Is Well Begun Half Job Done? Evidence from Educational Production Functions of University Students*

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Abstract

Using data from a large Italian university, we study the importance of the investment in early years of career. Applying the production function approach, we estimate the effect of academic performance, mainly first-year performance, on probability of graduating and of graduating with top marks, of graduating within the minimum period and of graduating with top marks and within the minimum period. Our estimates suggest that first year inputs are powerful predictors of the ultimate success of the undergraduates. We also find that there is complementarity between the measures of quantity and of quality in the subsamples of graduates, especially when graduation with top marks and with top marks and on time is considered; while there is no evidence of catching up in students performance over their careers. Changes in the rules of progression from on year to the next can considerably reduce the risk of graduating not within the minimum period.

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1 Introduction

There is an extensive economic literature regarding the nature of the education production function, that is, the way in which inputs from students, parents, teachers, schools, and other sources are combined to produce a student's academic achievement (Hanushek 2002, 2008). This literature focuses almost exclusively on primary and secondary education.[1] Another, more recent, literature has focused on early investments, i.e., investments that occur even before the start of formal schooling (Heckman and colleagues; Todd and Wolpin 2007; Fiorini and Keane 2014; Del Bono et al., forthcoming). But our knowledge of the production function used by university students is scant. An original focus of our study is on the role played by a student's first-year performance in determining his/her success in the university career. This is important because: (a) first year could be a strong predictor of future success, (b) strengthening the signal-to-noise ratio of the first year could increase the chances that students achieve their full potential, enhance universities' productivity (and create additional public good, see Card, Giuliano and others on opening up of US colleges); (c) social costs (i.e. streamlining resources in the university system and using public money efficiently). A regular feature of the Italian university system is the so called *Fuori Corso*, that is, students' enrolment extends beyond the legal length of their program (and possibility or repeating exams/resitting) (Brunello and Winter-Ebmer (2003) for Europe; Aina et al. (2011); Garibaldi et al. (2012) for Italy; Ehrenberg and Mavros (1995); Bound, Lovenheim, and Turner (2012)).

2 Institutional Background

In Italy, all individuals who hold a secondary school qualification can enrol in any university program.[2] High school qualifications are usually completed at the age of 18 or 19 years, and can be obtained through either academic tracks designed specifically to prepare for university studies (*Liceo*) or other vocational tracks.

[1]Recent empirical studies have focused on the effect of class size (Krueger 1999; Angrist and Lavy 1999; Hoxby 2000), peer effects (e.g., Hanushek et al. 2003), teacher quality (Rivkin et al. 2005), student, parent and teacher effort (De Fraja et al. 2010), and parental involvement (Houtenville and Smith Conway 2008).

[2]State imposed quotas on student numbers is typically slack or has been so until recently. In a handful of study programs (such as studies in medicine and health, veterinary, and architecture), excess demand is generally addressed with admission tests. Some institutions might require applicants to pass an entry exam to be admitted in other programs. But these are rare and will not be relevant to our work.

The main provision of Italian universities is academic degrees, called *Laurea*.[3] Up to 2001, the official length of an undergraduate program varied between four and six years, depending on the field of study: for example, the duration of medical programs was six years, engineering was five, while most of the programs in social sciences and humanities lasted four years. Since then Italian universities, as most other universities in Continental Europe, introduced a reform that implemented the "Bologna Process".[4] As a result, nearly all programs shifted to three-years undergraduate degrees. After the completion of this three-year program, students can continue and complete two additional years of specialization, which lead to a master's degree (or *Laurea Magistrale*). Our analysis will not focus on this degree, but only on undergraduate programs before and after the 2001 reform.

Methods and rules of assessment used to establish whether a student has passed or failed a given module differ across universities and, within each institution, across departments and programs of study. All universities, however, adopt the same marking scale: the minimum pass grade is 18 out of 30 marks, while the maximum mark is 30 plus honors (*Laude*). An undergraduate degree can be awarded only if a student has passed all modules (or credits) required in a given program and successfully defended a final-year written dissertation.[5] The final graduation mark, which is determined by a committee of faculty members on the basis of the grades obtained in all the exams of the program and in the final dissertation, ranges between 66 (passing level) and 110 *cum Laude*.

Progression from one year to the next is typically not conditional on past exam performance. Students can resit an examination several times if either they have not been successful in previous attempts or, even if they passed, they are dissatisfied with the mark obtained. As a result, students can take considerably longer than the normal completion time to obtain a degree in Italian universities. Students whose enrolment extends beyond the legal length of their program are known as *Fuori Corso* (Aina, Baici, and Casalone 2011; Garibaldi et al. 2012). Before the 2001 reform, the mean duration of a four-year program was about 7.5 years, with nearly 85 percent of undergraduates completing their

[3]Two-year vocational degrees have been available since the early 1990s in addition to standard four-year degrees. They were gained only by a small fraction of the student population (MIUR 2000) and, after 2000, were discontinued. They will not be part of our analysis.

[4]The reform, whose aim is to develop an integrated European higher education area, is described in Zgaga (2006). For Italy, Cappellari and Lucifora (2009) document a positive impact of the reform on college enrolment.

[5]Before the 2001 reform, the total number of modules needed to attain a four-year degree differed markedly across disciplines, going for instance from about 20 modules in mathematics and philosophy to about 35 in economics and psychology and 50 in medical sciences. After 2001, most three-year programs require a similar total amount of credits, which are roughly equally spread across the three years (i.e., about 60 credits per year for a total of 180 credits for the whole program).

degree as *Fuori Corso* students (ISTAT 2000; Garibaldi et al. 2012). After the shift to three-year college degrees, the mean duration is about 4.5 years and 57 percent of all graduates are *Fuori Corso* students (AlmaLaurea, 2011; MIUR 2012). There is not therefore an obvious set of year-on-year outcomes that students must achieve over their university career. This in turn makes it difficult or impossible to estimate standard value added models. We shall return to this point in the next section.

