on test scores of 15-year-olds.” *Applied Economics* 42: 3723–33.

Baker, Michael, Jonathan Gruber, and Kevin Milligan. (2008). “Universal Child Care, Maternal Labor Supply, and Family Well-Being.” *Journal of Political Economy* 116, no. 4: 709–45.

Bertrand, Marianne, Esther Duflo, and Sendhil Mullainathan. (2004). “How Much Should We Trust Differences-in-Differences Estimates?” *The Quarterly Journal of Economics* 119, no. 1: 249-275.

Besley, Timothy J., and Anne Case. (2000). “Unnatural Experiments? Estimating the Incidence of Endogenous Policies.” *Economic Journal*, 110, no. 467: F672-94.

Blundell, Richard and Monica Costa Dias. (2009). “Alternative Approaches to Evaluation in Empirical Microeconomics.” *Journal of Human Resources* 44, no. 3: 565–640.

Borman, Geoffrey D., Gina M. Hewes, Laura T. Overman, and Shelly Brown. (2003). “Comprehensive school reform and achievement: A meta-analysis.” *Review of Educational Research* 73, no. 1: 125–230.

Bulle, Nathalie. (2011). “Comparing OECD educational models through the prism of PISA.” Forthcoming. *Comparative Education.*

Bowlby, Jeffery W. and Kathryn McMullan. (2002). "At a Crossroads: First Results for the 18 to 20-Year-old Cohort of the Youth in Transition Survey." Statistics Canada. Catalogue no. 81-591-XPE

Chetty, Raj, John N. Friedman, and Jonah E. Rockoff. 2011. "The Long-Term Impacts of Teachers: Teacher Value-Added and Student Outcomes in Adulthood." NBER Working Paper # 17699.

Crawford, Donald B., and Vicki E. Snider. (2000). "Effective mathematics instruction the importance of curriculum." *Education and Treatment of Children* 23, no. 2: 122-142.

Currie, Janet, and Duncan Thomas. (2001). "Early Test Scores, Socioeconomic Status and Future Outcomes." *Research in Labor Economics* 20: 103-132.

Deke, John and Joshua Haimson. (2006). "Valuing Student Competencies: Which Ones Predict Postsecondary Educational Attainment and Earnings, and for Whom?" *Mathematica Policy Research*, Princeton, NJ. Submitted to: Corporation for the Advancement of Policy Evaluation.

Donald, Stephen G. and Kevin Lang. (2007). "Inference with difference-in-differences and other panel data." *The Review of Economics and Statistics* 89: 221–233.

ERES. 2011a. "Teaching practices, classroom climate and usefulness of classes as perceived by students." *Progress Report to Chart Knowledge Acquisition* 3(1).

ERES. 2011b."A few indicators of students' socio-motivational profile" *Progress Report to Chart Knowledge Acquisition* 3(2).

Hanushek, Eric A. (2003). "The Failure of Input-Based Schooling Policies." *The Economic Journal* 113: F64-F98.

Hanushek, Eric A. and Steven G. Rivkin. (2010). "The Quality and Distribution of Teachers under the No Child Left Behind Act." *Journal of Economic Perspectives* 24(3): 133–50.

Hanushek, Eric A. and Ludger Woessmann. (2008). "The role of cognitive skills in economic development." *Journal of Economic Literature* 46, no. 3, 607-68.

Heckman, James J., Hidehiko Ichimura and Petra Todd. (1998). "Matching as an Econometric Evaluation Estimator." *The Review of Economic Studies* 65, no. 2: 261-294

——. (1997). “Matching as an Econometric Evaluation Estimator: Evidence from Evaluating a Job Training Program.” *Review of Economic Studies* 64, no. 2: 605-654.

Heckman, James J. and Yona Rubinstein. (2001). “The Importance of Noncognitive Skills: Lessons from the GED Testing Program.” *American Economic Review* 91 no. 2: 145–149.

Heckman, James J., Jora Stixrud and Sergio Urzua. (2006). “The Effects of Cognitive and Noncognitive Abilities on Labor Market Outcomes and Social Behavior.” *Journal of Labor Economics* 24, no. 3: 411-482.

Hoxby, Caroline M. (2000). “The Effects Of Class Size On Student Achievement: New Evidence From Population Variation.” *The Quarterly Journal of Economics* 115(4): 1239-85.

Ingram, Beth F. and George R. Neumann. (2006). “The returns to skill.” *Labour Economics* 13: 35–59.

Knighton, Tamara, Pierre Brochu, and Tomasz Gluszynski. (2010). “Measuring Up: Canadian Results of the OECD PISA Study The Performance of Canada’s Youth in Reading, Mathematics and Science 2009 First Results for Canadians Aged 15.” Statistics Canada, Catalogue no. 81-590-XPE - No. 4.

Le, Vi-Nhuan, Brian M. Stecher, J. R. Lockwood, Laura S. Hamilton, Abby Robyn, Valerie L. Williams, Gery W. Ryan, Kerri A. Kerr, Jose Felipe Martinez, and Stephen P. Klein. (2006). “Improving Mathematics and Science Education: A Longitudinal Investigation of the Relationship between Reform-Oriented Instruction and Student Achievement.” Santa Monica, CA: RAND Corporation. (http://www.rand.org/pubs/monographs/MG480).

Machin, Stephen, and Sandra McNally. (2008). “The literacy hour.” *Journal of Public Economics* 92: 1441-62.

MELS. (1999). “The Education Reform What It’s All About.” Gouvernement du Québec, Ministère de l’Éducation, du Loisir et du Sport.

http://www.mels.gouv.qc.ca/reforme/mieux_enfants/dépcoul_a.pdf.

MELS. (2001). “Québec Education Program: Preschool Education, Elementary Education.” Gouvernement du Québec, Ministère de l’Éducation, du Loisir et du Sport. http://www.mels.gouv.qc.ca/ GR-PUB/m_englis.htm.

MELS. (2003). "Québec Education Program: Secondary Cycle One." Gouvernement du Québec, Ministère de l'Éducation, du Loisir et du Sport.

http://www.mels.gouv.qc.ca/GR-PUB/m_englis.htm.

MELS. (2005). "Education in Quebec. An Overview." Québec: Ministère de l'Éducation. http://www.mels.gouv.qc.ca/ scolaire/educqc/pdf/educqceng.pdf.

MELS. (2007). "Québec Education Program: Secondary Cycle Two." Gouvernement du Québec, Ministère de l'Éducation, du Loisir et du Sport.

http://www.mels.gouv.qc.ca/GR-PUB/m_englis.htm.

