

## INCOME-BASED AFFIRMATIVE ACTION IN COLLEGE ADMISSIONS\*

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We study whether college admissions should implement quotas for lower-income applicants. We develop an overlapping-generation model and calibrate it to data from Brazil, where such a policy is widely implemented. In our model, parents choose how much to invest in their child's education, thereby increasing both human capital and likelihood of college admission. We find that, in the long run, the optimal income-based affirmative action increases welfare and aggregate output. It improves the pool of admitted students, but distorts pre-college educational investments. The welfare-maximising policy benefits lower- to middle-income applicants with income-based quotas, while higher-income applicants face fiercer competition in college admissions. The optimal policy reduces intergenerational persistence of earnings by 5.7% and makes nearly 80% of households better off.

Affirmative action in college admissions is an important and controversial policy intended to promote educational opportunities for socially disadvantaged groups. Although the goals of the policy are clear, its impacts on individual decisions may have ambiguous effects on economic performance. For instance, the ways in which affirmative action shapes individual decisions regarding educational investments are subject to much debate.<sup>1</sup> On the one hand, it may level the playing field and incentivise beneficiaries to make additional investments in education. On the other hand, it could lower admission standards and disincentivise investments in education. Besides affecting investment decisions about education, affirmative action directly impacts the admission process by providing the admission committee with the applicants' social background information. With these data in hand, universities can adjust their admission standards for applicants from disadvantaged backgrounds in order to admit the most qualified candidates within that social group. This adjustment could lead to efficiency gains in college admissions by selecting applicants with higher returns to education.

In this paper, we study income-based affirmative action policies in college admissions in Brazil, where they are implemented on a large scale. We start by empirically showing that low-income

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<sup>1</sup> See Coate and Loury (1993), Moro and Norman (2003) and Fang and Norman (2006).

students outperform their higher-income peers in college when they have the same college-admission score. Our empirical findings suggest that efficiency gains can be obtained if college admissions favour low-income applicants because such a policy would substitute low-income students for high-income students with similar admission scores. Then, we investigate whether the efficiency gains generated by income-based affirmative action policies are economically meaningful and outweigh unintended distortions in educational investments. To that end, we build an overlapping-generation model and calibrate it to Brazilian data to study the long-run implications of income-based affirmative action for investment decisions, efficiency and welfare gains.

Our main result is that income-based affirmative action is an effective policy to promote educational opportunities and to improve welfare. Optimally designed income-based criteria for college admissions, not only improves welfare, but also increases aggregate output. Furthermore, such a policy would make nearly 80% of households better off and would reduce intergenerational persistence of earnings by 5.7%.

We enrich a standard overlapping-generation model with a detailed college admissions process; we numerically solve for the stationary equilibrium and we calibrate the model to the data. We model college admissions akin to the Brazilian market, providing a realistic framework consistent with our data.

College admissions in Brazil is a large and competitive market, with a national exam determining applicants' admission—an ideal setting to study and model income-based affirmative action in college admissions. In addition, we would like to highlight two aspects specific to the Brazilian market. First, in Brazil, the best college education is provided by public, tuition-free colleges.<sup>2</sup> Second, pre-college education can be either public or private, with big differences in quality. While nearly 90% of students attend a public high school, the fraction of these students admitted to a public college is very small. For instance, in the best university in Brazil (University of São Paulo), only 23% of the admitted students come from public high schools. Although these facts are specific to the Brazilian market, we show in robustness exercises that our findings are not driven by these features.

Our model encompasses four distinct generations: young child, old child, young parent and old parent. A child is born with *innate ability*, which is correlated with her parents' innate ability and interpreted as the ability inherited from the parents. Young children receive investments in early education from their parents. As a combination of educational investment decisions and innate ability, each young child develops college admission skill and human capital. The distinction between the two is key in our paper. On the one hand, *college admission skill* determines the likelihood of college admission, while, on the other hand, *human capital* determines future labour income. As a result of our calibration, educational investments have a higher marginal impact on admission skill than on human capital. Therefore, investment in early education affects the likelihood of college admission more than it affects the child's future labour earnings. To further improve future labour earnings, older children can attend college to gain a human capital boost and to access the labour market for skilled individuals.

The distinction between admission skill and human capital is the main source of inefficiency in our model. Future labour earnings and the returns to college education are based on human

<sup>2</sup> All top-10 and 18 of the top-20 universities are public in Brazil, using the ranking from the main Brazilian newspaper Folha de São Paulo. Assunção and Ferman (2013) also made a case for high-quality higher education being offered mainly through public institutions in Brazil. These institutions are tuition-free by law—article 206, paragraph 4, of the Brazilian Constitution states that a fundamental principle of education is that it will be tuition-free in all public schooling places.

capital. However, even if higher-education institutions aim to admit applicants with the highest returns to college, absent specific income-based admission policies, they are constrained to make admission decisions based on a noisy measure of admission skill (for instance, any kind of standardised tests). In our model, policies targeting lower- to middle-income students can have a positive impact on aggregate output because they can make college admissions more efficient. In equilibrium, lower-income students lack the necessary resources to invest in a successful college application, and are therefore less likely to attend college. From an efficiency standpoint, applicants with the highest returns to education should go to college, regardless of their socioeconomic characteristics. However, high-income applicants can heavily invest in early education to build a competitive admission profile. Given the limited number of college spots, high-income applicants crowd out lower-income ones. Income-based affirmative action may tackle this source of inefficiency, as it alters college demographics by admitting more lower- and middle-income applicants with higher returns to education and fewer high-income ones with lower returns to education.<sup>3</sup>

In our quantitative exercise, an income-based affirmative action policy specifies a number of college spots to be allocated to each income quintile. We numerically solve for two distinct optimal policies: one that maximises efficiency (i.e., aggregate output) and one that maximises welfare.

The welfare-maximising policy significantly changes the composition of admitted students. It reduces the number of admitted students from the top quintile by 25% and increases the number of admitted students from the other income groups. Specifically, the optimal policy implies a three-fold increase in the number of admitted students from the bottom quintile of the income distribution. Such a policy makes 80% of households better off. Households in the first four quintiles are, on average, willing to forgo 0.57% of their consumption in every period and in every state of the world to have the policy implemented. Households in the top income quintile, however, are worse off, on average, and would have to be compensated by 1.9% of their consumption. In the aggregate, households are better off and willing to forgo 0.07% of their consumption to have the policy implemented. Also, the optimal policy promotes educational opportunities by reducing earnings persistence by 5.7%.

The efficiency-maximising policy is qualitatively similar to the welfare-maximising one as it favours applicants in the bottom four quintiles. However, it reallocates fewer college spots to quotas. Accordingly, its effects on earnings persistence and households' willingness to pay are attenuated. It reduces intergenerational persistence of earnings by 2.1%, and households are willing to forgo 0.02% of their consumption to have the efficiency-maximising policy implemented.

Our paper's main contribution is to the literature on intergenerational persistence of earnings, focusing on the effects of income-based affirmative action. Our model builds on Restuccia and Urrutia (2004). In their model, however, applicants are automatically admitted to college, while we model college admissions in detail to evaluate the economic implications of affirmative action. Restuccia and Urrutia (2004) showed that about half of the observed intergenerational earnings persistence is due to investments in early education. In line with this finding, Holter (2015) and Blankenau and Youderian (2015) found that investments in early and college education also

<sup>3</sup> Admission grades are the only criteria for college admission in Brazil. In other countries, there might be mechanisms other than educational investments operating to dissociate human capital from admission probability, such as parents using their social status and professional networks to increase the likelihood of their children being admitted to college. Extending our framework to include those mechanisms would not alter the qualitative implication that income-based affirmative action improves efficiency.

reduce persistence of earnings. Our paper contributes to this literature by showing that an optimal income-based affirmative action policy in college admissions reduces persistence of earnings.

Our paper is also closely related to the literature that analyses incentive implications of affirmative action in college admissions.<sup>4</sup> Assunção and Ferman (2013) found that affirmative action disincentivises effort for the preferentially treated students in the short run.<sup>5</sup> Adding to their results, our paper shows that, in the long run, preferentially treated students do not decrease their educational investments.

There are recent works that empirically evaluate the effects of affirmative action policies in Brazil. Vieira and Arends-Kuenning (2019) used the staggered adoption of policies across universities, and found that the enrolment effects were concentrated in the most competitive programs. Estevan *et al.* (2018) studied the affirmative action policy adopted by a large Brazilian university, and found little evidence of behavioural reactions regarding examination preparation effort. Mello (2022) studied the interaction between the National Law of Quotas and a policy that centralised applications in a nationwide online platform. We contribute by providing a complementary quantitative framework to interpret the long-term effects of income-based affirmative action policies.

Our work also relates to recent literature on high-stake exams and education economics (e.g., Ebenstein *et al.*, 2016; Arenas *et al.*, 2021). We contribute to this area of research by quantifying the relationship between income and college performance controlling for admission scores. Relying on the uniqueness of our data, we merged data on college admission exams and college performance exams at the student level. The majority of college students in the country take these two exams. The unconditional relation between income and college performance is strong and positive, as lower-income students significantly underperform in college. Our data allow us to add classroom fixed effects, and when we do that, the sign of this relation is still negative. Using data on college admission scores, we can compare students with the same admission score and in the same classroom. After controlling for scores of college entrance exams, we find that the relation between income and college performance flips, with lower-income students outperforming high-income ones.

Finally, our paper is related to the literature that studies the effects of banning affirmative action in college admissions (Chan and Eyster, 2003; Arcidiacono, 2005; Epple *et al.*, 2008; Fryer and Loury, 2013). Our contribution to these studies is to endogenise educational investment decisions in a general equilibrium setting; we find income-based affirmative action to be a sound policy to reduce persistence of earnings and improve welfare.

The rest of the paper is organised as follows. Section 1 presents empirical evidence supporting our economic mechanism. Section 2 presents our benchmark model. Section 3 shows our calibration procedure. Section 4 reports our policy evaluation results, along with robustness exercises and the analysis of the affirmative action policy being implemented in Brazil. Finally, Section 5 presents our concluding remarks.

<sup>4</sup> See Hickman (2010), Krishna and Robles (2012), Assunção and Ferman (2013), Hickman (2013), Krishna and Tarasov (2013), Kapor (2015) and Veloso (2016).

<sup>5</sup> Our paper also relates to the literature on the effects of government policies on education incentives. In addition to Assunção and Ferman (2013), Peruffo and Ferreira (2017) studied the long-term effects of conditional cash transfer programs on schooling decisions in Brazil.

## 1. Empirical Motivation

In this section, we present empirical evidence for the main mechanism in our model: the mismatch between students' expected human capital and their likelihood of college admission. We show that low-income college students outperform their higher-income peers after controlling for admission scores, classroom fixed effects and demographic characteristics. This finding suggests potential efficiency gains from income-based affirmative action in college admissions, as these policies substitute relatively lower-income students for higher-income students with similar admission scores.

We use microdata of two eminent exams in Brazil. First, we use data from the national college admission exam, namely ENEM ('*Exame Nacional do Ensino Médio*'), which is a national standardised exam developed by the Ministry of Education and offered yearly. The ENEM exam was first introduced in 1998 with the objective of measuring the performance of high school graduates. Since 2009, ENEM has been used as a college admission exam. Currently, ENEM is used as the only admission exam for the majority of federal universities and several other higher-education institutions, including private universities.<sup>6</sup> It consists of 180 multiple-choice questions in four areas—mathematics, humanities, sciences and languages—as well as a written essay. In 2015, more than 8.7 million students took the ENEM exam. We interpret ENEM scores as college admission scores.

The second exam, ENADE ('*Exame Nacional de Desempenho de Estudantes*'), is a national exam developed by the Ministry of Education to evaluate higher education programs every year in Brazil. The exam is given to students who have completed at least 80% of their degree, and contains general questions, as well as questions specifically related to the students' majors. A total of 368,000 students took this exam in 2021.<sup>7</sup> We interpret ENADE scores as college performance.

We use microdata (Ministério da Educação, 2021a,b) on students taking ENADE from 2014 to 2019.<sup>8</sup> We rely on admission scores as a proxy for a student's likelihood of admission. Our sample is restricted to students admitted to college in 2012 or before, as the National Law of Quotas was approved that year. Including affirmative action beneficiaries in our sample would complicate the interpretation of ENEM scores as admission probabilities.

Our regression specification is given by

$$\text{ENADE}_i = \sum_{k=1}^n \beta_k \mathbb{I}\{\text{Income category}_i = k\} + \alpha \text{ENEM}_i + \gamma \mathbf{X}_i + \mu_{c(i)} + \varepsilon_i, \quad (1)$$

where  $i$  denotes an undergraduate student,  $c$  denotes classroom<sup>9</sup> and  $\text{ENADE}_i$  denotes the ENADE score of student  $i$ ;  $\text{Income category}_i$  is a categorical variable with six levels, indicating the student's family income in the year when the ENADE was taken;<sup>10</sup>  $\mathbf{X}$  is a vector of baseline control variables (age, race and gender);  $\mu_{c(i)}$  denotes student  $i$ 's classroom fixed effect and  $\varepsilon$  is an error term. The parameter of interest,  $\beta_k$ , expresses the expected ENADE score difference

<sup>6</sup> High school grades are not used as a criterion for public college admission in Brazil.