Most of the Italian universities are public and charge relatively modest tuition fees. Cattolica and very few other institutions are instead private. Upon enrolment in each academic year, their students pay tuition fees that are progressively determined on the basis of family income (e.g., Garibaldi et al. 2012). Students from low-income households are assigned to lower tuition brackets and may end up paying no more than what they would pay in public universities. Students from higher income families, instead, are assigned to higher brackets and pay more. With very limited access to financial aid, credit constraints may deter college enrolment among poorer households.[6] There is no evidence, however, that this deterrence effect differs depending on whether the university is public or private.

In sum, we do not expect to face any serious sample selection issue. Cattolica matches national averages of all comparable institutions in terms of quality of student intake (measured by either secondary school grades or the fraction of students coming from secondary school academic tracks), the proportion of undergraduates obtaining a degree with 110 *cum Laude*, and the fraction of *Fuori Corso* students (MIUR, various years from 1998 to 2010). Before presenting a more thorough description of our samples in Section 4, the next section illustrates the modeling framework and our identification concerns.

3 Methods

As most of the empirical literature that estimates educational production functions, we are confronted with two main problems (Hanushek 2002). The first is the difficulty of measuring all of a student's activities and inputs that are relevant to a successful university achievement. The second issue is the empirical problem of distinguishing a mere correlation between inputs and outcomes from a true causal effect. To illustrate these

[6]For instance, Checchi et al. (1999) document a negative association of low socioeconomic status with the probability of entering post-secondary education. Researchers also identify the socioeconomic gradient in university enrolment and attainment as one of the key determinants of a strong intergenerational correlation (Hanushek and Wößmann 2006; Brunello and Checchi 2007; Checchi and Flabbi 2007).

issues, let us define the production function for outcome y of individual i measured at end of his/her university career, T, as

$$y_{iT} = X'_{i\{t\}}\theta_{\{t\}} + \epsilon_{iT}, \tag{1}$$

where $X_{i\{t\}}$ is a vector of inputs observed over the whole university career of student i from time T backwards (the complete history of inputs), and ϵ_{iT} is an error term that captures both shocks to the individual university performance and other unobservables, such as innate ability, personality and motivation.[7]

The first problem, measurement of a student's inputs, originates from the fact that most of the available survey data include only a limited amount of information about what college students do over their university career. As a result, researchers have tended to focus on issues other than the estimation of educational production functions for college students (such as time to degree, student withdrawal, college costs, financial aid, and peer effects). Indeed, focusing on the effect of just a few of the many inputs into university performance is problematic, because the estimated effect of any included input depends on what other inputs are omitted in equation (1).

To address this measurement problem we analyze detailed administrative data from a large higher education institution. The data are informative not only because they cover a long period of time and highly diverse areas of study, but also because they contain precise information on all the exams taken by each student who is regularly enroled at Cattolica. Specifically, let c_{it} be the exam credits cumulated in all modules taken by student i in a given academic year t and let s_{it} denote the corresponding mean scores. Assuming away the role of other conditioning variables for simplicity, the production function (1) can be rewritten as

$$y_i = \sum_{t=1}^{T} \gamma_t c_{it} + \sum_{i=1}^{T} \lambda_t s_{it} + \varepsilon_i, \tag{2}$$

where ε_i is an error term that captures shocks to student i's university career path which are not under the individual's control as well as omitted variables (such as unobserved innate endowments) and measurement error. The length of the university career is given by T, which is either 4 or 3 years, depending on whether we consider students enrolled

[7] As mentioned in the previous section, a canonical value added (VA) model with contemporaneous inputs, X_T and a lagged measurement of the outcome variable, y_{T-1}, cannot be estimated, since we have a set of measures of y that can only be observed at T. Below we will come back to this point.

before or after the 2001 Bologna agreements.[8] This specification allows for the full student history of observed inputs to affect y, that is, both the inputs (credits and marks) obtained in the final university year as well as the inputs recorded in *all* previous years. There are still a number of important inputs that are left out of (2), such as class attendance, extra-curricular activities, and lecturer quality, although this latter input may be of lesser concern in our data set, since the within-cohort variation in teaching provision is likely to be minimal.[9]

A distinctive feature of the paper is to understand the role played by each student's first-year performance, which is summarized by c_{i1} and s_{i1}. We make this assessment in two ways. We begin by estimating (2) using only c_{i1} and s_{i1} as relevant inputs, and repeat the same exercise for each of the other years separately. Although this yields biased estimates of the production function parameters, it constitutes a useful benchmark. We then estimate the whole production function and assess the relevance of the first-year performance relative to that of the other years by means of partial R^2 comparisons. Despite its simplicity, this exercise is informative of the production process and allows us to understand the extent to which a "good start" represents a springboard to a degree.

It is, however, unclear what a good start really is. Some students may start well if they pass all first-year exams within the time defined by their curriculum. Others may believe a good start coincides with the achievement of top marks, even if they do not sit in all their first-year exams. This suggests there might be a trade-off between c, which can be taken as a measure of quantity, and s, which can be seen as a measure of quality. It is therefore important to ascertain whether there is complementarity or substitutability in those inputs in any given academic year. We do this by adding $\sum_t \delta_t c_{it} s_{it}$ to the cumulative model (2). If $\delta_t > 0$, there is complementarity, whereas $\delta_t < 0$ indicates substitutability, and clearly there could be complementarity at one stage of the skill formation and substitutability at another. This exercise will inform us whether (and when) students face a quality-quality trade-off and is thus likely to give us a new understanding of the observed increase in the

[8]Despite the widespread phenomenon of *Fuori Corso* described in the previous section, we restrict our attention to the inputs that students use during the prescribed period of their program. This allows us to have a level playing field to evaluate the performance of all students. The time length is therefore either 4 or 3 years, depending on whether we consider the old or new regime, respectively.