MELS. (2011). "Indicateurs de l'éducation - Édition 2011." Gouvernement du Québec, Ministère de l'Éducation, du Loisir et du Sport.

Mourshed, Mona, Chinezi Chijioke, and Michael Barber. (2010). "How the world's most improved school system keep getting better." McKinsey&Company.

Murnane, Richard J., John B. Willett, and Frank Levy. (1995). "The Growing Importance of Cognitive Skills in Wage Determination." *Review of Economics and Statistics* 77, no. 2: 251-266.

Murnane, Richard J., John B. Willett, Yves Duhaldeborde, and John H. Tyler. (2000). "How important are the cognitive skills of teenagers in predicting subsequent earnings?" *Journal of Policy Analysis and Management* 19 no. 4: 547–568.

Neal, Derek A. and William R. Johnson. (1996). "The role of pre-market factors in black-white differences." *Journal of Political Economy* 104, no. 5: 869–895.

Pinker, Steven. (1997). "How the Mind Works." New York: W. W. Norton & Compagny.

Rivkin, Steven G., Eric A. Hanushek, and John F. Kain. (2005). "Teachers, Schools, and Academic Achievement." *Econometrica* 73(2): 417-58.

Rose, Heather, and Julian R. Betts. (2004). "The Effect of High School Courses on Earnings." *Review of Economics and Statistics* 86, no. 2: 497-513.

Rosenbaum, Paul R. and Donald B. Rubin. (1983). "The Central Role of the Propensity Score in Observational Studies for Causal Effects." *Biometrika.* 70 (1), pp. 41–55.

Rouse, Cecilia Elena, and Alan B. Krueger. (2004). “Putting computerized instruction to the test: a randomized evaluation of a "scientifically based" reading program.” *Economics of Education Review* 23(4): 323-38.

Schafer, Joseph L. (1997). “Analysis of incomplete multivariates data.” London: Chapmand and Hall/CRC Press.

Teddlie, Charles, and David Reynolds. 2000. “The International Handbook of School Effectiveness Research.” Falmer Press, London.

Wooldridge, Jeffrey M. 2003. “Cluster-Sample Methods in Applied Econometrics.” *American Economic Review* 93(2): 133-38.

8 Tables

Table 1: Influence of math score on later outcomes

	High school dropout	Highest level of education	Total personal income
CAT/2 score			
Coef.	-0.015120	0.009723	25.367860
dy/dx	-0.000665	0.001226	25.367860
z	-4.74	4.18	2.16
Regression:	logit	ord. logit	linear

Note: Shows the association between the math score and adulthood outcomes. We use observations from the last wave of the NLSCY since it provides us with the oldest cohort of children (age 24-25). We use the math score for which the number of respondents was the highest given the age group: grades 5-6 score (survey year 1996). We report the marginal effect (dy/dx) of the math score. For the highest level of education, we report the margin for the probability of having a University degree. Controls include gender, age, province of residence, area of residence and the education level of the primary care giver at the time of the CAT/2 test. Standard errors (not reported here) are bootstrapped to account for the clustering and stratifications of the NLSCY.

Table 2: Reform schedule on students observed by school grade and academic year

Grade 1	Academic Year						
entry year	1996	1998	2000	2002	2004	2006	2008
1989-90	7 - 8	.					
1991-92	5 - 6	7 - 8	.				
1993-94	3 - 4	5 - 6	7 - 8	.			
1995-96	2	3 - 4	5 - 6	7 - 8	9 - 10		
1997-98		2	3 - 4	**5*** 6	**7*** 8	**9*** 10	
1999-00			$\boxed{2}$	$\boxed{3 - 4}$	$\boxed{5 - 6}$	$\boxed{7 - 8}$	$\boxed{9 - 10}$
2001-02				.	.	.	.
2003-04					.	$\boxed{3 - 4}$	.
2005						$\boxed{2}$	.
2007							$\boxed{2}$

Note: Shows the school grades pre and post reform in which students are observed and passed the CAT/2 test. Students entering grade 1 in 1989 and 1990 are grouped together, and so are students entering grade 1 in 1991 and 1992, and so on. This grouping is conformed to the reform approach which groups students by school cycle (e.g. grade 1 and 2). Boxed grades are under the reform, while unboxed grades are not. Grades in bold with an asterisk "*" are not under the reform, but students in these grades were treated by the reform while in grade 4 in academic year 2001. An empty cell is denoted by ".". A cell is empty if the number of students observed is equal to zero or only includes a small number of grade repeaters, or if the test administered that year was not comparable to all other years (grades 9-10, academic year 1996 to 2000).

Table 3: Summary statistics

	Québec (treated)		Rest of Canada (control)	
	Mean	Std. dev.	Mean	Std. dev
Student characteristics				
male	0.49	(0.50)	0.51	(0.50)
ppvt (age 4-5)	99.64	(15.11)	100.16	(14.81)
school grade				
2	0.10	(0.30)	0.11	(0.31)
3 and 4	0.22	(0.42)	0.22	(0.41)
5 and 6	0.24	(0.43)	0.23	(0.42)
7 and 8	0.28	(0.45)	0.27	(0.44)
9 and 10	0.16	(0.36)	0.18	(0.38)
Family characteristics				
family structure				
one parent	0.21	(0.41)	0.18	(0.38)
two parents	0.79	(0.41)	0.82	(0.39)
maternal education				
less than secondary	0.16	(0.37)	0.09	(0.29)
secondary	0.24	(0.42)	0.23	(0.42)
some post-secondary	0.18	(0.38)	0.20	(0.40)
college or university	0.41	(0.49)	0.47	(0.50)
mother works (dummy)	0.81	(0.39)	0.84	(0.37)
household income ('000s)	66.92	(47.26)	77.56	(60.44)
area of residence				
rural	0.14	(0.34)	0.13	(0.34)
urban, $\leqslant$30,000	0.15	(0.36)	0.19	(0.39)
urban, 30,000 to 99,999	0.09	(0.29)	0.09	(0.29)
urban, 100,000 to 499,999	0.06	(0.24)	0.21	(0.41)
urban, $\geqslant$500,000	0.55	(0.50)	0.38	(0.48)
Nbr. of obs.	7,745		33,390	

Note: Shows the mean and standard deviation on a number of student and family characteristics of Québec students (left) and RofC students (right). The sample is restricted to students' observations used to compute the estimated impact of the reform: all grade 2 students, students in grade 3 to 8 in academic year 2000 to 2006 (except for grades 7 and 8 students in academic year 2004), and students in grades 9 and 10 in academic year 2002, 2004 and 2008.