<sup>7</sup> One reason why the number of ENEM takers is considerably higher than the number of ENADE takers in a given year is that each discipline is evaluated in the ENADE exam at a triennial frequency. See Bacalhau *et al.* (2019) for more details on the ENADE exam.

<sup>8</sup> See Online Appendix A for details on the dataset construction.

<sup>9</sup> A classroom is a group of students in the same higher-education institution, major, ENADE year and class cohort.

<sup>10</sup> We do not have information on family income in the year when the student started their undergraduate studies.

Table 1. College Performance by Income Levels.

	(1)	(2)	(3)
Less than 1.5 min. wages, < p30, N = 71, 210	−9.085*** (0.090)	−3.274*** (0.095)	−0.280** (0.086)
From 1.5 to 3 min. wages, [p30, p60], N = 118, 416	−7.178*** (0.082)	−1.737*** (0.086)	0.364*** (0.078)
From 3 to 4.5 min. wages, [p60, p75], N = 86, 705	−6.040*** (0.085)	−1.064*** (0.086)	0.461*** (0.078)
From 4.5 to 6 min. wages, [p75, p85], N = 55, 701	−4.621*** (0.092)	−0.768*** (0.091)	0.478*** (0.082)
From 6 to 10 min. wages, [p85, p95], N = 55, 329	−3.018*** (0.093)	−0.297*** (0.089)	0.418*** (0.081)
More than 10 min. wages, > p95, N = 46, 310	—	—	—
Base controls	Yes	Yes	Yes
Classroom fixed effects	No	Yes	Yes
ENEM (admission score)	No	No	Yes
No. of observations	433,671	433,671	433,671

Notes: This table shows the regression estimates of parameters  $\beta_k$  in (1). For each earnings category, we report the corresponding percentile interval in the family earnings distribution (according to PNAD 2015), and the number of observations used in the regressions. Dependent variable: ENADE score (last-year undergraduate exam). More than 10 minimum wages is the base category. Base controls are age, race and gender. A classroom is a group of students in the same higher-education institution, major, ENADE year and class cohort. Mean (SD) of the dependent variable: 46.81 (14.52). Robust standard errors are reported in parentheses. \*\*\*  $p < 0.001$ .

between a student with family income in category  $k$  and a comparable student in the same classroom with family income in the baseline category (more than 10 minimum wages).

Table 1 shows the regression coefficient estimates for three specifications. In the first column, we control for age, race and gender (base controls), but do not include classroom fixed effects and ENEM scores as a control variable. These estimates show that, after controlling for demographic characteristics, higher-income students perform better than low-income students. To interpret the magnitude of this effect, we note that college students with family incomes lower than a 1.5 minimum wage (which corresponds to the 30th percentile of the family earnings distribution) score, on average, nine points lower on ENADE than students whose family income is higher than ten minimum wages. This corresponds to an expected score of  $9.085/14.52 = 0.64$  SDs lower.

In the first column, college performance is a strictly decreasing function of the family’s income. One reason that high-income students obtain better scores than low-income students is that they self-select into different degrees and/or higher-education institutions, potentially with more competitive admissions and superior quality, which would translate into higher ENADE scores in the graduation year.

To control for this mechanism, we add classroom fixed effects in the second column. The estimates are now markedly closer to zero, meaning that selection into different institutions and degrees explains a large amount of the college performance inequality between low- and high-income students. Comparing students in the same classroom, those with a family income lower than 1.5 minimum wages are expected to have ENADE scores 3.27 points lower than students in the top income category. Note that the estimates in this column are still an increasing function of students’ income categories. Even though within-classroom comparisons are considerably fine and granular, there can still be a considerable amount of heterogeneity in admission probabilities across students in the same classroom. We now add admission scores as a control variable to account for this mechanism.



Table 2. *College Performance by Income Levels (Students Who Do Not Work).*

	(1)	(2)	(3)
Less than 1.5 min. wages, < $p_{30}$ , $N = 39,385$	−10.418*** (0.123)	−2.934*** (0.140)	−0.146 (0.127)
From 1.5 to 3 min. wages, [ $p_{30}$ , $p_{60}$ ], $N = 49,374$	−7.899*** (0.116)	−1.555*** (0.128)	0.462*** (0.116)
From 3 to 4.5 min. wages, [ $p_{60}$ , $p_{75}$ ], $N = 32,948$	−6.455*** (0.123)	−1.138*** (0.130)	0.388** (0.119)
From 4.5 to 6 min. wages, [ $p_{75}$ , $p_{85}$ ], $N = 22,770$	−4.778*** (0.134)	−1.004*** (0.136)	0.221 (0.124)
From 6 to 10 min. wages, [ $p_{85}$ , $p_{95}$ ], $N = 24,594$	−3.107*** (0.132)	−0.584*** (0.131)	0.125 (0.119)
More than 10 min. wages, > $p_{95}$ , $N = 24,614$	—	—	—
Base controls	Yes	Yes	Yes
Classroom fixed effects	No	Yes	Yes
ENEM (admission score)	No	No	Yes
No. of observations	193,685	193,685	193,685

Notes: This table shows the regression estimates of parameters  $\beta_k$  in (1) for the subsample of students who do not work. For each earnings category, we report the corresponding percentile interval in the family earnings distribution (according to PNAD (2015)), and the number of observations used in the regressions. Dependent variable: ENADE score (last-year undergraduate exam). More than 10 minimum wages is the base category. Base controls are age, race and gender. A classroom is a group of students in the same higher-education institution, major, ENADE year and class cohort. Mean (SD) of the dependent variable: 48.75 (14.80). Robust standard errors are reported in parentheses. \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ .

The last column shows the expected relative college performance of students with the same demographic characteristics, who study in the same classroom and who obtained similar admission grades, conditional on the family’s income category. Note that the estimates are no longer a monotonic function of income. Instead, ENADE scores now follow an inverse U-shaped curve as a function of income. Students in the bottom income category still perform significantly worse than higher-income students, but performance (relative to the top income category) becomes positive and increases as we move to higher incomes, reaching a peak in the fourth category (75% to 85 % of the income distribution).

Students with family incomes between percentiles 30 and 60 outperform students with family incomes higher than percentile 95 by 0.364 points, on average. Families who live on 1.5 to 3 minimum wages per month in Brazil face highly unfavourable economic and social conditions.<sup>11</sup> Our results indicate that a student coming from this background—who is admitted with the same admission score to the same institution and degree of someone in the top income category—has positive unobserved characteristics that allow her to attain a higher college return.

One potential reason that students in the bottom income group perform worse is that they might face adverse conditions, such as having to work to complement family earnings or being required to help with domestic tasks for long hours. To shed some light on this possibility, we run the same regressions restricting the sample to students who do not work.

Table 2 shows the estimates for this subsample. The first and second columns present the same patterns as in the previous table. The third column, however, shows a different pattern: the difference between the performances of students in the bottom and top income categories are statistically insignificant. Furthermore, the second income category is the one with the highest expected performance. Compared to the regression estimates in Table 1, the regressions for

<sup>11</sup> According to the World Bank, 20% of the Brazilian population lived in poverty (defined as living on less than \$5.50 per day in 2011 PPP terms) in 2016.

the sample of students who do not work are stronger in suggesting that low-income students outperform higher-income students who have similar admission likelihoods.<sup>12</sup>

Overall, the empirical evidence shows the existence of a mismatch between students' expected human capital (measured by ENADE scores) and their likelihood of college admission (measured by ENEM scores). Furthermore, this mismatch is systematically related to income differences, with high-income students having lower human capital returns than lower-income students who have similar admission probabilities.

Our results are consistent with a recent literature on high-stake exams (e.g., Ebenstein *et al.*, 2016; Arenas *et al.*, 2021), questioning the validity of exam scores as an unbiased measure of students' human capital. In Brazil, there are firms and organisations that specialise in coaching students for the national college admission exam (ENEM). For instance, these institutions offer private lessons and even large-scale courses to review past exams and go over practice tests. Also, several high school curricula have been adjusted to improve students' performance in college admission exams. This setting arguably amplifies the imbalance between scholastic knowledge and future labour market outcomes, which is what our empirical findings suggest.

In the next section, we present an overlapping-generation model designed to speak to our empirical findings. The fundamental element of the model is that investments in pre-college education affect, simultaneously, the likelihood of college admission and the expected human capital. However, investments affect the first more than they do the latter. As higher-income families invest more in pre-college education, higher-income applicants have a higher chance of being admitted. However, controlling for the admission probability, lower-income applicants have higher expected human capital.

## 2. Model

In this section, we present and discuss our theoretical model. Later, in Sections 3 and 4, we use our model at calibrated parameters to provide a quantitative assessment of the long-run implications of income-based affirmative action policies.

Although our framework is general, some of its features are designed to represent the admissions process in Brazil. In order to let our model speak to the data, we have tailored it to the Brazilian college admissions process. In particular, the main differences between our calibrated model of college admissions and the US market are (i) our model features public college with the tuition cost being borne entirely by tax payers, (ii) public school is less efficient than private school and (iii) the number of public college spots is fixed. In Section 4.4, we show that the substantive message of our results holds even if we relax these model assumptions, specific to the Brazilian market.

### 2.1. Set-Up

We develop a model of four overlapping generations based on Restuccia and Urrutia (2004). Each agent lives four periods, the first two as a child (young and old child) and the last two as an

<sup>12</sup> One limitation of our analysis is related to dropouts. Low-income students may face a higher probability of dropping out compared to their high-income peers, which could imply that our sample is systematically biased. To mitigate concerns related to this, we run the regressions using only students with admission scores higher than the median score in the classroom and find that the estimates remain qualitatively unchanged. This subsample is supposedly less biased because low-income students with high admission scores might have higher returns from college completion and therefore lower dropout probabilities.



adult (young and old parent). Each generation is a continuum of measure one, and a family unit comprises one parent and one child. At each point in time, there are two different family units: one with a young child and a young parent, and another with an old child and an old parent. Each period in the model is interpreted as a 16- to 18-year period. There is no population growth. Agents are heterogeneous in their innate ability levels; a young child is born with an innate ability level that depends on her parents innate ability, following an autoregressive process. Decisions are made at the family level, assuming no intra-household frictions. The family makes consumption and educational investment choices, maximising the family's welfare, which is measured by discounted lifetime utility of the entire dynasty. Furthermore, households have access to a perfect credit market within-period, but no credit market across periods.

### 2.1.1. *Young parent*

A young parent is identified by her human capital ( $h_y$ ), her higher-education degree ( $d_c = 1$  for college degree and 0 otherwise) and her young child's innate ability ( $\pi$ ). A young parent chooses how much to consume ( $c_y$ ), how much to invest in the pre-college education of her child ( $e$ ) as well as the type of school her child attends ( $s = 1$  for public and 0 for private school). The young parent maximises utility from current consumption plus a discounted continuation value, given by the value function when the young parent becomes an old parent. For an old parent, the household is identified by her human capital ( $h_o$ ), her higher-education degree ( $d_c$ ), her old child's innate ability ( $\pi$ ), and the educational choices previously made when the household was young ( $e$  and  $s$ ).

Formally, the young parent's optimisation problem is given by

$$V_y(h_y, d_c, \pi) = \max_{c_y \geq 0, e \geq 0, s \in \{1, 0\}} u(c_y) + \beta V_o(h_o, d_c, \pi, e, s) \quad (2)$$

subject to

$$c_y + e = (1 - \tau)[d_c w_c + (1 - d_c)w_n]h_y, \quad (3)$$

$$h_o = \xi h_y. \quad (4)$$

The function  $V_y(\cdot)$  is the value function of the young parent,  $u(\cdot)$  is the utility function of the family and  $\beta$  is a discounting parameter. Next, we discuss each of the constraints and respective variables in detail.

The young parent's budget constraint is given by (3). The parent inelastically supplies human capital services in the labour market. There are two distinct labour markets in the economy, one for those with a college degree—i.e., skilled workers—and another for those without a higher education—i.e., unskilled workers. With a college degree ( $d_c = 1$ ), the young parent's labour income is equal to  $w_c h_y$ , but without a college degree ( $d_c = 0$ ), her labour income is given by  $w_n h_y$ , where  $w_c$  and  $w_n$  are wage rates determined in equilibrium. The government proportionally taxes labour income at rate  $\tau$ , and the young parent decides how to allocate her after-tax labour income between consumption ( $c_y$ ) and investment in her young child's early education ( $e$ ). We assume no credit market between periods: all the young parents' earnings are either consumed or invested in early education. However, since each period represents 16 to 18 years, the budget constraint in (3) implies a perfect credit market within-period. In addition to choosing how much to invest in early education and how much to consume, a young parent also decides whether her child attends public ( $s = 1$ ) or private school ( $s = 0$ ).