[9]We have mentioned that classical VA models cannot be estimated. However, the cumulative specification (2) could be interpreted as one. To see this, suppose the model of interest is given by (after dropping the i subscript for convenience): $y_T = \alpha y_{T-1} + \beta_T x_T + \nu_T$, where $\alpha < 1$ and x is used as a generic (scalar) input for simplicity. If we substitute for y_{T-1} in this expression, we find $y_T = \alpha^2 y_{T-2} + \alpha\beta_{T-1}x_{T-1} + \beta_T x_T + (\nu_T + \alpha\nu_{T-1})$. Repeating this substitution back to the first period, we obtain $y_T = \sum_{s=0}^{T-1} \alpha^s \beta_{T-s} x_{T-s} + \sum_{s=0}^{T-1} \alpha^s \nu_{T-s}$, and the term with the lagged outcome disappears if we have a sufficiently long time horizon. This expression is essentially equivalent to (2).

time to a degree completion (Brunello and Winter-Ebmer 2003; Aina, Baici, and Casalone 2011; Bound, Lovenheim, and Turner 2012; Garibaldi et al. 2012).

Besides this cross-sectional trade-off, we examine two other important and related features of the skill formation technology. One is the possibility that a given input used in one year augments the productivity of the same input at later stages. This will be explored by introducing in (2) a set of interaction terms, such as $\theta_j c_{ik} c_{i,k+m}$, and $\phi_j s_{ik} s_{i,k+m}$, where j goes up to 6 when $T = 4$ and up to 3 when $T = 3$, $k, m = 1, ..., 3$, and $k + m \leq T$. With θ and ϕ we generalize the notion of self-productivity illustrated by Cunha and Heckman (2007), Heckman (2008), and Cunha, Heckman, and Schennach (2010) in the context of early child development. The other feature is the possibility of dynamic complementarity in inputs, that is, the level of investment in exam quality at one stage could bolster the investment in exam quantity at a later stage, and viceversa. This process will be captured by a new set of interactions of the type $\vartheta_j c_{ik} s_{i,k+m}$ and $\varphi_j s_{ik} c_{i,k+m}$.

Such features of the technology lead us naturally to the second problem faced by the empirical literature, distinguishing a mere correlation between inputs and outcomes from a true causal effect. In equation (2), or its variants that try to account for self-productivity as well as cross-sectional and dynamic input complementarity, endogeneity usually comes in three forms: (a) omitted variables; (b) simultaneity (or reverse causality); and (c) measurement error in observed inputs. Now, the latter is likely to be of limited import in our case since we use highly reliable administrative data. The second issue may also be unimportant because of the temporal sequence of inputs and outcomes implied by (2): any of the inputs (exam marks and credits) observed during the university career of a student are expected to affect y_i (e.g., final mark at graduation and completion within the legal length of the program), but we do not expect i's final outcomes to affect c or s realized at any *prior* time (Gottschalk 1996).

The first source of concern, due to omitted variables, may appear more problematic, since there will be always activities other than those we measure that can affect student performance. In our context, however, it is hard to think of other inputs that determine y which are not already embedded in either c or s, or both. Put differently, students cannot graduate or complete within the legal period if they do not pass all the examinations scheduled in their program of study (i.e., without attaining full credits). Likewise, they cannot gain top marks at graduation unless they receive high marks in their exams on average. Of course, students could attend (noncompulsory) support classes or advanced lab sessions in addition to their standard lectures, something we do not observe. As suggested by much educational research, students may also benefit from a wide array of academic and non-academic experiences, including active participation in course learning, regular attendance to lecturers' office hours, course- and non-course-related interactions with peers, extra-curricular involvement, and engagement in paid work and volunteer activities (e.g., Pascarella 1980; Astin 1993; Pascarella et al. 2004; Pascarella and Terenzini 2005). Information on such activities is not available in our administrative data. Nonetheless, we expect to capture most of the influence of these additional inputs on y through the direct effects of c and s.

We mentioned that ε_i in (2) contains also the individual's (unobserved) innate ability. To account for the possible correlation between this unobservable and our observed inputs, we consider an instrumental variables (IV) approach. Our instruments for both c and s are: (i) the type of high school completed; and (ii) the deviation of the individual grade received at the end of secondary school from the national mean observed for each high school type. An extensive economic literature has documented that both domains have an impact on college performance as well as other later outcomes.[10] Most of the studies in this literature, however, do not control for students' year-on-year achievements while at university. Our identifying assumption therefore is that high school track and grades have an effect on college outcomes, but only through c and s. In the spirit of partial identification, our IV estimates should be seen as offering additional evidence on the technology parameters of interest, which would have to be compared to the estimates we obtain from the other approaches we employ.

4 Data

We base our empirical analysis on unique administrative data from Università Cattolica of Milan, Italy, a large private higher education institution that offers undergraduate and graduate degrees in several subject areas.[11] Our work focuses only on the undergraduate provision. During the period for which we have information (from 1990 to 2008), Cattolica switched from four-year to three-year undergraduate degrees. We therefore distinguish two provision regimes, which differ depending on the date of first enrolment: before the 2001 reform (four-year programs, from the academic year 1990/91 to the academic year 2000/01) or after the reform (three-year programs, from 2001/02 to 2007/08). The data cover all the students enroled in the following eight programs of study: Business

[10] See Dustmann (2004) Brunello and Checchi (2007), Cappellari (2012), Brugiavini, Carraro, and Kovacic (2015)

[11] The data include students enroled both in the central campus in Milan and in other campuses (Piacenza and Brescia). Data from the Rome campus are instead excluded (see below).

and Economics; Banking and Finance; Political Science; Law; Mathematics and Physics; Language and Linguistics; Education; Literature and Philosophy.[12]

Of the 53,552 active students with full valid records enroled at Cattolica over the sample period, we drop 426 individuals who were previously enroled in other institutions. We then exclude 2,840 students who have been enroled fewer years than the minimum period required to attain a degree or graduated with number of exams (or credits) below the minimum required. Finally, we remove 1,106 students who were aged 26 years or more at the time of matriculation. Our sample then consists of 49,184 individuals: 35,454 students come from the pre-reform period, while the remaining 13,730 are from the post-reform period. Conditional on having completed a degree, we have a subsample of 44,069 graduates, 34,179 and 9,890 from the four- and three-year programs, respectively.