Table 4: Math scores summary statistics by school grade, academic year and treatment group

		Québec (treated)							Rest of Canada (control)						
		1996	1998	2000	2002	2004	2006	2008	1996	1998	2000	2002	2004	2006	2008
GRADE 2															
Years in reform		0	0	**1**	.	.	**2**	**2**	0	0	0	.	.	0	0
CAT/2	Mean	340	320	**298**	.	.	**284**	**301**	313	293	289	.	.	279	280
	Std. dev.	(48)	(40)	**(39)**	.	.	**(38)**	**(39)**	(47)	(38)	(42)	.	.	(40)	(39)
	% reponse	65	49	**91**	.	.	**94**	**94**	77	52	75	.	.	88	86
.	Nbr. obs	135	114	**285**	.	.	**242**	**163**	683	506	929	.	.	1,065	906
GRADES 3-4															
Years in reform		0	0	0	**3**	.	**3-4**	.	0	0	0	0	.	0	.
CAT/2	Mean	431	402	391	**377**	.	**353**	.	394	375	358	366	.	347	.
	Std. dev.	(60)	(48)	(53)	**(44)**	.	**(53)**	.	(58)	(55)	(52)	(49)	.	(52)	.
	% reponse	70	40	90	**91**	.	**95**	.	74	51	81	84	.	88	.
	Nbr. obs.	281	185	396	**572**	.	**787**	.	1,377	1,076	1,429	2,022	.	3,862	.
GRADES 5-6															
Years in reform		0	0	0	1-0	**5**	.	.	0	0	0	0	0	.	.
CAT/2	Mean	507	484	469	465	**418**	.	.	474	451	431	440	436	.	.
	Std. dev.	(48)	(50)	(53)	(53)	**(55)**	.	.	(60)	(59)	(56)	(51)	(53)	.	.
	% reponse	73	47	90	95	**94**	.	.	73	53	77	88	89	.	.
	Nbr. obs.	292	184	307	388	**528**	.	.	1,322	998	1,275	1,469	1,956	.	.
GRADES 7-8															
Years in reform		0	0	0	0	1-0	**7**	.	0	0	0	0	0	0	.
CAT/2	Mean	590	533	540	524	517	**495**	.	540	504	492	492	473	485	.
	Std. dev.	(73)	(57)	(71)	(58)	(60)	**(67)**	.	(78)	(69)	(73)	(68)	(60)	(70)	.
	% reponse	73	41	89	93	94	**91**	.	76	45	76	77	89	87	.
	Nbr. obs.	225	175	269	336	354	**518**	.	1,241	878	1,147	1,236	1,402	1,834	.
GRADES 9-10															
Years in reform		.	.	.	0	0	1-0	**9**	.	.	.	0	0	0	0
CAT/2	Mean	.	.	.	637	606	605	**599**	.	.	.	583	579	567	596
	Std. dev.	.	.	.	(90)	(82)	(87)	**(86)**	.	.	.	(85)	(91)	(81)	(88)
	% reponse	.	.	.	87	92	91	**84**	.	.	.	66	84	86	82
	Nbr. obs.	.	.	.	184	221	261	**343**	.	.	.	864	1,166	1,209	1,538

Note: Shows the summary statistics on the CAT/2 test (mean, standard deviation, response rate to the test and number of observations) by school grade, academic year and treatment group (Québec vs RofC). Summary statistics on treated students post-reform are in bold. The response rate is the ratio of the weighted number of students with non missing scores on the CAT/2 test over the total weighted number of students. Years in the reform refer to the number of years of treatment (it is always equal to zero in the RofC, while it is only equal to zero for Québec students not treated by the reform). The number of years in the reform for grades 3-4 students in 2006 is "3-4" since it is equal to 3 for students in grade 3 and equal to 4 for students in grade 4. The same logic holds for students in grades 5-6 in 2002, 7-8 in 2004 and 9-10 in 2006. An empty cell is denoted using a "." (see Table 2's footnote for further details).

Table 5: Estimated effects of the treatment on the treated

Dependent variable:	Base specifications		Alternative specifications					
CAT/2 score	DID		DID			MDID		
	without	with	with	impute	excl.			
	covariates	covariates	PPVT	m(10)	Ontario	kernel	llr	nn (5)
GRADE 2								
Years 1996, 2000								
Coef.	-17.32**	-21.18***	-14.23	-15.64**	-21.04**	-17.86***	-18.47**	-16.76**
Std.err.	(8.38)	(8.17)	(9.27)	(7.88)	(9.01)	(5.91)	(8.50)	(7.79)
Nbr.obs	2,032		1,668	2,620	1,502	1,139		
Years 1996, 2006								
Coef.	-22.29***	-24.31***	-19.89**	-18.51**	-32.70***	-26.83***	-25.67***	-18.86**
Std.err.	(8.37)	(8.09)	(9.33)	(7.97)	(8.57)	(5.33)	(8.02)	(8.28)
Nbr.obs	2,125		1,809	2,543	1,510	968		
Years 1996, 2008								
Coef.	-6.06	-11.07	-5.13	-6.05	-11.51	-7.34	-7.00	-2.52
Std.err.	(8.55)	(8.37)	(10.04)	(8.09)	(8.86)	(6.50)	(10.34)	(10.05)
Nbr.obs	1,887		1,565	2,317	1,312	652		
GRADES 3-4								
Years 2000, 2002								
Coef.	-21.97***	-19.64***	-16.80***	-17.40***	-16.21***	-11.06***	-10.39**	-6.41
Std.err.	(5.03)	(4.43)	(4.50)	(4.56)	(4.73)	(3.67)	(4.69)	(4.52)
Nbr.obs	4,419		4,088	5,194	3,303	2,278		
Years 2000, 2006								
Coef.	-27.60***	-16.66***	-14.12***	-15.13***	-18.03***	-11.04**	-11.78**	-10.01*
Std.err.	(5.27)	(4.87)	(4.91)	(4.94)	(5.30)	(4.45)	(5.42)	(5.16)
Nbr.obs	6,474		6,115	7,818	4,943	3,133		
GRADES 5-6								
Years 2000, 2002								
Coef.	-13.40**	-13.43**	-12.54*	-12.69**	-9.41	-14.37***	-13.92**	-16.57***
Std.err.	(6.23)	(5.97)	(6.63)	(6.09)	(6.13)	(4.94)	(5.99)	(5.96)
Nbr.obs	3,439		3,139	4,053	2,608	1,550		
Years 2000, 2004								
Coef.	-20.30***	-20.13***	-17.79***	-18.33***	-19.41***	-21.64***	-22.22***	-17.21***
Std.err.	(6.12)	(5.86)	(6.50)	(6.25)	(6.12)	(4.80)	(6.24)	(6.66)
Nbr.obs	4 066		3,632	4,698	3,054	2,103		

Note: Shows the estimated effects of the reform by school grade (top panel grade 2, middle panel grades 3-4, bottom panel grades 5-6). Refer to Table 5's note on the next page for further details.