Finally, the human capital of the young parent increases linearly when she becomes an old parent. This captures a life-cycle profile of earnings, and the human capital of a parent evolves according to (4), where parameter  $\xi \geq 1$  is a life-cycle parameter and  $h_o$  is the human capital of the young parent in the subsequent period.<sup>13</sup>

### 2.1.2. Human capital formation

A key aspect of human capital formation captured in our framework is that it depends on both early educational investment and innate ability. In addition, a college degree further increases human capital.

The early educational investment ( $e$ ) is transformed into an effective early educational investment ( $\hat{e}$ ), with a technology that depends on the type of school attended ( $s$ ), according to

$$\hat{e} = s\alpha(e + g) + (1 - s)e. \quad (5)$$

The parameter  $\alpha \geq 0$  captures the quality difference between public and private school, while the variable  $g \geq 0$  represents a government transfer that does not vary across public school students. According to (5), if the child attends public school ( $s = 1$ ), private and public investments in education are perfect substitutes; however, the return to investments in education depend on the type of school attended. As a result of our calibration,  $\alpha$  is less than one. Hence, if a young child goes to public school, she receives a government subsidy  $g$ , but early educational investments face lower marginal returns. In contrast, a private school ( $s = 0$ ) has a higher marginal return to educational investments, but no government subsidy.

Our model has two types of colleges, private and public, with different qualities and costs of enrolment. Specifically, human capital formation is described by

$$h'_y = \begin{cases} \pi \hat{e}^\psi & \text{if no college,} \\ \bar{p}\pi \hat{e}^\psi & \text{if public college,} \\ p\pi \hat{e}^\psi & \text{if private college,} \end{cases} \quad (6)$$

where  $h'_y$  is the human capital of the old child. The parameter  $\bar{p}$  ( $p$ ) measures the human capital gain from attending a public (private) college, and  $\psi \in [0, 1]$  represents the elasticity of human capital in adulthood with respect to investments in pre-college education. This human capital formation process is consistent with Ben-Porath (1967), Becker and Tomes (1979) and Restuccia and Urrutia (2004). Our specification for human capital formation implies that returns to college education increase with early educational investments and innate ability. Intuitively, both pre-college educational investments and innate ability help students to learn from college courses, thus allowing them to achieve a higher level of human capital after college. Finally, our calibration indicates that public colleges increase human capital more than private ones do.<sup>14</sup>

### 2.1.3. Old parent

Similar to a young parent, an old parent allocates her family labour income between consumption and investment in her child's college education to maximise the discounted lifetime utility of the

<sup>13</sup> We assume that parents perfectly observe their children's innate abilities. A different approach would be that a parent does not observe their child's ability and forms expectations on it based on their own innate ability. Such an imperfect information aspect could make additional room for government policies to improve economic allocations if parents are not better informed than the government. Therefore, adopting this alternative modelling could reinforce our findings that affirmative action policies can generate relevant gains for society.

<sup>14</sup> The difference in quality between public and private universities is consistent with the Brazilian market.

family. The value function of an old parent is given by

$$V_o(h_o, d_c, \pi, e, s) = \max\{V_o^{\text{not apply}}(h_o, d_c, \pi, e, s), V_o^{\text{apply}}(h_o, d_c, \pi, e, s)\}, \quad (7)$$

where  $V_o^{\text{not apply}}(\cdot)$  is the value of not applying and  $V_o^{\text{apply}}(\cdot)$  is the expected value of applying to college.

If a child does not apply to college, then she joins the labour market without a college degree and inelastically supplies human capital services. Thus, the value of not applying is

$$V_o^{\text{not apply}}(h_o, d_c, \pi, e, s) = \max_{c_o \geq 0} u(c_o) + \beta \mathbb{E}_{\pi'}[V_y(h'_y, d'_c = 0, \pi')|\pi]$$

subject to

$$c_o = (1 - \tau)[(d_c w_c + (1 - d_c)w_n)h_o + w_n h'_y],$$

$$\hat{e} = s\alpha(e + g) + (1 - s)e,$$

$$h'_y = \pi \hat{e}^\psi,$$

where the first constraint is the budget constraint, the second is the effective education investment function, and the third specifies the human capital of the old child without a college degree according to (6). The budget constraint includes the after-tax income from all family members combined. The continuation value of the old parent is the expected value function of her own child as a young parent in the next period. This expectation is over the innate ability distribution of the old parent's grandchild, which follows an autoregressive process:

$$\log(\pi') = \rho \log(\pi) + \sigma_\pi \varepsilon_\pi.$$

The random variable  $\varepsilon_\pi$  is an independent and identically distributed (i.i.d.) standard normal. Parameter  $\rho$  captures the persistence of innate ability between distinct generations and  $\sigma_\pi$  captures the noisiness of this process.

The expected value of applying to college is a combination of the value if the old child is admitted to public college,  $V_o^{\text{admitted}}$ , and the value if she is not admitted,  $V_o^{\text{not admitted}}$ :

$$V_o^{\text{apply}}(h_o, d_c, \pi, e, s) = q(h_o, d_c, \pi, e, s) V_o^{\text{admitted}}(h_o, d_c, \pi, e, s) \\ + [1 - q(h_o, d_c, \pi, e, s)] V_o^{\text{not admitted}}(h_o, d_c, \pi, e, s).$$

If a child applies to college, the outcome of her application is random. The probability of being admitted to public college is given by  $q(h_o, d_c, \pi, e, s)$ , and it is an equilibrium object that we discuss in depth in the next subsection, along with a description of the college admission market. An applicant's probability of college admission depends primarily on her college admission skill, which is a function of  $\pi$  and  $\hat{e}$ , and college applicants with higher admission skills are more likely to be admitted. In addition, the likelihood of college admission might also depend on the type of high school attended ( $s$ ) and even on the parent's income ( $wh_o$ ), according to the affirmative action implemented.

If an old child's college application is successful, she may go to either a private or a public college, which differ in costs and human capital gains. For this reason, if an old child is admitted to college, the old parent's value function is described as

$$V_o^{\text{admitted}}(h_o, d_c, \pi, e, s) = \max_{c_o \geq 0, r \in \{0,1\}} u(c_o) + \beta \mathbb{E}_{\pi'}[V_y(h'_y, d'_c = 1, \pi')|\pi]$$

subject to

$$\begin{aligned} c_o + r\alpha\eta &= (1 - \tau)[(d_c w_c + (1 - d_c)w_n)h_o + w_c h'_y(1 - \eta - b)], \\ \hat{e} &= s\alpha(e + g) + (1 - s)e, \\ h'_y &= (1 - r)\bar{p}\pi\hat{e}^\psi + r\underline{p}\pi\hat{e}^\psi, \end{aligned} \quad (8)$$

where the first constraint specifies the budget constraint, the second is the effective education investment function and the third defines the human capital of the old child, according to (6). The variable  $c_o$  is the consumption of the old family and  $r$  is the decision to attend private college (i.e.,  $r = 1$ ) or public college (i.e.,  $r = 0$ ). Parameter  $\eta$  represents the time spent in college,  $a$  is the tuition cost per unit of time and  $b$  captures the time spent applying to college. Both  $\eta$  and  $b$  represent the opportunity costs associated with a college education since the old child can work only a fraction  $1 - \eta - b$  of that period. The cost of a public college education is not factored into the budget constraint because it is fully subsidised by the government. This assumption, however, can be relaxed by assuming that the government finances only a fraction of the tuition rather than bearing the entire cost. Our quantitative and qualitative results are robust to this change.

If an old child is not admitted to a public college then she may still attend a private college and join the skilled labour market. We assume that all college applicants are automatically admitted to a private college. According to Brazilian college data (2008 INEP report, Tables 7, 9 and 11), nearly seven times more students apply to public college than there are public college spots available. However, for a private college, the ratio of applicants to private college spots is about 1.3. Moreover, only 5% of the public college spots are unfilled, while 50% of the private college spots are unfilled. Based on these data, we assume that no minimum admission score is needed to attend a private college.<sup>15</sup>

Conditional on the child not being admitted to the public college, an old parent chooses between enrolling her child in a private ( $k = 1$ ) college or not enrolling her child in any college ( $k = 0$ ). The old parent's optimisation problem if her child is not admitted to a public college is therefore given by

$$V_o^{\text{not admitted}}(h_o, d_c, \pi, e, s) = \max_{c_o \geq 0, k \in \{0, 1\}} u(c_o) + \beta \mathbb{E}_{\pi'}[V_y(h'_y, d_c' = k, \pi')|\pi] \quad (9)$$

subject to

$$\begin{aligned} c_o + az\eta &= (1 - \tau)[(d_c w_c + (1 - d_c)w_n)h_o \\ &\quad + h'_y((1 - k)w_n(1 - b) + kw_c(1 - \eta - b))], \\ \hat{e} &= s\alpha(e + g) + (1 - s)e, \\ h'_y &= (1 - k)\pi\hat{e}^\psi + k\underline{p}\pi\hat{e}^\psi. \end{aligned}$$

Although credit and savings markets are absent from the model, a single budget constraint per period implies a perfect credit market within-period. Given the interpretation of 16 to 18 years per period, an old child can use the family's income until her 32nd–36th birthday to repay any student loan she takes to go to college.

<sup>15</sup> These data are from a report by the National Institute for Educational Research at the Brazilian Ministry of Education (INEP/MEC 2008 report).

#### 2.1.4. Admissions

We model college admissions as a competitive market in which applicants compete for college spots. A young child builds college admission skill ( $z$ ) by combining innate ability and effective early education investment, according to

$$z = \pi \hat{e}^\gamma, \quad (10)$$

where the parameter  $\gamma \in [0, 1]$  measures the elasticity of admission skill with respect to educational investments.<sup>16</sup> We interpret an individual's admission skill as the scholastic knowledge that a child acquires up until high school. It is a combination of a child's intelligence (innate ability) and the investments made in her education. The fundamental source of inefficiency in this model is that  $\gamma \neq \psi$ . In Subsection 2.3 we discuss this issue in detail.

As the result of an old child's application, public college observes a noisy signal of her admission skill. This signal is interpreted as her application score or her grade on the admission exam, and it is defined by

$$\log(\mathcal{P}) = \log(z) + \sigma_p \varepsilon_p,$$

where  $\varepsilon_p$  is an i.i.d. standard normal and  $\sigma_p$  is the noisiness of admissions.

The measure of potential applicants is one, which includes all old children, while the measure of spots available at the public college is given by parameter  $\mathcal{S}$ . Given the number of college spots available, the public college admits applicants with the highest scores ( $\mathcal{P}$ ) until all the spots are filled. Thus, the probability of public college admission is the probability of being among the top  $\mathcal{S}$  applicants according to the admission score. By the law of large numbers, there is a unique grade point cutoff, say  $\bar{q}$ , such that every applicant with  $\mathcal{P} \geq \bar{q}$  is admitted. The cutoff  $\bar{q}$  is the price that clears the admissions market.

Thus, under no affirmative action, the probability of college admission is given by

$$q(h_o, d_c, \pi, e, s) = \text{Prob}(\mathcal{P} \geq \bar{q}) = 1 - \Phi\left(\frac{\log(\bar{q}) - \log(z)}{\sigma_p}\right),$$

where  $\Phi(\cdot)$  is a standard normal cumulative distribution function.

#### 2.1.5. Affirmative action

In our model, income-based affirmative action in college admissions changes the likelihood of a successful college application by conditioning it on the applicant's income or on the type of high school she attended. If affirmative action is implemented, preferentially treated students have a different grade point cutoff from other applicants. The cutoff grade for the preferentially treated applicants is, of course, less than or equal to the other applicants' cutoff.

In our model, quotas are equivalent to giving bonus points to the preferentially treated applicants. Proposition 1 in Online Appendix B shows that, for every equilibrium with quotas, there is an equilibrium with bonus points that results in the same allocation. Conversely, for every equilibrium with bonus points, there is an equilibrium with a quota that results in the same allocation. This result allows us to study the effects of quotas on college admissions by implementing bonus points instead of quotas.<sup>17</sup> When the policy is implemented, preferentially treated applicants have

<sup>16</sup> This specification is in line with Restuccia and Urrutia (2004).

<sup>17</sup> The main reason to use bonus points is that solving for the equilibrium under bonus points is computationally less intensive than under quotas.

a bonus point added to their application score. Specifically, the admission score becomes

$$\log(\mathcal{P}) = \begin{cases} \log(z) + \sigma_p \varepsilon_p & \text{if not preferentially treated,} \\ \log(z) + \log(\mathcal{P}_{\text{bonus}}) + \sigma_p \varepsilon_p & \text{if preferentially treated,} \end{cases}$$

where  $\mathcal{P}_{\text{bonus}}$  are extra points given to preferentially treated applicants, as specified by the policy. The magnitude of such bonuses defines the intensity of the policy, as more points given imply that more college spots are allocated to preferentially treated applicants.