4.1 Outcomes

We analyze four individual outcomes stratified by pre- and post-reform regime. From the sample of all undergraduates enrolled, we define an indicator variable that takes value 1 for students who obtain a first degree by August 2008, and value 0 otherwise. Summary statistics for all outcomes, shows that 96.4 percent of the individuals enroled in any of the four-year programs became Cattolica graduates, whereas this is the case for only 72 percent of those enroled after the implementation of the Bologna agreements. This discrepancy, which is statistically significant at conventional levels, might reflect censoring: students enroled in the pre-reform period had a longer period of time to attain their degrees, while students enroled in the new three-year programs who have become *Fuori Corso* may have delayed their graduation after August 2008, beyond our observation period.

We consider three other outcomes defined on the subsample of the 44,069 graduates. One outcome is an indicator variable that takes value 1 for students who completed their degree with top graduation marks (110 *cum laude*) and 0 otherwise. We take this as a measure of quality of student performance. 19.3 percent of undergraduates with four-year degrees attained top marks as opposed to 25 percent of three-year program students. The table shows also that the average final graduation marks are 102.4 and 103.3 in the old and new regime, respectively. The difference in each measure before and after the

[12] Students enroled in the Agriculture and Psychology programs are excluded from the analysis, since the legal duration of their pre-reform curriculum was five years. Students enroled in the School of Medicine (located in Rome) are also dropped, because their (pre- and post-reform) curriculum has an official length of six years.

reform is always statistically significantly different, although the dispersion of the pre- and post-reform *Laurea* marks is similar at about 7.7 points.

Another outcome is a measure of speed to degree and takes value 1 if a student graduated within the minimum completion period, i.e., four years if the student was enroled before the 2001 reform or three years if the student was enroled under the post-2001 regime. Keeping in mind the censoring caveat mentioned above, the reform is associated with a sharp and statistically significant reduction in the fraction of *Fuori Corso* students: while 43.5 percent of them completed their four-year degree in time, 65.6 percent did so among those enroled in three-year programs. The final outcome combines the two previous measures: it is an indicator variable taking value 1 if a student completed a degree with top marks *and* within the minimum legal period, and 0 otherwise. Between the old and the new system, we observe a significant two-third increase in the proportion of graduates who achieved this outcome, from 12.5 percent in the pre-reform four-year program regime to 20.8 in the post-reform period.

4.2 Inputs

Following the model of Section 3, each of the four outcomes described above is produced by the combination of credits, c_i, and mean scores, s_i, accrued over the whole university career for each individual student.

Before describing our input measures, some notation is in order. Let N_{it} be the the total number of exams in the pre-reform four-year regime (or the number of credits in the post-reform three-year regime) that are given to student i in his/her program of study in academic year t (and $t = 1, ..., 4$ or $t = 1, 2, 3$ in the two regimes accordingly). Let n_{it} denote the actual number of exams (or credits) that student i passes (or acquires) in year t, while m_{it} defines the average mark of the exams (or credits) passed by individual i in year t.

Given this, we define our measure of input "quantity" as

$$c_{it} = \frac{n_{it}}{N_{it} + I(t > 1) \sum_{j=1}^{t-1} (N_{ij} - n_{ij})}, \quad (3)$$

where $I(z)$ is a function indicating that the event z occurs. At the end of the first year of study, $c_{i1} = n_{i1}/N_{i1}$; at the end of every subsequent year, the denominator in expression (3) accounts not only for the exams (or credits) scheduled in that year but also for the exams (or credits) from *previous* years that the student has not completed yet. By construction, c_{it} ranges between 0 and 1 and becomes equal to 1 when i graduates from Cattolica.

Our measure of input "quality" is a weighted average of the examination marks and is given by

$$s_{it} = \sum_{j=1}^{t} w_{ij} m_{ij}, \tag{4}$$

where w_{it} is a weight that accounts for the contribution of each exam to the total number of exams (or credits) collected by individual i in year t. The values of s_{it} range between 18 (i.e., the minimum pass grade) and 30 *cum Laude* (which we arbitrarily transform into 31).

Using the subsample of graduates, the fraction of exams passed is on average about 65 percent of the number required in the first year of study and around 50 percent in the three subsequent years among individuals enroled in the pre-Bologna programs.[13] In the three-year programs, we observe a significant increase in all year-specific quantity inputs by at least 10 percentage points, shifting c up to about 73 percent across all three years. Moving from the old to the new programs of study, we also notice a small (but statistically significant) increase in mean examination marks of approximately half of a point, from about 25.6 to 26.1, with a fairly stable dispersion of 2.5 points in both regimes.

As an additional way of describing our input and outcome data, Figure 1 takes advantage of the variation across departments to show that there is a strong positive relationship between the first-year quality input and average graduation marks. The results for the four-year programmes are presented in panel A, while those for the three-year programmes are in panel B. Each panel displays the mean value of s_1 across departments from low to high as one moves from left to right, and the mean graduation mark by department as one moves from bottom to top. The vertical line is drawn at the mean s_1 over all individuals in all departments and the horizontal line at the mean graduation mark over the whole sample. In each panel we also report the mean value of the quality inputs for the three or two years following the first, depending on whether we consider the pre- or post-Bologna agreement period.