Table 5: Estimated effects of the treatment on the treated (continue)

Dependent variable:	Base specifications		Alternative specifications					
CAT/2 score	DID		DID			MDID		
	without covariates	with covariates	with PPVT	impute m(10)	excl. Ontario	kernel	llr	nn (5)
GRADES 7-8								
Years 2000, 2006								
Coef.	-36.86***	-33.43***	.	-29.85***	-31.07***	-32.06***	-34.58***	-30.57***
Std.err.	(7.81)	(7.46)	.	(7.70)	(7.71)	(7.00)	(8.31)	(8.32)
Nbr.obs	3,768		.	4,446	2,817	2,059		
Years 2002, 2006								
Coef.	-22.47***	-23.08***	-26.44***	-21.86***	-27.70***	-30.11***	-34.37***	-27.82***
Std.err.	(7.52)	(6.70)	(6.49)	(7.10)	(7.25)	(6.38)	(8.31)	(7.99)
Nbr.obs	3,924		3,471	4,599	2,944	2,067		
Years 2004, 2006								
Coef.	-31.25***	-33.89***	-32.40***	-30.66***	-38.44***	-24.04***	-21.27***	-14.77**
Std.err.	(7.49)	(6.74)	(6.94)	(7.14)	(7.40)	(6.38)	(7.38)	(7.37)
Nbr.obs	4,108		3,803	4,627	3,059	2,065		
GRADES 9-10								
Years 2002, 2008								
Coef.	-51.53***	-45.12***	.	-40.49***	-31.58***	-33.12***	-39.99*	-32.51***
Std.err.	(12.41)	(10.75)	.	(10.76)	(11.27)	(9.56)	(23.61)	(11.89)
Nbr.obs	2,929		.	3,719	2,102	1,364		
Years 2004, 2008								
Coef.	-23.98**	-28.58***	-29.30***	-24.04**	-25.30**	-39.11***	-34.73**	-30.05**
Std.err.	(11.47)	(10.73)	(11.24)	(10.42)	(11.56)	(9.95)	(16.47)	(12.44)
Nbr.obs	3,268		2,948	3,832	2,347	1,360		
Years 2006, 2008								
Coef.	-28.63**	-33.75***	-39.44***	-28.14**	-18.72	-22.46**	-19.27	-17.29
Std.err.	(12.08)	(11.23)	(11.58)	(11.21)	(11.71)	(9.53)	(13.01)	(11.46)
Nbr.obs	3,351		3,093	3,938	2,404	1,363		

Note: This table shows the estimated effects of the reform by school grade (top panel grades 7-8, bottom panel grades 9-10). Column 1 shows the effects using DID without covariates. Column 2 shows the effects using DID with covariates (i.e. gender, school grade, family structure, maternal education, household income quartile, maternal work, and area of residence). Models presented in columns 3 to 8 augment the model presented in column 2. In column 3, the PPVT score at age 4 and 5 is controlled for. Cells related to students first interviewed beyond age 4 and 5 are left empty and are denoted using ".". In column 4, missing scores are imputed using multiple imputation by chained equations. Estimated results are based on 10 imputations. In column 5, all students from Ontario (Canada's largest province) are excluded. Columns 6, 7 and 8 show the effects using MDID with kernel, local linear regression and nearest neighbor with 5 neighbors matching respectively. All standard errors are bootstrapped to account for the clustering and stratifications of the NLSCY. Coefficient significance is denoted using asterisks: *** is p<0.01, ** is p<0.05, and * is p<0.1.