In this paper, we focus on income-based affirmative action, targeting low-income applicants. A policy must specify the bonus points that each subgroup of applicants—a group identified by their position on the income distribution—receives.

### 2.1.6. Production

There is one representative firm that hires human capital to produce consumption goods using a production function with constant elasticity of substitution between skilled and unskilled workers—that is, college- versus non-college-degree workers. The firm's profit maximisation problem is given by

$$\max_{H_c \geq 0, H_n \geq 0} Y - w_c H_c - w_n H_n,$$

where

$$Y = f(H_c, H_n) = A[\theta H_n^{\rho_Y} + (1 - \theta)H_c^{\rho_Y}]^{1/\rho_Y}.$$

In the firm's production function,  $A$  is a scale parameter,  $H_n$  is the human capital from unskilled workers,  $H_c$  is the human capital from skilled workers,  $\theta$  is a share parameter for unskilled labour and  $\rho_Y$  drives the elasticity of substitution between skilled and unskilled labour—specifically,  $1/(1 - \rho_Y)$  is the elasticity of substitution between college-degree (skilled) labour and labour without a college degree (unskilled).

### 2.2. Equilibrium

Let  $x_y = (h_y, d_c, \pi)$  and  $x_o = (h_o, d_c, \pi, e, s)$  denote the young and old households' state variables, respectively. We use the following equilibrium concept to solve the model.

**DEFINITION 1.** A *stationary recursive competitive equilibrium* is a set of value and policy functions, wages  $w_n$  and  $w_c$ , government expenditures on early education  $g$ , grade point cutoff  $\bar{q}$ , distributions  $\mu_y(x_y)$  and  $\mu_o(x_o)$  over the agents' states such that

- (i) agents maximise, i.e., given equilibrium prices, young and old parents, as well as the representative firm, optimise;
- (ii) markets clear, i.e., human capital, output and admissions markets clear;
- (iii) the government budget is balanced;
- (iv) distribution over the state space is stationary.

Below, we discuss in more detail the market-clearing conditions described in the equilibrium definition. We first clarify the human capital market clearing, then the resource constraint, the government budget balance and, finally, the college admissions market-clearing condition.



The human capital markets clear when the aggregate human capital supplied by the households equals the representative firm's demand for human capital in each labour market, skilled and unskilled.

From the firm's first-order conditions, in equilibrium, the relative wages satisfy

$$\frac{w_c}{w_n} = \frac{1 - \theta}{\theta} \left( \frac{H_c}{H_n} \right)^{\rho_Y - 1}.$$

From the household supply, skilled aggregate human capital is the sum of the human capital of all skilled agents working in a given period—the old child's generation, as well as the young and the old parents' generations. Similarly, the unskilled aggregate human capital is the sum of the human capital of all unskilled workers.

Formally, let  $\mu_y(x_y)$  and  $\mu_o(x_o)$  be the stationary density distribution functions over the state space. Since there is a measure one of agents in each generation, the aggregate human capital of workers with a college degree (skilled) can be written as

$$\begin{aligned} H_c = & \int h_y^{(\text{college})} \mu_y(x_y) dx_y + \int h_o^{(\text{college})} \mu_o(x_o) dx_o \\ & + (1 - \eta - b) \int \mathbf{1}^{\text{apply}}(x_o) \\ & \times [q(x_o) h_y^{(\text{public college})}(x_o) + (1 - q(x_o)) k(x_o) h_y^{(\text{private college})}(x_o)] \mu_o(x_o) dx_o, \end{aligned}$$

where  $k$  is the decision to attend private college when public college admission is denied (see (9));  $h_y'$  is the old child's human capital (see (6));  $q$  is the probability of college admission; and  $\mathbf{1}^{\text{not apply}}$  and  $\mathbf{1}^{\text{apply}}$  are dummy variables indicating the decision of whether or not to apply to college (see (7)). These are equilibrium objects and depend on their respective state variables. The integrals are over the entire state space. We find in our calibration that the public college provides a higher human capital return than the private college. Therefore, in the equation above we use the fact that students who apply and are admitted choose to attend the public college.

Analogously, the non-college-degree (unskilled) aggregate human capital is given by

$$\begin{aligned} H_n = & \int h_y^{(\text{no college})} \mu_y(x_y) dx_y + \int h_o^{(\text{no college})} \mu_o(x_o) dx_o \\ & + \int \{\mathbf{1}^{\text{not apply}}(x_o) h_y^{(\text{no college})}(x_o) \\ & + \mathbf{1}^{\text{apply}}(x_o) [(1 - q(x_o))(1 - k(x_o)) h_y^{(\text{no college})}(x_o)(1 - b)]\} \mu_o(x_o) dx_o. \end{aligned}$$

The resource constraint is given by

$$Y = f(H_c, H_n) = C_y + C_o + E + F + G,$$

where  $C_y$  and  $C_o$  are the aggregate consumption of the young and old parents,  $E$  is the aggregate expenditure on early education,  $F$  is the aggregate expenditure on college education (both public and private) and  $G$  is the aggregate government expenditure on early education. Since not all young children attend public school, we have  $G = \zeta g$ , where  $\zeta$  is the measure of students in public school. The resource constraint guarantees that everything that is produced ( $Y$ ) is either consumed ( $C_y + C_o$ ) or invested in education ( $E + F + G$ ). Note that the resource constraint is automatically satisfied, given that all agents' budget constraints hold.

The government budget being balanced states that

$$\tau Y = \tau f(H_c, H_n) = \zeta g + aS\eta,$$

where the total amount of tax collected by the government ( $\tau Y$ ) finances both investments in early education ( $\zeta g$ ) and subsidised public college ( $aS\eta$ ). We treat  $\tau$  as a tax rate parameter to be calibrated because the government chooses  $g$  in order to keep its budget balanced. This modelling choice is without loss of generality relative to the alternative of fixing  $g$  and adjusting  $\tau$  endogenously. This approach makes the calibration procedure more straightforward, given that we can directly observe the tax rate  $\tau$  from the data.

The college admissions market has to clear in general equilibrium, i.e.,

$$\int q(x_o) \mathbf{1}^{\text{apply}}(x_o) \mu_o(x_o) dx_o = S,$$

which guarantees that the measure of admitted students equals the measure of spots available.

Finally, the stationary distribution is described by the following laws of motion:

$$\begin{aligned} \mu_y(h_y, d_c = 0, \pi) &= \int [\mathbf{1}^{\text{not apply}}(x_o) + \mathbf{1}^{\text{apply}}(x_o)(1 - q(x_o))(1 - k(x_o))] \\ &\quad \times \mathbf{1}[h_y^{(\text{no college})}(x_o) = h_y] f(\pi | \tilde{\pi}(x_o)) \mu_o(x_o) dx_o, \\ \mu_y(h_y, d_c = 1, \pi) &= \int \mathbf{1}^{\text{apply}}(x_o) \{q(x_o) \mathbf{1}[h_y^{(\text{public college})}(x_o) = h_y] \\ &\quad + (1 - q(x_o))k(x_o) \mathbf{1}[h_y^{(\text{private college})}(x_o) = h_y]\} \\ &\quad \times f(\pi | \tilde{\pi}(x_o)) \mu_o(x_o) dx_o, \end{aligned}$$

$$\mu_o(h_o, d_c, \pi, e, s) = \mu_y(h_o/\xi, d_c, \pi) \mathbf{1}[\tilde{s}(h_o/\xi, d_c, \pi) = s] \mathbf{1}[\tilde{e}(h_o/\xi, d_c, \pi) = e].$$

Here  $\mathbf{1}[\cdot]$  is the indicator function,  $\tilde{\pi}(x_o)$  denotes the innate ability associated with the state  $x_o$ ,  $f(\cdot | \tilde{\pi})$  is the density function describing the innate ability distribution of an unborn child whose parent has innate ability given  $\tilde{\pi}$ , and  $\tilde{s}(x_y)$  and  $\tilde{e}(x_y)$  are the policy functions of young households in state  $x_y$ .

### 2.3. Inefficiencies and the Affirmative Action Mechanism

In this section, we discuss how income-based affirmative action policies might improve college admissions by making it more efficient. We highlight the fundamental inefficiency in our model and how income-based affirmative action policies can help mitigate it.

In our framework, a young parent invests in early education to increase the human capital of her child. These educational investments affect future human capital in two distinct ways. First, according to (6), they increase human capital directly because human capital depends on early educational investments, regardless of whether a college degree is attained. A key parameter driving this relation is  $\psi$ , which is the elasticity of future human capital with respect to effective early educational investments. Second, according to (10), these investments also increase college admission skill, at an elasticity parameterised by  $\gamma$ . By affecting admission skill, early educational investments indirectly boost the expected value of future human capital by increasing the likelihood of college admission.

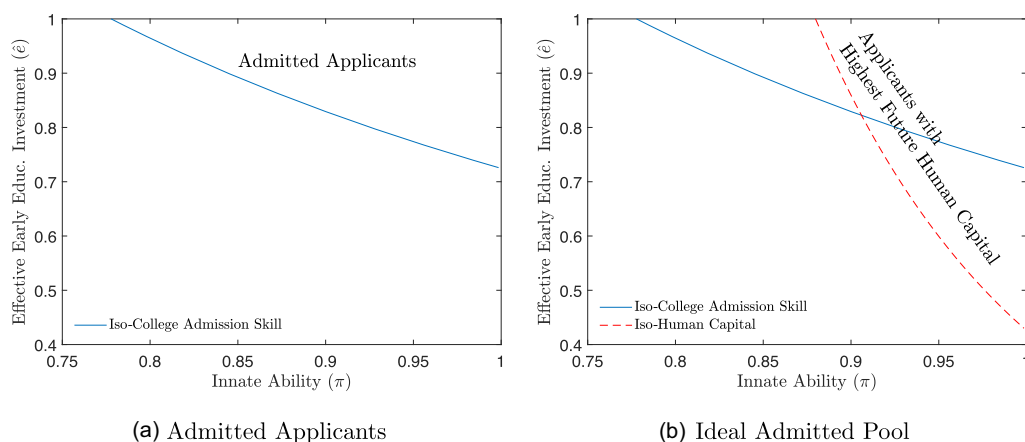


Fig. 1. *Inefficiency in College Admissions.*

*Notes:* This figure reports an iso-admission skill curve in (a). Along this curve, the combination of effective early education investment ( $\hat{e}$ ) and innate ability ( $\pi$ ) leads to the same admission skill. The level of admission skill represented by the curve is such that there is exactly a measure  $\mathcal{S}$  of agents above that level—for simplicity, we assume that  $\hat{e}$  and  $\pi$  follow independent uniform distributions in the unit interval.

We use the calibrated parameters from Table 3. Similarly, (b) adds an iso-human capital curve.

The fundamental source of inefficiency in our model relies on the fact that parental investments in early education affect human capital less than they affect admission skill. That is, as a result of our calibration—which is described in Section 3—we have  $\psi < \gamma$ . Hence, investments in pre-college education are more effective at increasing the probability of college admission than at raising the human capital gain that college provides. The second key ingredient behind the inefficiency in college admissions is that low-income parents may not have the resources to invest in their child's education. From the agents' optimisation problem, we know that early educational investments are a weakly increasing function of parents' income; that is, higher-income parents invest more in early education than low-income parents invest.<sup>18</sup> Thus, if we compare two applicants with the same admission skills, but different income levels, the low-income applicant has lower early educational investments and therefore higher innate ability. It follows that the low-income applicant also has higher future human capital. Thus, even after controlling for admission skill, income is informative about educational investments, innate ability and, most importantly, future human capital.

### 2.3.1. *Affirmative action mechanism*

The wedge between admission skill and future human capital implies that, by admitting students based on admission skills alone, college admissions are inefficient. Future human capital is not observable, and the admissions office is forced to rely on a noisy signal of applicants' admission skills. This source of inefficiency is illustrated in Figure 1 through a stylised example. In (a), the solid line is an iso-admission-skill curve for different levels of effective early educational investment and innate ability. Applicants located above the isocurve are those with the highest level of admission skill and represent the pool of admitted applicants under a perfectly precise

<sup>18</sup> We can derive this relation by applying the envelope theorem to the young parents' optimisation problem described in (2).

admissions' signal ( $\sigma_p = 0$ ). In contrast, for a given distribution of innate ability and effective early educational investments, the efficiency-maximising policy maximises aggregate human capital. In (b), we add a dashed line, which is an iso-future-human-capital curve, and the applicants located above this isocurve are those with the highest future human capital. Figure 1 highlights how the pool of admitted students is different from those with the highest future human capital. This example stresses the importance of early educational investments as an instrument to manipulate applicants' probability of admission. Income-based affirmative action can mitigate this distortion by conditioning admissions on parents' income.