If first-year marks are key predictors of the graduation mark, then we expect to see the dark bullets (which refer to first-year performance) either in the northeast quadrant of each diagram for top performers or in the southwest quadrant of each diagram for bottom performers. It is apparent from both panels that this is precisely the case, and

[13] The statistics on c and s computed on all students (rather than graduates) are presented in the online appendix.

it is confirmed by the strong positive slope of the linear fit of the relationship between first-year performance and graduation marks. This pattern is broadly confirmed when we look at the succeeding years across all departments.

4.3 Other Variables

Appendix Table A1 contains summary statistics of the primary control variables in the data set, computed over the subsample of graduates and distinguished by program of study. In general, the individual characteristics observed in the old system are statistically significantly different from the corresponding characteristics observed in the new regime, although in many cases these differences are quantitatively small.

Just below 70 percent of all Cattolica graduates are women, and about 90 percent start university immediately after completion of their secondary school studies. Individuals enroled in post-reform programs have an average high school grade of 84 percent, about 3 points more than the corresponding mean among students enroled in the pre-reform period.[14] Around one quarter of graduates were educated in private high schools and more than three-fifths gained qualifications from the academic tracks (*Liceo*).[15]

Nearly 80 and 85 percent of students graduate from the programs offered in the Milan campus before and after the 2001 reform, respectively. Before and after the implementation of the Bologna agreements we also observe a considerable reduction in the fraction of graduates from Law (down to 5 percent from 16 percent), Education (from 17 to 11 percent), and Banking and Finance (from 5 to 2 percent), and a growth in the proportion of graduates in Literature and Philosophy (up to 21 percent from 13 percent), Language and Linguistics (from 14 to 20 percent), and Political Science (from 5 to 9). The Business and Economics department has the largest fraction of graduates, which has remained constant between the four- and three-year program periods at about 30 percent.

Other controls that are not reported in the table, but included in the analysis, are entry cohort fixed effects and indicator variables of the region of residence at the time of enrolment,[16] in addition to the already mentioned secondary school fixed effects.

[14]Secondary school grades range between 60 and 100.

[15]In the analysis we do not use broad categories for the type of high school attended. We instead control for secondary school fixed effects. We include approximately 2,000 secondary school dummy variables in the analysis of the old system, and between 1,300 and 1,550 dummy variables in the analysis of the new regime.

[16]We include 19 standard regions as well as Lombardy without the city of Milan, which is used as our base location.

5 Empirical Results

5.1 Baseline Estimates

5.1.1 Four-Year Programs

Table 1 presents the baseline results for all four-year programs in the sample. The estimates are obtained when the inputs of each year are included separately, i.e., we have four regressions for each output measure.[17]

According to the estimates in the first row, one additional exam in the first year implies an increase of: (i) 1.7 percentage point in the probability of graduating (which corresponds roughly to a 2 percent; column (i)), (b) almost 1.3 percentage points in the probability of completing with top marks (7 percent increase), (iii) 12.6 percentage point in the likelihood of completing within the minimum legal period of four years (nearly 30 percent increase), and (iv) 3.2 percentage points in the probability of completing within the legal time and with top marks (26 percent increase). All such changes are statistically significant.

Similarly, from the second row of Table 1, we find that one additional mark obtained in any of the first-year exams leads to a rise of: (i) 0.1 percentage points in the probability of obtaining a degree, (ii) 5.4 percentage points in the likelihood of graduating with a mark of 110 *cum Laude* (corresponding to a 28 percent increase at the outcome mean), (iii) 1.1 percentage points in the likelihood of completing the degree within the minimum period (a 3 percent increment), and (iv) 3.6 percentage points in the probability of completing with top marks and within the minimum period (or 29 percent increase). Apart from the first estimate, which is significant only at the 10 percent level, all the others are statistically significant at the 1 percent level.

To get a sense of how important these estimates are, we compare them to the effect of high school graduation marks. For instance, a 10 percent rise in the average grade received at the end of secondary school (about 8.1 points, or 0.7 standard deviations) is associated with a 0.1 percentage point increase in the probability of graduating, a 5.3 percentage point increment in the likelihood of graduating with top marks, a 2.2 percentage point increase in the probability of obtaining a degree within the minimum period, and a 3.2 percentage point step-up in the probability of completing within the minimum period and with top marks. The effect of c_1 is greater than the impact of a 10 percent rise in

[17] The figures refer to the impact on y of an increase at the sample mean by one exam or its credit equivalent (in the case of c) or of an increase at the sample mean by one mark in each academic year (in the case of s).

the average high school graduation mark across all outcomes, except for the likelihood of obtaining a degree with top marks. The same is for s_1, but in this case the exception is for the probability of graduating within the minimum four-year period. Noting that a 0.7 standard deviation increase in the average score at secondary school exit is substantial, the impacts of c_1 and s_1 on our outcomes are therefore equally considerable.

How do these estimates compare to the impact of the same inputs measured in subsequent years? To address this question we consider the rest of the rows in Table 1, where we report the estimates obtained when the year-specific inputs are included separately for each of the other three years. We find that the effects of both c_1 and s_1 are quantitatively similar, and statistically identical, to the impacts of input quality and quantity of years 2, 3, and 4. This evidence suggests that the first-year inputs are powerful predictors of the ultimate success of the undergraduates in our sample.

Moving to the results obtained when all inputs are jointly estimated, Table 2 reveals that the two first-year inputs lose their explanatory power to predict the probability of completing a degree (column (i)). The effects of s_1 on the likelihood of graduating with 110 *cum Laude* and the probability of graduating with top marks and within the minimum legal period are of size comparable to, or greater than, the effects of s_2, s_3, and s_4. The effect of c_1 on the probability of graduating within four years is always positive and significant, but it is now smaller than the corresponding impacts of c_3 and c_4.