Table 6: Distributional Effect of Treatment on the Treated

Dependent variable:			25th		50th		75th		90th	
CAT/2 score	Mean	(Std.err.)	Perc.	(Std.err.)	Perc.	(Std.err.)	Perc.	(Std.err.)	Perc.	(Std.err.)
GRADE 2										
Years 1996, 2000*										
DID	-20.25**	(7.98)	-11.88	(9.52)	-14.88	(12.98)	-40.19***	(11.19)	-25.10***	(5.81)
CIC dci	-17.04**	(7.51)	-14.00	(8.97)	-10.00	(12.60)	-28.00**	(12.44)	-13.00	(13.36)
CIC lower	-17.81**	(7.53)	-14.00	(9.08)	-10.00	(12.65)	-28.00**	(12.93)	-13.00	(14.12)
CIC upper	-16.48**	(7.50)	-14.00	(8.92)	-10.00	(12.60)	-25.00**	(12.34)	-13.00	(13.36)
Years 1996, 2006										
DID	-24.01***	(8.03)	-13.00	(7.92)	-25.14**	(12.61)	-46.54***	(11.29)	-40.14***	(6.73)
CIC dci	-21.22***	(8.00)	-8.00	(6.84)	-14.00	(14.84)	-37.00**	(14.74)	-31.00**	(13.25)
CIC lower	-22.02***	(8.00)	-9.00	(6.96)	-14.00	(14.81)	-37.00**	(14.71)	-39.00***	(13.31)
CIC upper	-20.58**	(7.99)	-8.00	(6.82)	-14.00	(14.89)	-37.00**	(14.85)	-28.00**	(13.55)
Years 1996, 2008										
DID	-10.20	(8.16)	-3.87	(8.12)	-10.93	(12.98)	-35.71***	(12.09)	-24.38*	(13.86)
CIC dci	-5.43	(7.92)	2.00	(7.31)	-1.00	(13.36)	-18.00	(13.48)	0.00	(18.14)
CIC lower	-6.23	(7.97)	-1.00	(7.49)	-1.00	(13.52)	-18.00	(13.51)	-5.00	(18.34)
CIC upper	-4.83	(7.89)	2.00	(7.27)	-1.00	(13.31)	-18.00	(13.63)	0.00	(18.49)
GRADES 3-4										
Years 2000, 2002*										
DID	-19.42***	(4.33)	-15.49***	(5.54)	-18.49***	(4.27)	-16.35***	(4.17)	-23.87***	(7.07)
CIC dci	-15.17***	(4.18)	-16.00***	(5.91)	-17.00***	(4.77)	-11.00**	(4.76)	-15.00*	(8.10)
CIC lower	-15.59***	(4.19)	-16.00***	(6.04)	-18.00***	(4.90)	-11.00**	(4.91)	-15.00*	(8.19)
CIC upper	-14.71***	(4.18)	-16.00***	(5.92)	-17.00***	(4.82)	-11.00**	(4.74)	-15.00*	(8.08)
Years 2000, 2006										
DID	-16.38***	(4.76)	-23.58***	(5.83)	-17.21***	(5.29)	-8.58*	(4.77)	-10.25	(7.13)
CIC dci	-16.72***	(5.01)	-21.00***	(6.29)	-16.00**	(7.25)	-9.00	(5.84)	-11.00	(7.87)
CIC lower	-17.22***	(5.01)	-22.00***	(6.30)	-16.00**	(7.35)	-9.00	(5.98)	-11.00	(7.94)
CIC upper	-16.14***	(5.01)	-21.00***	(6.30)	-16.00**	(7.20)	-9.00	(5.78)	-9.00	(7.87)
GRADES 5-6										
Years 2000, 2002										
DID	-13.44**	(5.97)	-15.49***	(4.94)	-9.37	(8.37)	-20.17***	(7.73)	-13.24	(8.51)
CIC dci	-9.47	(6.05)	-10.00*	(5.62)	0.00	(7.80)	-17.00	(10.63)	-16.00	(11.44)
CIC lower	-10.03*	(6.07)	-10.00*	(5.65)	0.00	(7.89)	-17.00	(10.68)	-16.00	(11.34)
CIC upper	-8.84	(6.04)	-10.00*	(5.65)	0.00	(7.78)	-17.00	(10.79)	-16.00	(11.55)
Years 2000, 2004*										
DID	-20.28***	(5.82)	-16.55***	(6.24)	-15.58**	(7.80)	-30.22***	(7.51)	-22.15**	(8.66)
CIC dci	-19.46***	(6.23)	-13.00*	(6.83)	-14.00	(9.03)	-35.00***	(10.32)	-25.00**	(11.80)
CIC lower	-20.09***	(6.23)	-14.00**	(6.98)	-14.00	(9.09)	-35.00***	(10.45)	-25.00**	(11.89)
CIC upper	-18.85***	(6.22)	-13.00*	(6.77)	-14.00	(9.02)	-32.00***	(10.24)	-24.00**	(11.77)

Note: Shows the estimated distributional effect of the treatment on the treated on grade 2 students (top panel), grades 3-4 students (middle panel) and grades 5-6 students (bottom panel). Refer to Table 6's note on the next page for further details.

Table 6: Distributional Effect of Treatment on the Treated (continue)

Dependent variable: CAT/2 score	Mean	(Std.err.)	25th Perc.	(Std.err.)	50th Perc.	(Std.err.)	75th Perc.	(Std.err.)	90th Perc.	(Std.err.)
GRADES 7-8										
Years 2000, 2006⋆										
DID	-33.47***	(7.42)	-23.38**	(11.43)	-39.20***	(9.28)	-30.52***	(10.01)	-25.19**	(9.91)
CIC dci	-29.82***	(7.36)	-28.00**	(11.24)	-39.00***	(10.28)	-22.00**	(10.74)	-6.00	(14.65)
CIC lower	-30.28***	(7.38)	-28.00**	(11.25)	-39.00***	(10.30)	-22.00**	(10.79)	-19.00	(14.73)
CIC upper	-29.24***	(7.34)	-24.00**	(11.26)	-39.00***	(10.30)	-21.00**	(10.70)	-6.00	(14.69)
Years 2002, 2006⋆										
DID	-22.73***	(6.75)	-26.05***	(6.43)	-25.03***	(7.25)	-10.19	(9.86)	-7.84	(7.35)
CIC dci	-23.74***	(7.34)	-25.00***	(7.58)	-24.00***	(8.75)	-12.00	(11.20)	-1.00	(12.78)
CIC lower	-24.35***	(7.36)	-26.00***	(7.55)	-26.00***	(8.85)	-12.00	(11.20)	-5.00	(13.13)
CIC upper	-23.13***	(7.33)	-25.00***	(7.61)	-23.00***	(8.75)	-12.00	(11.26)	-1.00	(12.68)
Years 2004, 2006⋆										
DID	-33.68***	(6.63)	-26.11***	(8.58)	-31.13***	(9.34)	-28.11***	(9.75)	-27.19***	(8.79)
CIC dci	-34.47***	(7.35)	-34.00***	(8.81)	-35.00***	(10.26)	-26.00**	(13.25)	-32.00*	(17.12)
CIC lower	-35.01***	(7.36)	-35.00***	(8.79)	-35.00***	(10.30)	-26.00*	(13.58)	-32.00*	(17.19)
CIC upper	-33.94***	(7.35)	-33.00***	(8.85)	-35.00***	(10.27)	-26.00**	(13.20)	-32.00*	(17.10)
GRADES 9-10										
Years 2002 2008⋆										
DID	-44.13***	(10.72)	-49.95**	(21.96)	-40.50***	(13.44)	-38.42***	(13.22)	-21.65*	(12.51)
CIC dci	-43.51***	(11.11)	-66.00***	(23.37)	-46.00***	(16.78)	-47.00***	(15.85)	-24.00	(17.09)
CIC lower	-43.91***	(11.11)	-66.00***	(23.38)	-48.00***	(16.88)	-47.00***	(15.84)	-24.00	(17.11)
CIC upper	-43.13***	(11.10)	-65.00***	(23.46)	-46.00***	(16.78)	-47.00***	(15.86)	-24.00	(17.13)
Years 2004, 2008⋆										
DID	-28.12***	(10.54)	-33.69**	(14.65)	-29.69**	(11.73)	-25.68**	(12.07)	-16.13	(16.22)
CIC dci	-26.87***	(10.29)	-37.00***	(14.14)	-24.00	(15.12)	-27.00*	(14.22)	-16.00	(15.67)
CIC lower	-27.45***	(10.28)	-37.00***	(14.17)	-24.00	(15.15)	-27.00*	(14.14)	-17.00	(15.56)
CIC upper	-26.37**	(10.30)	-36.00**	(14.18)	-24.00	(15.23)	-27.00*	(14.40)	-16.00	(15.85)
Years 2006, 2008⋆										
DID	-33.56***	(11.12)	-28.05**	(13.32)	-28.47**	(12.55)	-24.05*	(13.65)	-31.96	(24.89)
CIC dci	-33.57***	(11.27)	-37.00***	(14.17)	-40.00***	(15.02)	-36.00**	(15.97)	-42.00*	(23.07)
CIC lower	-34.13***	(11.27)	-38.00***	(14.22)	-41.00***	(14.86)	-36.00**	(16.08)	-42.00*	(23.23)
CIC upper	-32.95***	(11.27)	-37.00***	(14.13)	-40.00***	(15.14)	-34.00**	(15.98)	-42.00*	(23.07)