### 3. Calibration

We numerically solve our model for the stationary recursive competitive equilibrium, as described in the Online Appendix D. Some parameters are calibrated directly from the data or from the literature, while others have to be calibrated by targeting related moments from the data. In our calibration, we use Brazilian data prior to the implementation of any affirmative action policy in college admissions.<sup>19</sup>

We assume that agents have CRRA preference,  $u(c) = (c^{1-\sigma} - 1)/(1 - \sigma)$ , with risk aversion captured by  $\sigma$ . We calibrate this parameter at 1.5, which is a reasonable parameter value, considering several estimates from the literature (e.g., Restuccia and Urrutia, 2004). The discount  $\beta$  is calibrated at 0.52, which is equivalent to 0.96 per year, considering that each period is equivalent to 16 years. The life-cycle parameter  $\xi$  represents the increase in human capital from young to old adulthood. Using the 2004 Brazilian National Household Survey (PNAD),<sup>20</sup> we estimate  $\xi$  at 1.06 by using data on workers aged between 33 and 64, and regressing earnings on a dummy indicating whether the worker is between 49 and 64, controlling for race, gender and state fixed effects.<sup>21</sup>

On the production technology, the scale parameter  $A$  is normalised to 10. As the production function features constant returns to scale, this is without loss of generality. In addition, we normalise  $\bar{p}$  to 1, making  $\bar{p}$  represent the human capital gain from public college relative to private college. We calibrate the parameter  $\rho_Y$  in order to match the elasticity of substitution between skilled and unskilled labour, estimated by Havranek *et al.* (2020) at 0.46; that is,  $1/(1 - \rho_Y) = 0.46$ , which implies that  $\rho_Y = 1 - 1/0.46 \approx -1.174$ .<sup>22</sup>

In the model, each period represents 16 years, and we assume that the time spent in college is four years ( $\eta = 4/16$ ) and that the time spent applying to college is one year ( $b = 1/16$ ).<sup>23</sup> To calibrate the measure of public college spots ( $S$ ), we use estimates from the Brazilian National Household Survey data. In 2004, 17% of adults between the ages of 18 and 28 were enrolled in college or had already earned a higher degree. This fraction does not vary much with the age group

<sup>19</sup> Affirmative action in college admissions was first implemented in Brazil in 2004/2005 at the University of Brasilia, followed by the Federal University of Bahia and other public universities in subsequent years.

<sup>20</sup> PNAD is an acronym for *Pesquisa Nacional por Amostra de Domicílios*.

<sup>21</sup> Restuccia and Urrutia (2004) calibrated this life-cycle parameter according to their PSID estimates. Specifically, they estimated the average earnings of a 49–64-year-old person in the labour force who has a college degree, relative to those of a 33–48-year-old person with the same qualifications. They used the 1990 PSID data and estimated this life-cycle parameter at 1.12, which is similar to our estimates for Brazil.

<sup>22</sup> Havranek *et al.* (2020) estimated the elasticity of substitution using a meta-analysis of different studies and controls for publication and attenuation biases. We use their estimate for developing countries.

<sup>23</sup> Our main results remain qualitatively unchanged if we recalibrate the model, assuming that the time spent applying to college is half a year,  $b = 0.5/16$ .

Table 3. *Calibration Targets.*

	Parameters		Moments	Data	Model
i	$\sigma_\pi$	0.78	SD of log earnings	0.95	0.94
ii	$\rho$	0.30	Intergenerational correlation of earnings	0.46	0.44
iii	$\sigma_p$	1.08	Fraction of applicants	0.34	0.32
iv	$a$	8	College expenditure relative to GDP	0.014	0.013
v	$\psi$	0.15	Early education expenditure relative to GDP	0.060	0.060
vi	$\bar{p}$	2.74	College wage premium	2.68	2.66
vii	$\theta$	0.74	Fraction of students in private college	0.12	0.12
viii	$\gamma$	0.78	Fraction of low-income students in public college	0.07	0.06
ix	$\alpha$	0.54	Fraction of students in public school	0.87	0.88

*Notes.* This table reports all calibration targets along with their respective parameters in the model. The first two columns provide the model parameters, and the last three columns provide their respective moments, both in the data and in the model. The SD of log earnings (row i) and the intergenerational correlation of earnings (row ii) use the Brazilian National Household Survey (PNAD 2004) data. The fraction of applicants (row iii) is computed based on the 2008 report made by the National Institute for Educational Research at the Brazilian Ministry of Education (INEP/MEC 2008) using 2004/8 data. Educational expenditure moments (rows iv–v) use data from the Brazilian Household Budget Survey (POF 2004) and the World Bank (2004). Finally, we compute the college wage premium (row vi), the measure of students in private college (row vii), the fraction of low-income students in public college (row viii) and the fraction of students in public school (row ix) using PNAD 2004. A detailed description of the construction of these moments is provided in Subsection 3.1. Low-income students in row viii refer to those in the second quintile of the income distribution.

considered,<sup>24</sup> which means that, in the model, a measure 0.17 of young children should go to either a public or a private college in equilibrium. To calibrate the measure of public college spots, we need the fraction of college students attending public institutions. In the Brazilian Educational Census, 28% of total college enrolment was in public institutions of higher education in 2004.<sup>25</sup> Thus, the measure of public spots is calibrated at  $S = 0.048$ , which is 28% of 0.17.

Finally, the tax rate,  $\tau$ , is directly calibrated from the data. It represents the government expenditures on education (primary, secondary and tertiary) over GDP, which was 4% in 2004, according to the World Bank. Next, we discuss the remaining parameters, which are calibrated by simultaneously matching moments from the data.

### 3.1. Calibration Targets

The remaining nine parameters are calibrated to simultaneously match the following nine moments from the data: (i) SD of log earnings; (ii) intergenerational correlation of earnings; (iii) fraction of applicants; (iv) aggregate college expenditures relative to GDP; (v) early education expenditures relative to GDP; (vi) college wage premium; (vii) fraction of students in private colleges; (viii) fraction of low-income students in public colleges; and (ix) fraction of students in public schools. Table 3 reports all of these moments in the model and in the data, as well as their related parameters.

#### 3.1.1. SD of log earnings

In the model, the parameter  $\sigma_\pi$  affects innate ability and earnings dispersion and, hence, is chosen to match the SD of log earnings. Using the PNAD 2004 data, the SD of log earnings is 0.95 for adults between 32 and 65 years old, after controlling for state, race and gender fixed effects.

<sup>24</sup> We considered ages between 18 and 24/26/28/30/32, and the respective fractions were between 16.3% and 17.3%.

<sup>25</sup> Data statistics were taken from the INEP (2008) report. In 2004, there were 4,163,733 students enrolled in institutions of higher education, 1,178,328 of whom were in public institutions.

### 3.1.2. *Intergenerational correlation of earnings*

The intergenerational correlation of earnings measures the persistence of earnings between two generations of the same family. Specifically, it is the slope coefficient of regressing the log earnings of the old parent on the log earnings of her child. For Brazil, and for developing economies in general, however, there are no panel data that would allow for such an estimation to the best of our knowledge. Ferreira and Veloso (2006) overcame this challenge by estimating the intergenerational persistence of earnings in Brazil using a synthetic parents' income, inferred from parental education and occupation, similar to Angrist and Krueger (1992), Arellano and Meghir (1992) and Björklund and Jäntti (1997).<sup>26</sup> We calibrate our model using 2004 data; hence, young parents are 32–36 years old in 2004 and were therefore born in 1968–72. For the cohort born in 1967–71—the closest to our calibrated time period—Ferreira and Veloso (2006) estimated intergenerational earnings persistence at 0.46.<sup>27</sup> In our model, parameter  $\rho$  drives the persistence in innate ability, and, in equilibrium, it also drives the persistence in earnings. To match the intergenerational correlation of earnings, we calibrate  $\rho$  at 0.30. This is consistent with the estimation made by Holter (2015), as well as with the calibrations of Restuccia and Urrutia (2004) and Blankenau and Youderian (2015).

### 3.1.3. *Fraction of applications*

Based on the Brazilian educational census, the ratio between applicants and public college spots is 7. Since we have a measure of 4.8% of public college spots, the measure of applicants is targeted at 34%. The noise of the admission exam ( $\sigma_p$ ) directly affects this moment. For instance, if there is no noise in the admissions process and the admission skill is perfectly observed, then only students who are admitted would apply to college. Thus, we calibrate  $\sigma_p$  to match the measure of applicants at 0.34.

### 3.1.4. *College expenditure relative to GDP*

To measure expenditures in college education relative to GDP in Brazil, we rely on two data sources. First, according to the Brazilian Household Budget Survey (POF)<sup>28</sup> for 2003–4, the average fraction of after-tax income spent on education was 4.08%. Second, according to World Bank data, the average Brazilian tax revenue rate for the period was 15.9%, which means that 3.43% ( $4.08 \times (1 - 0.159)$ ) of households' before-tax income was spent on education. Also, according to the World Bank, the Brazilian government spent 4.01% of GDP on education in the same period. Hence, the total—households and government—expenditure in college education was 7.44% of total output ( $4.01\% + 3.43\%$ ). Finally, according to the World Bank, 18.92% of total education expenditures are allocated to higher education in Brazil, and, therefore, the aggregate investments in education are 1.4% ( $0.1892 \times 7.44\%$ ) in higher education and 6%

<sup>26</sup> This is a two-stage procedure using the Brazilian National Household Survey data. First, they created a subsample of parents (between 25–64 years old, working full time and located in urban areas), and regressed their income on education and occupation dummies, controlling for cohort fixed effects. In a second step, the first-stage regression was used to forecast the wages of the actual parents, because the survey data contained parents' education and occupation, but not their wages. This procedure allowed them to construct synthetic wages for parents, given their occupation and educational background. Finally, they estimated intergenerational persistence of earnings for different cohorts by regressing log synthetic earnings of parents on log earnings of their child.

<sup>27</sup> See Table 15 in Ferreira and Veloso (2006). For the United States, the intergenerational correlation of earnings is slightly slower at about 0.40, using the PSID data (Solon, 1992).

<sup>28</sup> Pesquisa de Orçamento Familiar.



$((1 - 0.1892) \times 7.44\%)$  in pre-college education relative to GDP. Hence, we match college education expenditures over GDP at 1.4% by varying the cost of college education (parameter  $a$ ).

### 3.1.5. *Early education expenditure relative to GDP*

From the previous calculations using data from the World Bank for Brazil and the Brazilian Household Budget Survey, 1.4% of GDP is spent in higher education and 6% is spent in pre-college education. We target pre-college expenditures over GDP at 6% by varying the concavity of the human capital formation function (parameter  $\psi$ ). From (6), it is clear that, as parameter  $\psi$  increases, so does the return from pre-college education. This is true regardless of the college education obtained—no college or a private college or a public college degree. Therefore,  $\psi$  affects pre-college educational investment of *every* agent investing in education, independently of their expected level of college education. As a result, a higher  $\psi$  leads to an increase in aggregate expenditures on early education.

### 3.1.6. *College wage premium*

We compute the college wage premium as the average wage conditional on having a college degree relative to not having a college degree. Formally, to estimate the college wage premium, we regress earnings for adults between 32 and 48 years old on a dummy for college degree, controlling for state, race and gender fixed effects. In 2004, the college wage premium was 2.68 for college graduates relative to those with only a high school degree. The public college human capital gain ( $\bar{p}$ ) drives the college wage premium by increasing the earnings of college graduates from public college, so we calibrate  $\bar{p}$  to match the college wage premium.

### 3.1.7. *Fraction of students in private college*

The measure of agents attending college depends on the human capital gains from a college degree. In the model, a key determinant of college gains is the share of non-college human capital relative to college human capital in the firm's production technology. The parameter  $\theta$  drives the demand for skilled labour, equilibrium wages and, therefore, equilibrium human capital gains from college. When  $\theta$  decreases, the weight on college-degree labour increases, which increases the demand for skilled labour, pushing up college-degree wages and the supply of skilled labour. Because the public college spots are fixed, any change in the supply of skilled labour comes from private college education. As a result, we calibrate  $\theta$  to match the measure of students in the private college.<sup>29</sup>

### 3.1.8. *Fraction of low-income students in public college*

To calibrate the elasticity of admission skill with respect to early educational investments (parameter  $\gamma$ ), we target the fraction of public school students in the 40th percentile of the income distribution, which is 7% for the Brazilian case.<sup>30</sup> Given that admission skill ( $z$ ) is the

<sup>29</sup> It is important to point out that  $\theta$  might affect the college wage premium, as well. On the one hand, a lower  $\theta$  increases wages, which might lead to a higher college wage premium. On the other hand, an increased pool of college students will lower the average human capital of college graduates by having more, arguably less-skilled, students in private college. More importantly,  $\bar{p}$  does not affect the benefit of private college much because it primarily affects the earnings for those attending public college. As a result, we can calibrate  $\theta$  and  $\bar{p}$  to match the measure of students in the private college and the college wage premium.