The table also shows a significantly negative relationship between the quantity of exams passed in the first year and the probability of graduating with top marks ($\gamma_1 = -0.01$ (s.e.=0.002), column (ii)). An almost identical negative effect is found for the likelihood of obtaining a degree with top marks and within the minimum legal period of completion ($\gamma_1 = -0.009$ (s.e.=0.001), column (iv)). These results suggest the existence of a possible trade-off between the quantity of exams passed in the first year of study and the quality of the end-of-program achievement. Another possible trade-off is between speed to degree and input quality in the first year ($\lambda_1 = -0.003$ (s.e.=0.001), column (iii)). Together, these estimates indicate the possibility of a quantity-quality trade-off. Below we shall explore complementarities between the two inputs more directly.

Student performance in the first year turns out to be crucial across essentially all outcomes and regardless of whether we include each yearly pair of inputs separately or jointly. The only exception is in Table 2 for the likelihood of obtaining a degree (column (i)).

5.1.2 Complementarities

To be written

1. δ_t (cross-sectional complementarity)
2. θ_j (self-productivity of c) and ϕ_j (self-productivity of s)
3. ϑ_j (dynamic complementarity in c) and φ_j (dynamic complementarity in s)

We also find evidence of a significant (albeit small) quantity-quality trade-off in the case of s_1 and the probability of graduating within the minimum period ($\lambda_1 < 0$ in colum (iii)), but the same outcome is instead positively correlated to c_1: one standard deviation increase in c_1 leads to a significant BB percentage point rise in the likelihood of graduating on time, which corresponds to a XX percent increase in the average outcome at baseline.

We also find positive λ_1 coefficients (quality) for the probability of graduating with 110 cum Laude and the probability of graduating on time and with top marks (columns (ii) and (iv), respectively). Although the size of these effects is smaller, the impact is still economically relevant and statistically significant.

5.2 Learning Persistence

Due to the fact that our outcomes can only be observed at T (i.e., we have time-invariant measures of y), we cannot readily focus on outcome dynamics and learning persistence, which are two key aspects of student performance. Nonetheless, by investigating the distinctive contributions of inputs measured at various stages of academic careers we have anyway provided some insights on the mechanisms behind the dynamics of students performance. If all that matters for the achievement of a give final result is initial performance and subsequent contributions have only minor effects, then we should observe that ones position in the distribution of performance is rather stable over time, resulting in a high degree of persistence in the educational production function.

We now make another step in the direction of understanding the dynamics of the performance-generating process and explicitly model the possibility of catching-up. The idea that heterogeneous behaviors may result in a catching up effect for some meaningful econiomic outcome is a feature of various structural models. Perhaps the most famous one is the Mincer/Ben-Porath model of human capital investments. There, individuals are heterogeneous in their investment decisions, which are costly in terms of foregone earnings early in the life-cycle, but pay off later on in terms of steepest life-cycle earnings growth, inducing a trade-off between initial earnings and earnings growth that results in a catching up between investors and non-investors at some point in the middle of their working careers. In Chiappori's et al (1999) model of learning, wages display a 'late beginner' property due to heterogeneous learning ability in an environment characterized by downward wage rigidities, fixed wage hierarchies and promotions. In their model, late beginners are the slowest in learning relevant productive abilities, and compensate unsatisfactory initial performances with better performances in subsequent periods, which enable them catching-up (or even overtaking) early beginners.

We investigate the existence of catching up in students' performance over their careers by adopting a specification similar to Chiappporis et al. (1999). Lets partition the career in three stages: the initial one (stage 1), the intermediate one (stage 2) and the final one (stage 3). Performance in the first period is governed by the following initial condition equation:

Where p denote performance that is relevant for the achievement of the final goal (i.e p=s,c using the notation from the previous section) and x1 is a vector of relevant control for period 1. Performance in the intermediate period depends on first period performance:

Finally, performance in the final period depends on all the past history of the process:

According to the catching up hypothesis, final performance should be negatively correlated with initial performance once intermediate performance has been controlled for, i.e. Empirically , we will be estimating simultaneously dichotomous versions of equations (*) to (***) by means of trivariate probit models (as in Chiappppori et al. 1999) which will enable us identifying the dynamic structure while controlling for spurious correlations in performance via the covariance structure of the model unobservables. Results are in table 5 and they suggest, both for quality and quantity performance, that there is not evidence of catching up over the academic careers.

6 Conclusions

Using data from a large Italian university, we study the importance of the investment in early years of career. The estimates of the effect of academic performance, mainly first-year performance, on probability of graduating and of graduating with top marks, of graduating within the minimum period and of graduating with top marks and within the minimum period suggest that first year inputs are powerful predictors of the ultimate success of the undergraduates. Our production functions also suggest that there is complementarity between the measures of quantity and of quality in the subsamples of graduates, especially when graduation with top marks and with top marks and on time is considered; while there is no evidence of catching up in students performance over their careers. Changes in the rules of progression from on year to the next can considerably reduce the risk of graduating not within the minimum period.

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Table 1: Old system: Baseline estimates - inputs by academic year

	Probability of:			
	Obtaining a degree (N = 35,454)	Graduating with 110 cum laude (N = 34,179)	Graduating within the minimum period (N = 34,179)	Graduating with top marks and on time (N = 34,179)
c_1	0.017***	0.013***	0.124***	0.032***
	(0.001)	(0.001)	(0.002)	(0.001)
s_1	0.001	0.053***	0.012***	0.036***
	(0.001)	(0.001)	(0.001)	(0.001)
R^2	0.137	0.353	0.337	0.271
c_2	0.016***	0.010***	0.112***	0.031***
	(0.001)	(0.001)	(0.001)	(0.001)
s_2	-0.001	0.060***	0.011***	0.038***
	(0.001)	(0.001)	(0.001)	(0.001)
R^2	0.146	0.370	0.406	0.296
c_3	0.014***	0.008***	0.103***	0.029***
	(0.000)	(0.001)	(0.001)	(0.001)
s_3	0.000	0.054***	0.008***	0.030***
	(0.001)	(0.001)	(0.001)	(0.001)
R^2	0.158	0.362	0.488	0.304
c_4	0.013***	0.006***	0.097***	0.025***
	(0.000)	(0.001)	(0.001)	(0.001)
s_4	-0.000	0.054***	0.001	0.027***
	(0.001)	(0.001)	(0.001)	(0.001)
R^2	0.174	0.358	0.597	0.306

Notes: Standard errors are reported in parenthesis. * p-value < .10, ** p-value < .05, *** p-value < .01.