Note: Shows the estimated distributional effect of the treatment on the treated on grades 7-8 students (top panel) and grades 9-10 students (bottom panel). The dependent variable is the CAT/2 score. DID refers to the difference-in-difference estimator in level. CIC dci refers to the discrete changes-in-changes estimator with conditional independence, while CIC lower and upper refer respectively to the lower and upper bounds of the estimator. The first column shows the mean effect, while columns 3, 5, 7 and 9 show the distributional effect at the 25th, 50th, 75th and 90th percentiles. All specifications control for the set of covariates listed in the footnote of Table 5. To denote our main longitudinal cohort of treated students, we use "⋆" beside the year. Standard errors are bootstrapped to account for the clustering and stratifications of the NLSCY. Coefficient significance is denoted using asterisks: *** is p<0.01, ** is p<0.05, and * is p<0.1.

Table 7: Falsification exercises

Dep. Var.: CAT/2		Coef..	Std.err.	Nbr.obs.	All groups
GRADE 2					
Years	2000-2006	-11.02*	(5.65)	1,788	after
	2000-2008	9.49	(6.19)	1,590	after
	2006-2008	21.22***	(5.93)	1,598	after
GRADES 3-4					
Years	1996-2000	-3.50	(5.74)	2,642	before
	2002-2006	-2.02	(4.61)	5,480	after
GRADES 5-6					
Years	1996-2000	1.41	(6.55)	2,443	before
	2002-2004	-8.75*	(5.32)	3,248	after$^{\#}$
GRADES 7-8					
Years	2000-2002	-1.61	(7.39)	2,281	before
	2002-2004	9.73	(7.91)	2,523	before
	2000-2004	6.09	(8.64)	2,396	before
GRADES 9-10					
Years	2002-2004	-8.93	(12.28)	1,811	before
	2004-2006	-5.75	(13.28)	2,113	before
	2002-2006	-10.86	(12.16)	1,868	before

Note: Shows the mean effect using standard DID with covariates (see Table 5's note for list of covariates) using groups that are either all before the reform or all after the reform (column 4, before vs after) in both Québec and the RofC. The dependent variable is the CAT/2 score. In grades 5-6, years 2002 versus 2004 are classified as after$^{\#}$ because only grade 5 students were treated and for only one year while in grade 4 in 2001. Standard errors are bootstrapped to account for the clustering and stratifications of the NLSCY. Coefficient significance is denoted using asterisks: *** is p<0.01, ** is p<0.05, and * is p<0.1.

Table 8: Comparion of TIMSS performance across provinces

	Mathematics Achievement				Mathematics Achievement			
	Grade 4				Grade 8			
Year	1995	1999	2003	2007	1995	1999	2003	2007
International	500	500	500	500	500	500	500	500
Québec	550	-	506	519	556	566	543	528
Ontario	489	-	511	512	501	517	521	517
Alberta	523	-	-	505	-	-	-	-
British Columbia	-	-	-	505	-	522	-	509
	Coef.	Std.err.	t-stat	N	Coef.	Std.err.	t-stat	N
DID estimate	-40.83	20.08	-2.03	8	-31.00	18.07	-1.72	8
	Science Achievement				Science Achievement			
	Grade 4				Grade 8			
Year	1995	1999	2003	2007	1995	1999	2003	2007
International	500	500	500	500	500	500	500	500
Québec	529	-	500	517	510	540	531	507
Ontario	516	-	540	536	496	518	533	536
Alberta	555	-	-	543	-	-	-	-
British Columbia	-	-	-	537	-	542	-	526
	Coef.	Std.err.	t-stat	N	Coef.	Std.err.	t-stat	N
DID estimate	-24.67	23.29	-1.06	8	-28.75	24.56	-1.17	10

Note: Mean scores were obtained from the Trends in International Mathematics and Science Study (TIMSS), years 1995, 1999, 2003 and 2007. DID estimates account for aggregated shocks at the provincial level (Wooldridge, 2003)