<sup>30</sup> Using PNAD data, 7% of public college students are in the bottom 40% of the income distribution. To compute these moments of the college income distribution, we use the 2002 PNAD data so that we do not include students in private college with a ProUni scholarship. The affirmative action policy to be implemented in Brazil focuses on the first

main driver of the college admissions probability (i.e., test scores), parameter  $\gamma$  reflects the sensitivity of the probability of college admission with respect to pre-college education. As a result,  $\gamma$  affects the returns of pre-college education on the unconditional expected future human capital exclusively, by making the probability of college admission more responsive to pre-college educational investments. As a direct implication, college applicants on the margin of being admitted are the most affected by changes in  $\gamma$ , because additional investment in pre-college education may significantly improve their odds of a successful college application. For all the other agents, the returns to pre-college education do change, but minimally—e.g., those who do not even apply to college or those who apply and are already likely to be admitted.

The fraction of low-income applicants admitted is sensitive to  $\gamma$  precisely because it affects marginal applicants' investment decisions the most. Importantly, marginal applications from wealthier families benefit disproportionately more from a higher value of  $\gamma$ . Lower-income households have a higher marginal utility of consumption, and, therefore, small adjustments to their consumption-investment bundle are enough to optimally adjust their policy functions. Hence, higher  $\gamma$  means that higher-income applicants increase their investment in pre-college education more than lower-income households do. As a result, more low-income applicants are crowded out from being admitted to college, and fewer lower-income applicants are admitted.

### 3.1.9. *Fraction of students in public school*

The fraction of students in public high schools was 87% in 2004, and, in the model, this fraction is directly affected by public school inefficiency (parameter  $\alpha$ ). If  $\alpha$  is low (high) then public school has a lower (higher) return and more (fewer) young parents would enrol their child in a private school. Thus, we calibrate  $\alpha$  to match the fraction of young children in public schools.

Finally, in Online Appendix E, we further verify our calibration strategy by using the methodology developed by Daruich (2018) to highlight that each one of the targeted moments from the data relates to a different parameter in the model. His methodology provides a clean and intuitive way to depict the sensitivity of model-implied moments with respect to specific parameters of the model. The general idea is to randomly simulate different parameterisations of a model and compute moments implied by each parameterisation. Then, we show that each parameter directly relates to a specific model-implied moment while not being affected by other parameters.

## 3.2. *Other Non-Targeted Moments*

In this section, we verify how our model performs in terms of matching non-targeted moments that are directly linked to our economic mechanism. As the main policy we study is income-based affirmative action, it is crucial that our calibrated model matches the income distribution.

First, we verify that the model matches other moments of the income distribution and the overall level of inequality. In the first panel of Table 4, we report different percentiles of income distribution relative to the median income. The model successfully replicates the cross-sectional distribution of income. For instance, the log income of the 90th percentile relative to the median is 1.25 in the data and 1.33 in the model. At the bottom of the distribution, the model mirrors the data more closely. The log income of the 5th percentile relative to the median is  $-1.36$  in the data and  $-1.34$  in the model. The log income of the last decile relative to the median is  $-1.03$  both

quintile of the income distribution, for which we also have a good fit. The fraction of public college students in the bottom quintile is 2.8% in the data and 3.2% in the model. We further discuss this in panel B of Table 2.

Table 4. *Non-Targeted Moments.*

	Data	Model
<i>Panel A: income distribution, <math>\log(h_o)</math></i>		
prc 5 - prc 50	−1.36	−1.34
prc 10 - prc 50	−1.03	−1.03
prc 25 - prc 50	−0.55	−0.41
prc 75 - prc 50	0.59	0.72
prc 90 - prc 50	1.25	1.33
prc 95 - prc 50	1.69	1.82
Gini index	0.524	0.526
<i>Panel B: fraction of college students from different income quintiles</i>		
Fraction from income quintile 1	0.02	0.02
Fraction from income quintile 2	0.05	0.04
Fraction from income quintile 3	0.09	0.06
Fraction from income quintile 4	0.18	0.13
Fraction from income quintile 5	0.65	0.75

*Notes:* This table reports several moments from the data and their model counterpart. In panel A, we report the percentile of the log income distribution relative to the median. In the model, this variable is  $\log(wh_o)$ . We could have also included income of the old child, but the results would be similar. To compute these cross-sectional moments of the income distribution, we use family income reported in the Brazilian National Household Survey (PNAD 2004). In panel B, we compare the income distribution of students admitted to public college relative to the overall population. In the model, we report the fraction of students coming from each income quintile. In the data, we follow the same reasoning and condition family income on students who are newly admitted to college; then we compute the fraction coming from each quintile.

in the data and in the model. The model also implies a Gini index close to the index observed empirically, with 0.524 being estimated from the data and 0.526 in the model.

In addition to the unconditional income distribution, we also verify whether the model matches the income distribution among public college students. The unconditional income distribution and the distribution conditional on attending public college are strikingly different. This is directly related to our mechanism because affirmative action policies directly affect the income distribution of college students. As part of our calibration exercise, we match the fraction of students from the bottom 40th percentile—see row viii in Table 3. However, we do not attempt to match other moments of that distribution. For example, in the data, 65% of students starting public college are from the top quintile of the income distribution, while only 2% are from the bottom quintile. In the model, we find similar fractions at 75% and 2%, respectively. The second panel of Table 4 reports the fraction of students from each quintile, and, although not directly targeted by our calibration, the model closely matches the data counterparts.

4. Policy Evaluation

In this section, we describe the effects of income-based affirmative action, by comparing the steady-state equilibrium of our calibrated model with and without such policies.<sup>31</sup> We study the implications of income-based affirmative action policies for aggregate output, intergenerational correlation of earnings and welfare. Welfare is measured as a population-weighted average of agents' value functions. Aggregate output measures the efficiency of college admissions because it is equal to the aggregate value of human capital in the economy. Thus, both welfare and aggregate output are important measures of the economic performance of income-based affirmative action

<sup>31</sup> In Online Appendix F, we numerically solve for the transition dynamics.

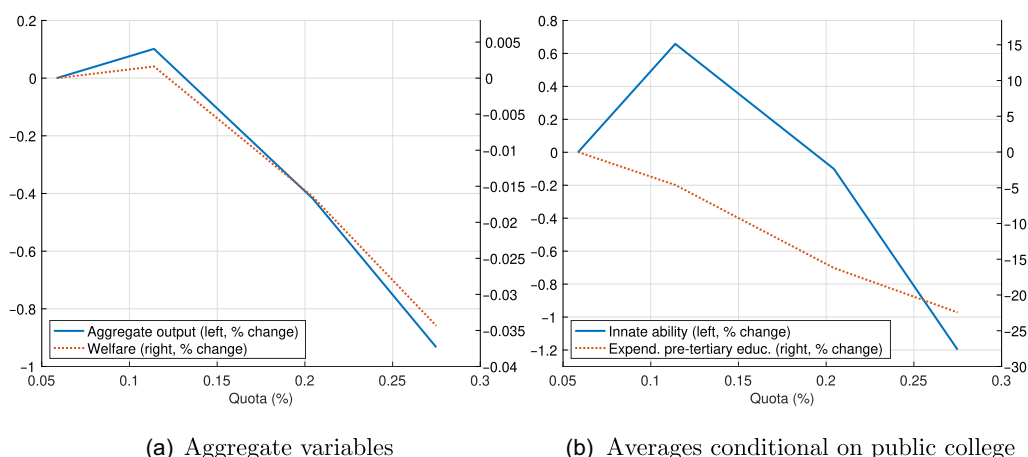


Fig. 2. *Affirmative Action for Low Income.*

*Notes:* This figure reports the effects of admissions quota policies for college applicants based on their income. The policy targets the bottom 40th percentile of the income distribution. Panel (a) plots the effects on aggregate output (left axis) and welfare (right axis) against the intensity of the policy—i.e., the fraction of students in the preferentially treated group attending public college. Panel (b) plots the implications for the average innate ability (left axis) and average expenditures on pre-college education (right axis) among public college students.

policies. In addition, persistence of earnings evaluates whether the policy effectively promotes educational opportunities for socially disadvantaged students.

Subsection 4.1 describes the trade-offs involved in favouring low-income applicants in college admissions. Subsection 4.2 discusses two distinct optimal policies: one that maximises aggregate output and another that maximises welfare. Finally, Subsection 4.3 evaluates the affirmative action currently being implemented in Brazil, and Subsection 4.4 presents several robustness exercises.

#### 4.1. *Understanding the Trade-Offs*

One of the main reasons that income-based affirmative action policies in college education are a controversial topic is that they are essentially associated with an economic trade-off. While such policies may level the playing field and admit students with relatively high college returns, who otherwise would not be admitted, income-based affirmative action may discourage investments from non-beneficiaries. Figure 2 shows this trade-off in our calibrated model. We simulate an income-based affirmative action policy benefiting applicants in the bottom 40th percentile of the income distribution. Panel (a) displays the effects on aggregate output and welfare for different levels of quotas for the preferentially treated group. Panel (b) plots the average innate ability, and the average expenditures on pre-college education among students admitted to public college, for different levels of quotas for the preferentially treated group.

For relatively low levels of the policy, aggregate output and social welfare increase, reaching a peak when the mass of eligible applicants who are admitted to public college doubles from its benchmark value of 5.8% to 11%. From this point, output and welfare start falling if more spots are allocated to applicants in the first two income quintiles.

Table 5. *Optimal Affirmative Action.*

	Max. efficiency (1)	Max. welfare (2)
Aggregate output change (bps)	23	10
Welfare change (bps)	2	3
Persistence of earnings change (bps)	-213	-574

*Notes:* This table reports the effect of optimal affirmative action policies on persistence of earnings, aggregate output and welfare. Column (1) reports the result for the affirmative action policy that maximises aggregate human capital. Column (2) reports the affirmative action policy that maximises welfare without decreasing aggregate human capital. We numerically solve for the optimal policies based on income quintiles. The effects are reported in basis points change relative to an economy without affirmative action.

The solid curve in (b) shows the reason that output and welfare follow this inverse U-shaped curve. For low levels of the quota policy, the average innate ability of students admitted to public college increases. This happens because there is a proportion of high-ability students living in poor households who do not have funds to invest in education. High-income households, some of which have children with relatively low innate abilities, make education expenditures to increase their children's likelihood of admission, preventing high-ability, low-income students from being admitted. An income-based affirmative action policy remedies this and improves admissions by substituting students with relatively low innate abilities for higher-ability eligible students. However, as the quota policy intensifies, it starts admitting eligible students with lower innate abilities, crowding out higher-ability students and leading to a fall in aggregate output.

Lower educational investments from the non-preferentially-treated students is an equilibrium backlash of the policy, resulting in lower aggregate output as policy intensity increases. These graphs show that investments in pre-college education decline with policy intensity; however, they do not decrease much when the policy magnitude is close to zero. Therefore, a small-scale policy can improve admissions efficiency and increase aggregate output, without reducing educational investments much.

#### 4.2. *Optimal Income-Based Affirmative Action*

We numerically compute two optimal income-based affirmative action policies. First, we solve for the income-based affirmative action policy that maximises aggregate output. Second, we compute the policy that maximises welfare. We solve for optimal policies targeting different income quintiles with different quotas, allowing the policymaker to observe which income quintile applicants belong to, but not the income itself.<sup>32</sup>

Table 5 reports the results of our numerical optimisation. In column (1), we report the implications of the optimal efficiency-maximising policy for aggregate output, welfare and intergenerational persistence of earnings. The efficiency-maximising affirmative action increases aggregate output by 23 basis points, while decreasing intergenerational persistence of earnings by 2.13%. This policy improves welfare, measured as the sum of all agents' utility. Column (2) shows the policy that maximises welfare. Such a policy improves welfare by 3 basis points and decreases persistence of earnings by 5.74%. In summary, income-based affirmative action can be an efficiency-enhancing policy that improves welfare, and it can also be a powerful tool

<sup>32</sup> The main reason for restricting the policy to condition on income quintiles is to keep the numerical optimisation problem computationally less intense.