Table 2: Old system: Baseline estimates all inputs together

	Probability of:			
	Obtaining a degree (N = 35,454)	Graduating with 110 cum laude (N = 34,179)	Graduating within the minimum period (N = 34,179)	Graduating with top marks and on time (N = 34,179)
c_1	0.001	-0.009***	0.009***	-0.008***
	(0.001)	(0.002)	(0.002)	(0.001)
s_1	-0.000	0.024***	-0.003***	0.017***
	(0.001)	(0.001)	(0.001)	(0.001)
c_2	0.001	-0.002	0.006***	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
s_2	-0.002***	0.032***	0.000	0.021***
	(0.001)	(0.001)	(0.001)	(0.001)
c_3	0.004***	0.004***	0.026***	0.013***
	(0.001)	(0.001)	(0.001)	(0.001)
s_3	-0.000	0.021***	0.000	0.010***
	(0.001)	(0.001)	(0.001)	(0.001)
c_4	0.011***	0.002**	0.079***	0.016***
	(0.000)	(0.001)	(0.001)	(0.001)
s_4	0.000	0.023***	-0.002*	0.006***
	(0.001)	(0.001)	(0.001)	(0.001)
R^2	0.176	0.410	0.609	0.342

Notes: Standard errors are reported in parenthesis. * p-value < .10, ** p-value < .05, *** p-value < .01.

Table 3: New system: Baseline estimates - inputs by academic year

	Probability of:			
	Obtaining a degree (N = 13,730)	Graduating with 110 cum laude (N = 9,890)	Graduating within the minimum period (N = 9,890)	Graduating with top marks and on time (N = 9,890)
c_1	0.079***	0.010***	0.085***	0.025***
	(0.001)	(0.002)	(0.002)	(0.002)
s_1	0.017***	0.094***	0.024***	0.075***
	(0.002)	(0.002)	(0.002)	(0.002)
R^2	0.480	0.476	0.467	0.440
c_2	0.064***	0.007***	0.077***	0.020***
	(0.001)	(0.001)	(0.001)	(0.001)
s_2	0.004***	0.097***	0.013***	0.077***
	(0.002)	(0.002)	(0.002)	(0.002)
R^2	0.572	0.492	0.536	0.460
c_3	0.039***	0.001	0.054***	0.009***
	(0.000)	(0.001)	(0.001)	(0.001)
s_3	0.005***	0.100***	0.009***	0.079***
	(0.001)	(0.002)	(0.002)	(0.002)
R^2	0.650	0.489	0.707	0.457

Notes: Standard errors are reported in parenthesis. * p-value < .10, ** p-value < .05, *** p-value < .01.

Table 4: New system: Baseline estimates all inputs together

	Probability of:			
	Obtaining a degree	Graduating with 110 cum laude	Graduating within the minimum period	Graduating with top marks and on time
c_1	0.004**	0.001	0.012***	0.006***
	(0.002)	(0.002)	(0.002)	(0.002)
s_1	0.001	0.046***	0.003	0.034***
	(0.002)	(0.003)	(0.002)	(0.002)
c_2	0.014***	0.000	0.010***	0.004***
	(0.001)	(0.002)	(0.001)	(0.002)
s_2	-0.002	0.047***	0.005**	0.038***
	(0.002)	(0.003)	(0.002)	(0.003)
c_3	0.032***	-0.001	0.049***	0.005***
	(0.001)	(0.001)	(0.001)	(0.001)
s_3	0.002	0.051***	-0.001	0.039***
	(0.002)	(0.003)	(0.002)	(0.003)
R^2	0.655	0.542	0.713	0.497

Notes: Standard errors are reported in parenthesis. * p-value < .10, ** p-value < .05, *** p-value < .01.

Table 5: Learning persistence

	Old System		New System	
	Credits	Scores	Credits	Scores
Initial	1.142***	0.037	0.159	0.205
	(0.148)	(0.225)	(0.269)	(0.223)
Intermediate	0.060	-0.365**	-0.687***	0.589**
	(0.128)	(0.149)	(0.097)	(0.261)

Notes: Standard errors are reported in parenthesis. * p-value < .10, ** p-value < .05, *** p-value < .01.

Table 6: Old system: cross sectional trade-off between inputs by academic year

	Probability of:			
	Obtaining a degree (N = 35,454)	Graduating with 110 cum laude (N = 34,179)	Graduating within the minimum period (N = 34,179)	Graduating with top marks and on time (N = 34,179)
c_1	0.027***	-0.433***	0.032**	-0.474***
	(0.006)	(0.011)	(0.014)	(0.010)
s_1	0.003**	-0.022***	-0.004	-0.049***
	(0.001)	(0.002)	(0.003)	(0.002)
$c_1 s_1$	-0.000*	0.017***	0.004***	0.020***
	(0.000)	(0.000)	(0.001)	(0.000)
R^2	0.137	0.385	0.338	0.330
c_2	0.039***	-0.388***	0.118***	-0.435***
	(0.004)	(0.008)	(0.010)	(0.007)
s_2	0.003***	-0.010***	0.012***	-0.044***
	(0.001)	(0.002)	(0.002)	(0.001)
$c_2 s_2$	-0.001***	0.015***	-0.000	0.018***
	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.147	0.417	0.406	0.388
c_3	0.051***	-0.329***	0.123***	-0.382***
	(0.003)	(0.006)	(0.007)	(0.005)
s_3	0.006***	-0.004***	0.012***	-0.041***
	(0.001)	(0.001)	(0.002)	(0.001)
$c_3 s_3$	-0.001***	0.013***	-0.001***	0.016***
	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.161	0.414	0.488	0.415
c_4	0.046***	-0.258***	0.095***	-0.319***
	(0.003)	(0.005)	(0.006)	(0.004)
s_4	0.006***	-0.001	0.001	-0.045***
	(0.001)	(0.002)	(0.002)	(0.001)
$c_4 s_4$	-0.001***	0.010***	0.000	0.013***
	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.177	0.403	0.597	0.415

Notes: Standard errors are reported in parenthesis. * p-value < .10, ** p-value < .05, *** p-value < .01.