9 Figures

Figure 1: Reform schedule and implementation

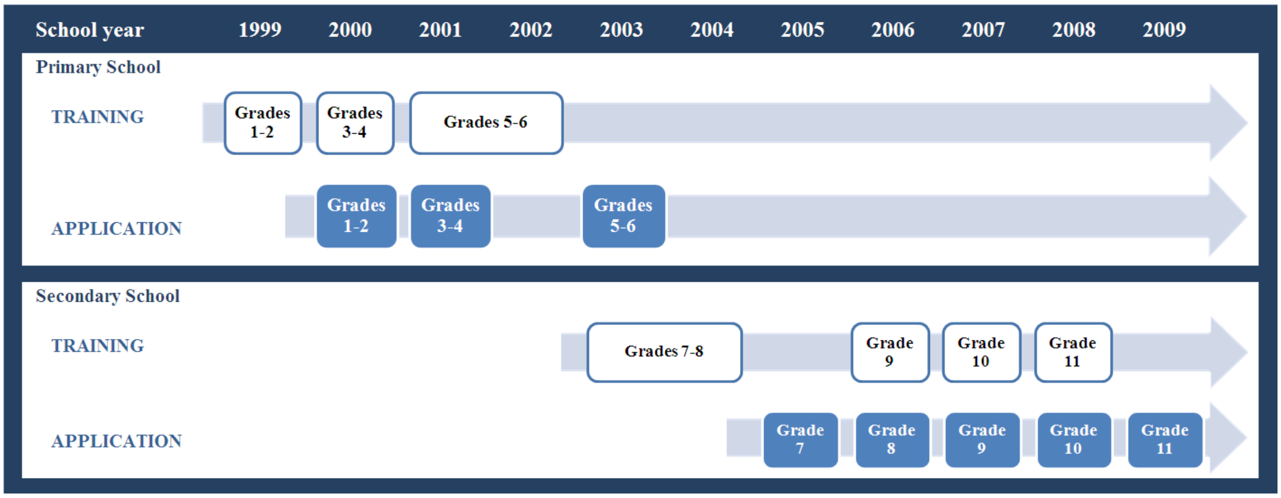
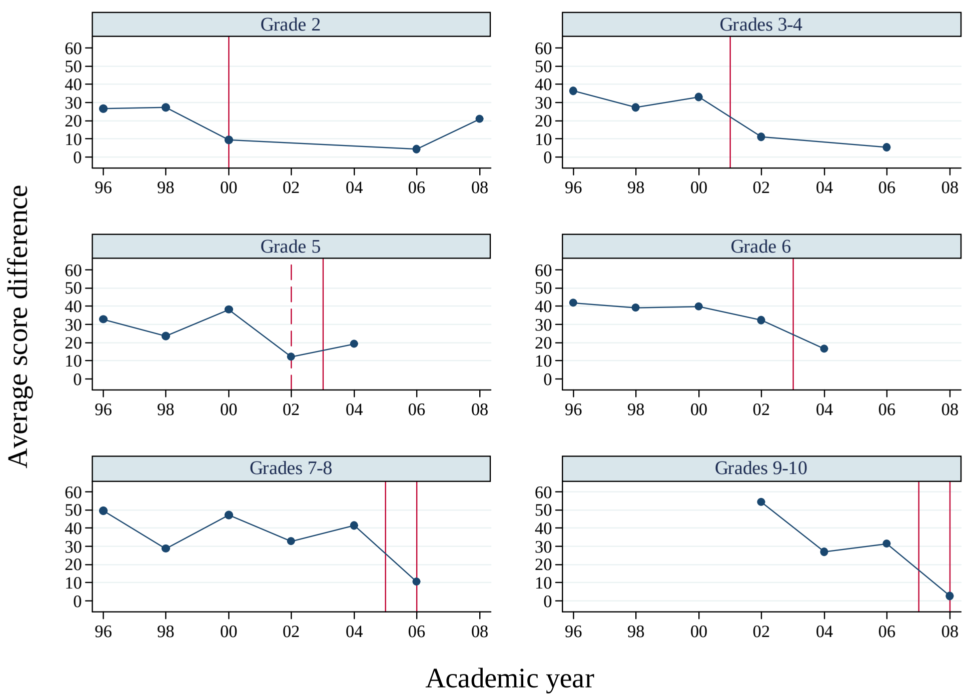
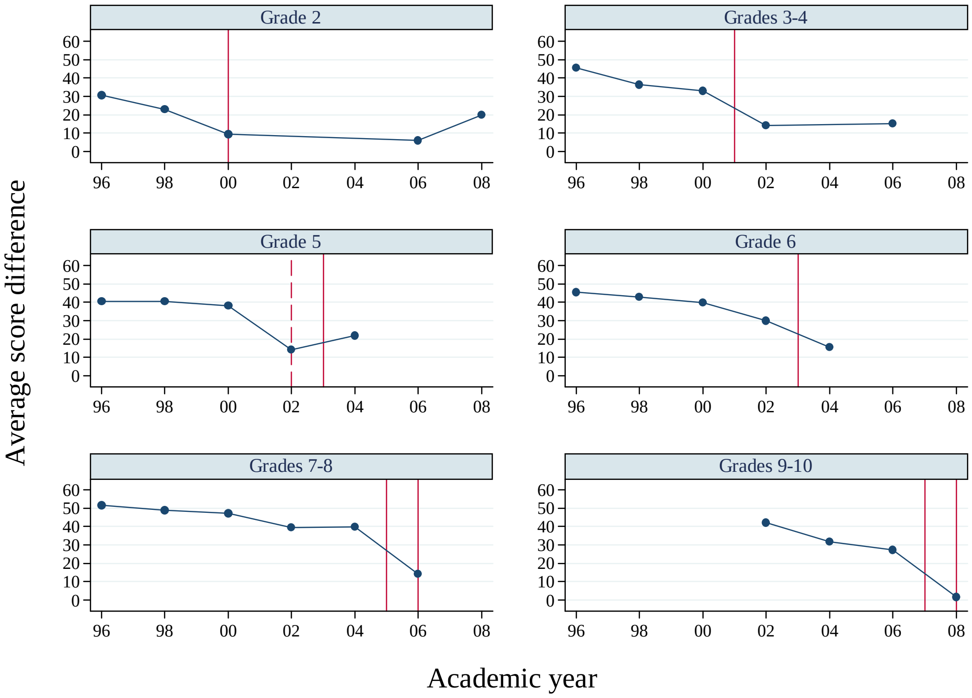