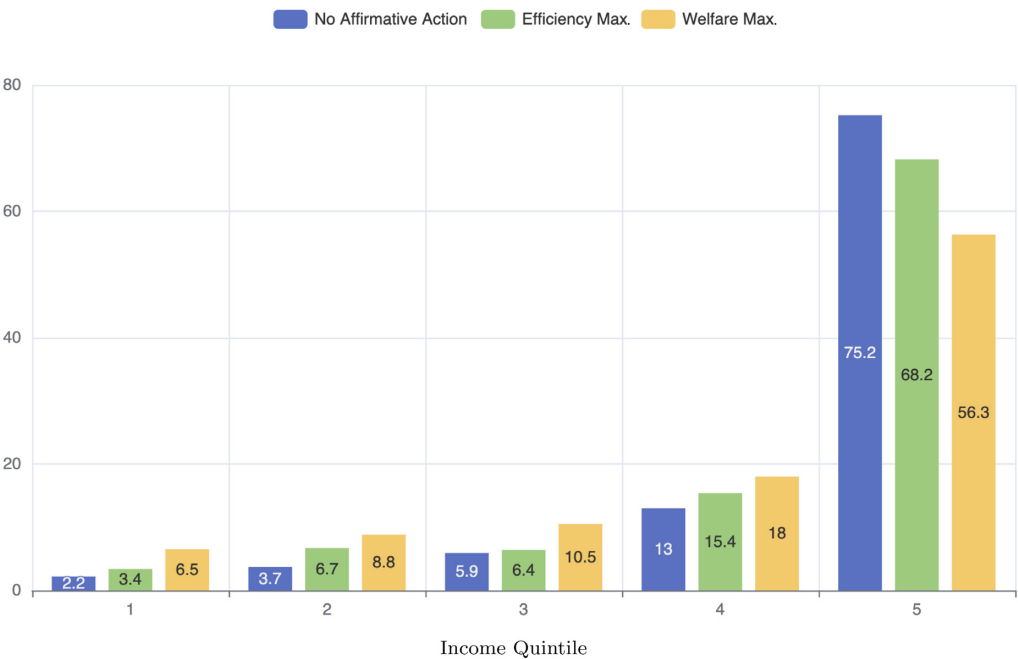


Fig. 3. *Income Distribution and Affirmative Action.*

*Notes:* This figure reports the fraction of students attending public college from each income quintile. We plot the income distribution under three different scenarios: without affirmative action, efficiency-maximising affirmative action and welfare-maximising affirmative action.

to promote educational opportunities at the aggregate level, effectively breaking persistence of earnings between the different generations of the same family.

The optimal policies implement different quotas based on the income quintile of the applicant. Figure 3 compares the income distribution of applicants admitted to public college under the optimal policies. Both optimal policies significantly admit more students from the lower quintiles and fewer applicants from the top quintiles. The efficiency-maximising policy is more moderate, with a lower quota allocated to low-income applicants in order to improve the pool of admitted students without disincentivising educational investments. In contrast, the welfare-maximising policy is more intense, targeting the families with the highest marginal utilities. Both optimal policies change college demographics significantly. For example, the efficiency-maximising policy increases the number of public college students from the second quintile of the income distribution by 80%, from 3.7% to 6.7%, while the welfare-maximising policy increases the number of public college students from the bottom quintile by a factor of three, from 2.2% to 6.5%. In both policies, students in the top quintile lose their spots so that eligible students are benefited.

To further understand the welfare effects of the optimal policy interventions, Table 6 reports two additional welfare measures associated with each policy. The first measure is the fraction of households that are better off under a given affirmative action policy. The first column shows that 78% of the households prefer the efficiency-maximising policy over the benchmark equilibrium, while 79% prefer the welfare-maximising policy over having no intervention. The welfare gains



Table 6. *Welfare Measures.*

	Max. efficiency		Max. welfare	
	Better-off households (%)	Willingness to pay (%)	Better-off households (%)	Willingness to pay (%)
Average	78	0.02	79	0.07
Quintile 1	97	0.18	98	0.55
Quintile 2	95	0.29	95	0.64
Quintile 3	95	0.13	97	0.53
Quintile 4	93	0.23	94	0.56
Quintile 5	10	−0.69	12	−1.90

*Notes:* This table reports two welfare measures for the efficiency-maximising and the welfare-maximising policies. The first is the measure of households that are better off in a given counterfactual policy (unconditional and conditional on income quintiles). The second is calculated based on the proportion of consumption a household would be willing to pay in all periods of time and states of nature to have a given policy implemented. We report the unconditional average willingness to pay across all households and the averages by income quintiles.

are significantly heterogeneous across households: while approximately 95% of households in the first four income quintiles are better off under either of the optimal policies, only 11% of households in the top quintile would gain from the policies being implemented.

The second welfare measure is the willingness to pay. We measure how much each household would be willing to pay in terms of its consumption in all time periods and states of nature to have a given policy implemented.<sup>33</sup> The second column shows that households in the first four income quintiles would be willing to pay, on average, 0.2% of their consumption in all periods and contingencies to have the efficiency-maximising policy implemented. Households in the top quintile, however, would have to have their consumption levels increased by 0.69%, on average, to be compensated for their losses.

Although there are no significant welfare differences between the two policies if one uses the first welfare measure, the willingness to pay shows that the welfare-maximising policy leads to even bigger and more heterogeneous welfare impacts. Households in the first four income quintiles, on average, would be willing to pay 0.57% of their consumption to have the welfare-maximising policy implemented, while those in the top quintile would require their consumption to be increased by 1.9% in all periods and contingencies to be compensated for their losses.

Table 6 shows that 12% of the households in the top income quintile benefit from the welfare-maximising policy, even though such intervention decreases the probability of their child going to public college. To shed light on this, Figure 4 plots the households' welfare gain by income and child ability for families in the bottom and in the top income quintiles.

Intuitively, the optimal policy directly favours lower-income families and curbs college access for households in the upper-income strata. However, high-income families are heterogeneous in the innate ability of their children. The highest-income households with low-ability children have higher expected welfare upon policy implementation, because they consider the benefits generated by the policy for their future generations. The income of these families is likely to mean revert in the near future as they enjoy the benefits generated by the policy. Panel (a) shows precisely this effect. The policy harms households in the top income quintile with the highest income and high-ability children. In contrast, families with low-ability children in the top quintile benefit from the policy.

<sup>33</sup> See Chatterjee *et al.* (2007) for more details on calculating willingness-to-pay measures in a similar environment.

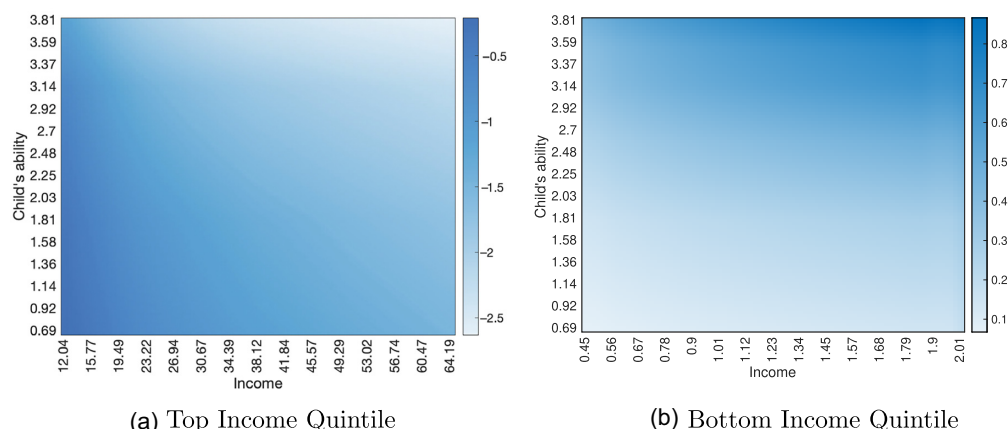


Fig. 4. *Willingness to Pay for the Welfare-Maximising Policy.*

*Notes:* This figure reports the households' willingness to pay for the welfare-maximising policy by income and child ability, conditional on the (a) bottom and (b) top income quintiles. We first calculate the average willingness to pay for each 10-by-10 points subset of the (income, child ability) grid mesh to obtain a continuously smooth heatmap. Second, we extend the smaller grid mesh containing the averages so that each of the two dimensions has 100 points. We use linear interpolation to calculate the predicted welfare gain in the larger grid mesh.

Figure 4(b) shows the welfare gain for households in the bottom income quintile. It highlights that families with high-ability children benefit the most among those in the bottom income quintile. The optimal policy specifically favours high-ability children from low-income applicants because they have a higher probability of a successful college application.

To further illustrate how the optimal income-based affirmative action policies target income groups differently, we compute the probability of attending public college conditional on income and on the future human capital quintile. We plot a heatmap of these probabilities in Figure 5. Panel (a) contains the heatmap of probabilities under no affirmative action. The average probability of attending public college for an applicant at the top income quintile and top human capital quintile is 30%, whereas an applicant in the same human capital quintile, but at the bottom of the income distribution, has only an 8.4% probability of attending public college. Strikingly, for the highest income quintile, even applicants with below-median human capital have a chance of attending public college. This highlights how income—and pre-college educational investments associated with it—can distort the pool of admitted students. Panels (b) and (c) report the heatmaps containing the probability of attending public college under the optimal efficiency- and welfare-maximising policies, respectively. Both policies benefit the lower-income quintile the most, but at different intensities.

There are two key forces at play in shaping these optimal policies. On the one hand, they target low-income families the most, benefiting the most-constrained applicants. By segmenting the admissions' market by income groups, these policies roughly control for educational investments in early education. Although families' investments in pre-college education may still distort the pool of admitted students within each income group, this is less of an issue for low-income applicants, given that they are more credit constrained. The policies, not only benefit applicants

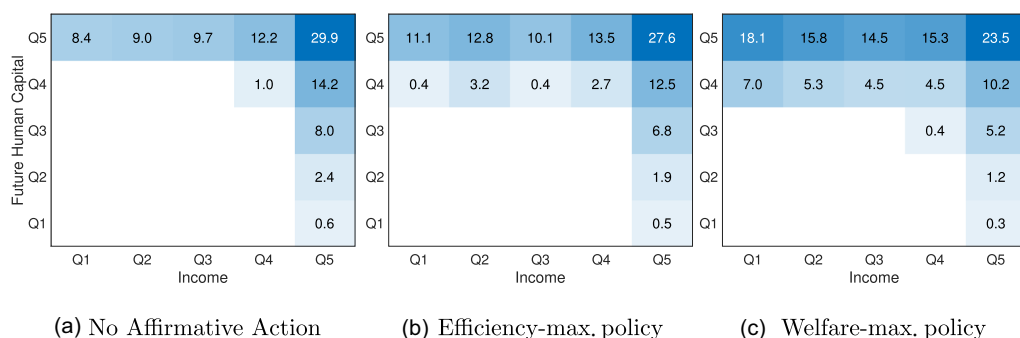


Fig. 5. *Probability of Attending Public College.*

*Notes:* This figure reports the probability of attending public college by income and the future human capital quintile. We define future human capital as the human capital a student would have if she were admitted to public college. Panel (a) reports the probabilities with no affirmative action in place. Panels (b) and (c) report these probabilities under the welfare- and efficiency-maximising policies, respectively. Each panel is a heatmap with the probabilities reported in each quintile combination. For the readability of the graph, we did not report probabilities below 0.2%.

with higher human capital gains from college education, but also take into account their effects on the human capital accumulation of future generations. Innate ability has some intergenerational persistence, and, by admitting low-income high-innate-ability applicants, optimal affirmative action policies induce social mobility for high-innate-ability families. Such social mobility allows future generations to enjoy a less credit-constrained environment, fostering future educational investments in high-innate-ability children. The optimal affirmative action policies effectively mitigate poverty traps, in which there could be generations of high-innate-ability families unable to invest in early education. On the other hand, the optimal policies are moderated in their intensities in order not to distort investment decisions. High-income families have the resources to invest in early education, and the optimal policies keep these investment incentives aligned.

The main difference between the welfare- and efficiency-maximising policies is their intensity. The welfare-maximising policy benefits low-income applicants more because they have high marginal utility and, therefore, the highest welfare gains from attending college. The efficiency-maximising policy also benefits low-income applicants, but not at the same intensity, as it trades off efficiency gains associated with higher aggregate output against welfare gains.

#### 4.2.1. *Evaluating the transition between steady-state equilibria*

The policy evaluation discussed above follows from comparing two steady-state equilibria: one with no policy in place and another with income-based affirmative action in college admissions. While this comparison allows us to infer the policy's long-term implications, it abstracts away from the transition between steady states. We present the transition dynamics of the efficiency-maximising policy in Online Appendix F. The main takeaway from this exercise is that aggregate output initially decreases and then increases, converging to the new steady state within a few generations. The welfare initially increases significantly and then continues to converge to its steady-state value.

The policy, as soon as it is implemented, successfully changes college demographics by admitting more low-income applicants with higher returns to college education and fewer high-

income applicants with lower returns to college education. On the one hand, when the policy is implemented, it benefits the families in lower-income quintiles the most, leading to a large initial welfare gain because of these families' higher marginal utility. On the other hand, upon implementation of the policy, there is a decline in the quality of non-college educated workers, leading to a decrease in aggregate unskilled human capital and, therefore, a decrease in aggregate output. As new generations arrive, families adjust their investment decisions, and the economy converges to the new steady state with higher aggregate output and higher welfare.