Table 7: Old system: cross sectional trade-off between inputs (all inputs together)

	Probability of:			
	Obtaining a degree (N = 35,454)	Graduating with 110 cum laude (N = 34,179)	Graduating within the minimum period (N = 34,179)	Graduating with top marks and on time (N = 34,179)
c_1	-0.003	-0.152***	0.006	-0.125***
	(0.007)	(0.012)	(0.013)	(0.010)
s_1	-0.001	-0.005**	-0.004*	-0.009***
	(0.001)	(0.002)	(0.002)	(0.002)
$c_1 s_1$	0.000	0.006***	0.000	0.005***
	(0.000)	(0.000)	(0.000)	(0.000)
c_2	-0.004	-0.196***	0.014	-0.189***
	(0.005)	(0.010)	(0.010)	(0.008)
s_2	-0.002**	-0.006***	0.002	-0.018***
	(0.001)	(0.002)	(0.002)	(0.002)
$c_2 s_2$	0.000	0.007***	-0.000	0.007***
	(0.000)	(0.000)	(0.000)	(0.000)
c_3	0.022***	-0.131***	0.016*	-0.172***
	(0.005)	(0.008)	(0.009)	(0.007)
s_3	0.003***	-0.000	-0.002	-0.020***
	(0.001)	(0.002)	(0.002)	(0.001)
$c_3 s_3$	-0.001***	0.005***	0.000	0.007***
	(0.000)	(0.000)	(0.000)	(0.000)
c_4	0.037***	-0.082***	0.085***	-0.142***
	(0.004)	(0.006)	(0.007)	(0.005)
s_4	0.005***	0.008***	-0.001	-0.023***
	(0.001)	(0.002)	(0.002)	(0.001)
$c_4 s_4$	-0.001***	0.003***	-0.000	0.006***
	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.179	0.472	0.609	0.484

Notes: Standard errors are reported in parenthesis. * p-value < .10, ** p-value < .05, *** p-value < .01.

Table 8: New system: cross sectional trade-off between inputs

	Probability of:			
	Obtaining a degree (N = 13,730)	Graduating with 110 cum laude (N = 9,890)	Graduating within the minimum period (N = 9,890)	Graduating with top marks and on time (N = 9,890)
c_1	0.130***	-0.312***	0.112***	-0.402***
	(0.011)	(0.015)	(0.017)	(0.014)
s_1	0.030***	-0.014**	0.033***	-0.068***
	(0.003)	(0.005)	(0.006)	(0.005)
$c_1 s_1$	-0.002***	0.012***	-0.001	0.016***
	(0.000)	(0.001)	(0.001)	(0.001)
R^2	0.481	0.503	0.468	0.493
c_2	0.132***	-0.256***	0.131***	-0.326***
	(0.006)	(0.010)	(0.011)	(0.010)
s_2	0.024***	-0.006	0.035***	-0.059***
	(0.002)	(0.005)	(0.005)	(0.004)
$c_2 s_2$	-0.003***	0.010***	-0.002***	0.013***
	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.577	0.529	0.538	0.532
c_3	0.077***	-0.112***	0.052***	-0.180***
	(0.003)	(0.006)	(0.005)	(0.005)
s_3	0.022***	0.015***	0.007*	-0.063***
	(0.002)	(0.005)	(0.004)	(0.004)
$c_3 s_3$	-0.001***	0.004***	0.000	0.007***
	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.654	0.512	0.707	0.528

Notes: Standard errors are reported in parenthesis. * p-value < .10, ** p-value < .05, *** p-value < .01.

Table 9: New system: cross sectional trade-off between inputs (all inputs together)

	Probability of:			
	Obtaining a degree (N = 13,730)	Graduating with 110 cum laude (N = 9,890)	Graduating within the minimum period (N = 9,890)	Graduating with top marks and on time (N = 9,890)
c_1	0.001	-0.118***	-0.007	-0.166***
	(0.011)	(0.016)	(0.015)	(0.015)
s_1	0.001	0.005	-0.004	-0.023***
	(0.003)	(0.006)	(0.005)	(0.005)
$c_1 s_1$	0.000	0.004***	0.001	0.006***
	(0.000)	(0.001)	(0.001)	(0.001)
s_2	0.007	-0.166***	0.027**	-0.177***
	(0.008)	(0.012)	(0.011)	(0.012)
s_2	-0.004	-0.017***	0.011**	-0.033***
	(0.003)	(0.005)	(0.005)	(0.005)
$c_2 s_2$	0.000	0.006***	-0.001	0.007***
	(0.000)	(0.000)	(0.000)	(0.000)
c_3	0.077***	-0.039***	0.051***	-0.098***
	(0.004)	(0.006)	(0.006)	(0.006)
s_3	0.022***	0.019***	0.001	-0.042***
	(0.003)	(0.005)	(0.005)	(0.005)
$c_3 s_3$	-0.002***	0.002***	-0.000	0.004***
	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.660	0.578	0.713	0.589

Notes: Standard errors are reported in parenthesis. * p-value < .10, ** p-value < .05, *** p-value < .01.