Figure 2: Average score differences: Québec vs RofC



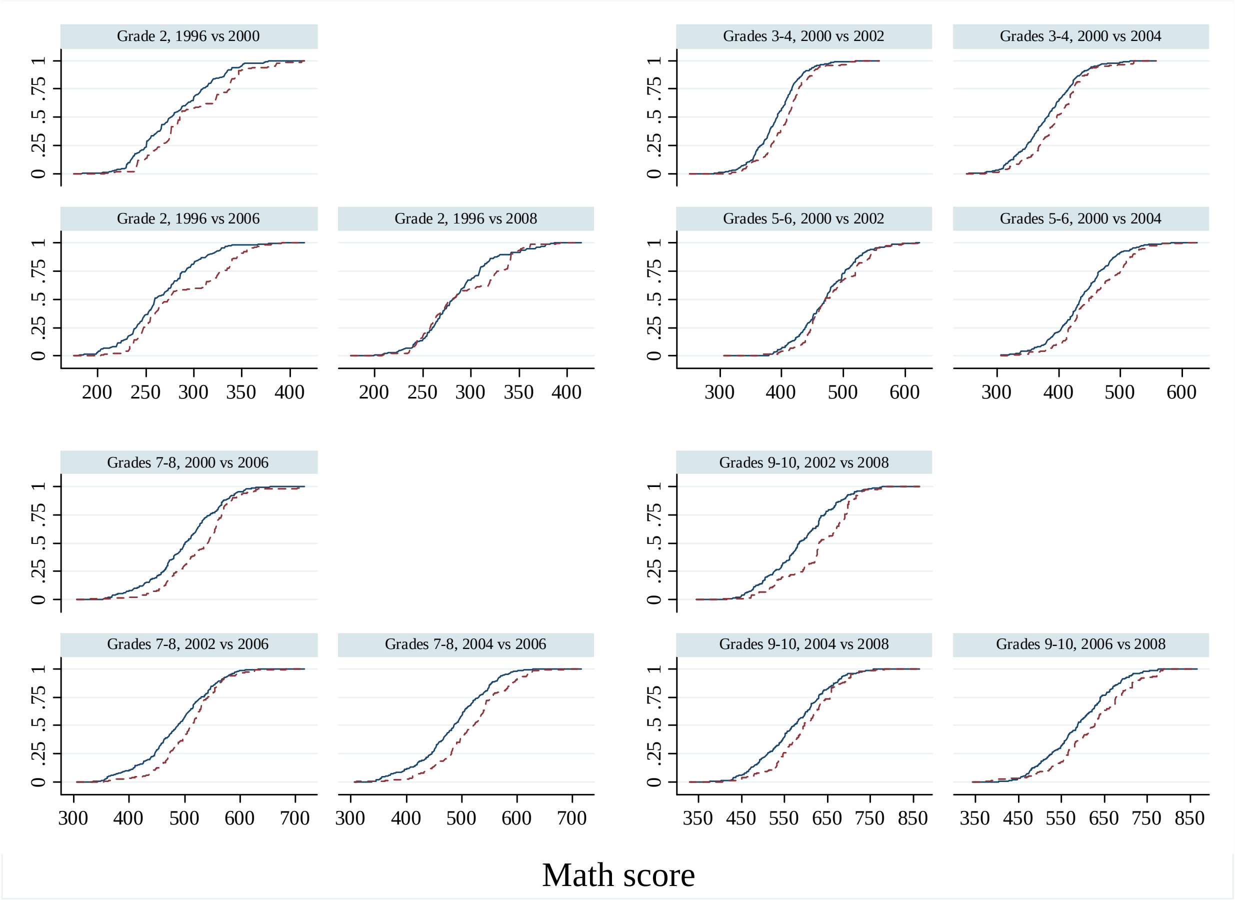
Note: Shows the average CAT/2 score differences between Québec and the RofC over time. The vertical line in each quadrant marks the first school year during which the reform was implemented. In grades 7-8 and 9-10 there are two vertical lines. This is because the reform was first implemented in grade 7 in academic year 2005, while it was only implemented in 2006 for grade 8. The same logic holds true for grades 9-10. The dashed line in grade 5 marks the cohort of students that was treated by the reform one year only, in 2001.

Figure 3: Matched average score differences: Québec vs RofC



Note: Shows the average matched CAT/2 score differences between Québec and the RofC (RofC) over time. Again, the vertical line in each quadrant marks the first school year during which the reform was implemented.

Figure 4: Observed and counterfactual cumulative test score distribution function of Québec students post reform



Note: Shows the CAT/2 score cumulative distribution function of Québec students post reform. The solid line represent the observed distribution. The dashed line represent the counterfactual distribution estimated using the CIC approach. This figure represents graphically the results presented in Table 6: grade 2 students (upper left), grades 3-4 and 5-6 (upper right), grades 7-8 (bottom left), and grades 9-10 (bottom right).

10 Appendix

Table 9: Competencies and broad areas of learning

Cross-curricular competencies
To use information effectively, and in new contexts
To solve problems using varied and effective strategies
To formulate and exercise appropriate critical judgment
To use creativity in consideration of all elements of the situation
To adopt effective work methods for the task to be performed
To use effectively information and communications technologies
To construct his/her identity
To cooperate with others with appropriate attitudes and behaviors
To communicate appropriately with clarity, coherence, appropriateness and precision
Broad areas of learning
Health and well-being
Career planning and entrepreneurship
Environmental awareness, and consumer rights and responsibilities
Media literacy
Citizenship and community Life

Source: Ministry of Education, Leisure and Sport.

Table 10: Estimated Effect on Grade 2 children (Prior period: Year 1998)

Dependent variable:			25th		50th		75th		90th	
CAT/2 score	Mean	(Std.err.)	Perc.	(Std.err.)	Perc.	(Std.err.)	Perc.	(Std.err.)	Perc.	(Std.err.)
GRADE 2										
Years 1998, 2000⋆										
DID	-17.05**	(7.21)	-18.90**	(9.04)	-16.80*	(9.08)	-18.56	(11.93)	-9.79	(8.57)
CIC	-16.78**	(7.06)	-25.00**	(10.08)	-25.00***	(8.48)	-18.00	(12.30)	-5.00	(10.07)
CIC lower	-17.22**	(7.06)	-25.00**	(10.10)	-26.00***	(8.45)	-19.00	(12.38)	-5.00	(10.38)
CIC upper	-16.36**	(7.05)	-25.00**	(10.34)	-25.00***	(8.56)	-18.00	(12.32)	-5.00	(10.00)
Years 1998, 2006										
DID	-21.43***	(7.58)	-19.09**	(8.15)	-18.41**	(9.05)	-27.46**	(11.32)	-25.72**	(11.80)
CIC	-22.82***	(8.41)	-19.00*	(9.78)	-20.00*	(11.26)	-28.00**	(13.95)	-27.00*	(16.22)
CIC lower	-23.37***	(8.41)	-19.00*	(9.81)	-21.00*	(11.27)	-28.00**	(14.07)	-29.00*	(16.40)
CIC upper	-22.23***	(8.42)	-16.00	(9.96)	-19.00*	(11.34)	-28.00**	(13.97)	-27.00*	(16.23)
Years 1998, 2008										
DID	-9.03	(8.20)	-4.84	(7.48)	-10.04	(9.14)	-16.09	(13.55)	-14.34	(16.72)
CIC	-8.93	(8.17)	-5.00	(9.53)	-13.00	(9.28)	-12.00	(13.96)	-3.00	(19.71)
CIC lower	-9.47	(8.18)	-6.00	(9.60)	-14.00	(9.31)	-12.00	(14.00)	-3.00	(19.69)
CIC upper	-8.36	(8.18)	-5.00	(9.52)	-12.00	(9.27)	-12.00	(14.02)	-3.00	(19.80)

Note: Shows the estimated effect of the treatment on the treated on grade 2 students. The reference period prior to the reform is academic year 1998 in all three cases. Standard errors are in parentheses. To denote our main longitudinal cohort of treated students, we use "⋆" beside the year. Standard errors are bootstrapped to account for the clustering and stratifications of the NLSCY. Coefficient significance is denoted using asterisks: *** is $p<0.01$, ** is $p<0.05$, and * is $p<0.1$.