#### 4.3. *Evaluating Affirmative Action in Brazil*

In 2012, the Brazilian congress approved the major-specific quota policy targeting low-income and public school students. Over the subsequent three years, the government gradually implemented the policy in all federally sponsored universities. The law says that 50% of students admitted to each degree program in federal universities must have studied in a public high school. Furthermore, half of those spots are reserved for low-income applicants—i.e., those with a family income less than 1.5 times the minimum wage per capita, who are those in the first three quintiles of the income distribution. Finally, a fraction of the spots for low-income applicants are reserved for non-white candidates, in line with the racial distribution in the university's geographical location.<sup>34</sup>

We use our calibrated model to shine a light on the long-run implications of the affirmative action policy implemented in Brazil. Formally, we evaluate a policy that considers the number of public college spots as fixed, and allocates 50% of those spots to applicants from public schools, with half of those spots reserved for applicants in the first three quintiles of the income distribution.

Table 7 shows that the Brazilian policy decreases long-run output by 0.17% and the population-weighted sum of all agents' value function (welfare) by 0.01%. In line with its objectives, the policy promotes educational opportunities by decreasing the intergenerational persistence of earnings by 4.27%.

The Brazilian policy benefits 73% of all households, with the majority of better-off households located in the first income quintiles. The average willingness to pay for the policy is 0.03%. The gains are concentrated in the lower income quintiles: households in the first, second and third quintiles would be willing to pay 0.30%, 0.49% and 0.47% of their consumption in all periods and contingencies of the policy steady state to have the quotas in place, respectively.<sup>35</sup>

Brazil's policy can be improved. Our framework allows us to test whether a policy is well designed to improve long-run welfare. This is an important contribution of our previous analysis.

<sup>34</sup> Federal law 12.711, August 29, 2012. Although the law was approved in 2012, in 2005, some universities had already started to implement affirmative action policies in a decentralised way. For example, the Federal University of Bahia introduced a similar quota system in 2005. After the implementation, the fraction of students from public schools increased by 50%, from 33.8% to 51%. In some selected majors, it increased more than 400%; for example, in architecture, the fraction of public school students increased from 10.7% in 2004 to 43.7% in 2005.

<sup>35</sup> According to our counterfactual exercise using our model at calibrated parameters, educational investments made by households would decrease by 10% in response to the Brazilian quota policy. In our calibration, more than half of public school students do not receive educational investments from their parents. These families face high marginal utility of consumption and optimally choose to consume their income without further investing in early education—they still receive government investment made to the public school system. Therefore, those households do not decrease education investments in response to quota policies, and this mechanism makes aggregate education investments less responsive to quota policies.

Table 7. *Long-Run Effects of the National Law of Quotas in Brazil.*

<i>Panel A: aggregate variables (% change)</i>		
Aggregate output		−0.17
Welfare		−0.01
Persistence of earnings		−4.27
	Better-off households	Willingness to pay
<i>Panel B: welfare measures (%)</i>		
Average	73	0.03
Quintile 1	98	0.30
Quintile 2	93	0.49
Quintile 3	93	0.47
Quintile 4	63	−0.12
Quintile 5	15	−1.07

*Notes:* This table reports the effects of the affirmative action policy implemented in Brazil starting in 2012. Panel A shows the percentage changes in aggregate output, aggregate welfare and intergenerational persistence of earnings. Panel B shows two welfare measures associated with the policy. The first is the proportion of better-off households under the policy (unconditional and conditional on income quintiles). The second welfare measure shows how many households would be willing to pay in terms of consumption in all time periods and contingencies to have the policy implemented (average willingness to pay across all households and conditional on income quintiles).

In the case of Brazil, we show that a better-designed policy could increase welfare, increase aggregate output and break the intergenerational persistence of earnings.

#### 4.4. *Robustness*

In this section, we show that income-based affirmative action in college admissions still improves welfare, and increases aggregate output under variations of our benchmark model and calibration. We conduct several robustness exercises.

Taken together, these exercises suggest that the economic mechanism behind our results, discussed in detail in Subsection 2.3, is not a feature of our modelling or calibrating choices, but a robust consequence of credit constraints and private investments in education.

*Households pay public college tuition.* In many countries, including the United States, students must pay college tuition regardless of the college's ownership type (public or private). We solve our model for a world in which the public college student has to bear the entire cost of a college education. In this case, all labour taxes collected by the government are invested in pre-tertiary education, and the budget constraint of the old parent when the old child goes to college (see (8)) becomes

$$c_o + a\eta = (1 - \tau)[(d_c w_c + (1 - d_c)w_n)h_o + w_c h'_y(1 - \eta - b)].$$

The first row of Table 8 shows the effects of the efficiency- and the welfare-maximising policies on aggregate output and welfare. Compared to the baseline optimal policies, the effects on aggregate variables are now even stronger.

*More public college spots.* Recently, there has been an increase in the number of public college spots at government-sponsored Brazilian universities. We compute the optimal policies for an alternative benchmark equilibrium in which the number of public college spots is 10% higher (e.g., we set  $S = 0.0528$ ). We obtain a result similar to that in the previous robustness exercise,

Table 8. *Robustness Analyses.*

Model variation (1)	Efficiency-maximising policy		Welfare-maximising policy	
	Output gain (2)	Welfare gain (3)	Output gain (4)	Welfare gain (5)
Baseline	23	2	10	3
Households pay public college tuition	23	6	21	6
More public college spots	37	3	37	3
Calibration with $\alpha = 1$	8	1	−8	2
College dropout risk	34	6	34	6
Imperfect substitution btw. $e$ and $g$	20	1	−4	6

*Notes:* This table reports the effect of optimal affirmative action policies on aggregate output and welfare. We numerically solve for the optimal affirmative action under different model specifications. Column (1) describes the alternative specifications—see Subsection 4.4 for details. Columns (2)–(3) report the effects of the optimal affirmative action policy on aggregate output and welfare, under the efficiency-maximising policy. Columns (4)–(5) report the effects under the welfare-maximising policy. The effects are reported in basis points change relative to the same economy without affirmative action. For reference, the first row repeats information of Table 5 regarding the baseline model specification.

with aggregate output and welfare increasing more under the optimal policies, compared to in the case in which  $S = 0.048$ .

*Calibration with  $\alpha = 1$ .* An essential characteristic of the Brazilian educational environment is that public schools have lower quality, on average, than private schools. We simulate the model assuming that  $\alpha = 1$ , meaning that public schools and private schools have the same quality. We find that the efficiency-maximising affirmative action policy increases output by 8 basis points and welfare by 1 basis point, while the welfare-maximising policy increases welfare by 2 basis points, but aggregate output falls by 8 basis points.

*College dropout risk.* To evaluate if our findings are robust to having college dropouts in the model, we modify our framework in two dimensions. First, we assume that, if a student drops out of college, forgone earnings equal two years of labour earnings (instead of four years when the students complete their college education). Second, based on the data, we assume that the probability of a student dropping out of college (public or private) is a function of her parents’ income:

$$\min\{\kappa_1[1 + (d_cw_c + (1 - d_c)w_n)h_o]^{\kappa_2}, 1\}.$$

This functional form follows Restuccia and Urrutia (2004). The parameter  $\kappa_1$  controls the overall dropout probability, and  $\kappa_2$  determines the correlation between dropping out and parents’ income. Low-income students in developing countries have higher incentives than high-income students to drop out in order to join the labour market and contribute to their households’ earnings.

We use PNAD 2004 data on family income and college dropping out to calibrate parameters  $\kappa_1$  and  $\kappa_2$ . Table 9 shows the moments in the data and in the model. We set  $\kappa_1 = 0.7$  for the model to fit a proportion of dropout equal to 16%, and  $\kappa_2 = -0.5$  so that the model reproduces the negative correlation between family income and dropping out found in the data. Table 8 shows that the efficiency- and the welfare-maximising policies are similar, and increase output and welfare by 34 and 6 basis points, respectively.

*Imperfect substitution between  $e$  and  $g$ .* We now allow for private and public expenditures to be imperfect substitutes in the formation of an agent’s human capital. The effective education investment of a student who attends public school is given by

$$\hat{e} = \alpha (e^\nu + g^\nu)^{1/\nu},$$



Table 9. *College Dropout Calibration.*

Moments	Data	Model
Fraction of dropouts (%)	16	16
Fraction dropouts by income quintile (%)		
Quintile 1	42	44
Quintile 2	37	35
Quintile 3	29	29
Quintile 4	24	24
Quintile 5	13	15

*Notes:* This table shows moments related to dropouts in the data and in the extended model that includes dropouts. See subsection ‘College dropout risk’ in Subsection 4.4 for more details. Moments in the data are calculated from the PNAD 2004 data.

where  $\nu \in (0, 1]$  determines the degree of substitutability between  $e$  and  $g$ . We set  $\nu = 0.7$  to allow for imperfect substitutability, and we find that the optimal income-based affirmative action policies remain qualitatively unchanged under this new parametrisation. Aggregate output increases by 20 basis points in the efficiency-maximising policy, while social welfare is improved by 6 basis points in the welfare-maximising intervention.<sup>36</sup>

4.4.1. *Credit constraint*

Our model features no credit market between periods. We want to emphasise that each period in our model represents approximately 16–18 years, and there is a perfect intraperiod credit market as agents optimise over one single budget constraint each period. Student loans are uncommon and do not constitute a large market in Brazil. However, we stress that this is a reasonable assumption even for the United States, given that the vast majority of student loans in the United States have repayment term of 10 years (Avery and Turner, 2012; Lochner and Monge-Naranjo, 2016; Mueller and Yannelis, 2019). In addition, not every student takes on student loans. In fact, according to the National Center for Education Statistics for the 2007–8 cohort, about 34.1% of students did not take on student loans. However, students who do take on loans can renegotiate their debt, effectively extending their repayment period. For the 1995–6 cohort of college students in the United States, out of those who took on student loans, the median percent of the amount owed 20 years after entering post-secondary education was 5% for students that attained a bachelor’s degree or higher, while the unconditional median was 22%.<sup>37</sup>

Therefore, the bulk of student debt is paid within a 20-year window: the median borrower paid nearly 80% of the loan, while the median borrower who attained a bachelor’s degree or higher paid 95%. This is consistent with the findings of Lochner and Monge-Naranjo (2014). Using data from the 2003 Baccalaureate and Beyond Longitudinal Studies, the authors documented a 8.3% non-payment rate and a 5.2% fraction of debt owed among borrowers 10 years after their graduation. In practice, there is also debt forgiveness for some non-profit and government employees, which may lead to long-term strategic default and inflate these statistics. In our model, all loan debt should be paid in an 18-year period, which is not far from the evidence based on US data. In addition, in order to have affirmative action policies to improve efficiency, it is enough that credit conditions vary with parents’ income. As long as low-income families face more credit constraints, which is a reasonable assumption, our economic mechanism showing

<sup>36</sup> If we vary  $\nu$  from 0.5 to 0.9, which implies an elasticity of substitution varying from 2 to 10, we find similar results.

<sup>37</sup> See Tables 2 (loan amount owed) and 15 (education loans) from NCES (<https://nces.ed.gov/DataLab/TablesLibrary>).

efficiency gains from affirmative action remains unchanged. College credit conditions varying by income is in line with the findings discussed by Lochner and Monge-Naranjo (2012).

## 5. Concluding Remarks

In this paper, we evaluate the effects of income-based affirmative action policies on welfare, efficiency and social mobility. Using microdata at the student level from Brazil, we find that low-income students outperform their higher-income peers in college when they have the same college-admission score. This suggests that efficiency gains can be obtained if college admissions favour low-income applicants. We investigate whether the efficiency and welfare gains generated by income-based affirmative action policies are economically meaningful and outweigh unintended distortions in educational investments. To that end, we build an overlapping-generation model with heterogeneous agents and calibrate it using data from Brazil.

Our main results are that (i) income-based affirmative action can promote economic efficiency and increase aggregate output, by improving the pool of students admitted to public college, and that (ii) an optimally designed affirmative action policy benefits nearly 80% of the families and reduces intergenerational persistence of earnings by 5.7%. Therefore, affirmative action in college admissions is an effective policy to improve welfare and to promote educational opportunities for socially disadvantaged students.

Given the significant welfare gains associated with an optimal policy, it might seem surprising that income-based affirmative action policies are politically controversial. Our results shed light on this apparent paradox from two different angles. First, our results show that—even for the optimal income-based affirmative action—households on the top quintile of the income distribution would significantly oppose the policy. This resistance might pose challenges when trying to pass such policies through the political process. Second, the design of an optimal income-based affirmative action policy is complicated, and, as a result, a suboptimal policy may be implemented. For example, our analysis shows that the policy implemented in Brazil is such a case.

The framework developed in this paper can be extended to study other educational policies designed to alleviate the negative effects generated by the mismatch between college admission criteria and human capital. In addition to affirmative action, other policies that can be beneficial include optimal public school investments for lower-income students, vouchers for private schools and improving the quality of admission exams, among others. We leave this endeavour for future research.

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Additional Supporting Information may be found in the online version of this article:

### Online Appendix Replication Package

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