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Heterogeneous Human Capital: Perspectives on Income Inequality and Leadership in Technology

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Abstract

This paper highlights a new driver of inequality, that may become increasingly prominent over the years: the inequality between skilled workers graduating from elite universities and those from standard institutions.

This paper emphasizes that heterogeneity in higher education is a key factor in understanding both inequality and technological leadership. We introduce a new framework for analyzing economic growth, inequality, and leadership in technology, diverging from traditional innovation models by incorporating the concept of heterogeneity in higher education.

The paper shows that a disparity between elite and standard universities not only contributes to inequality but also fosters technological leadership. The disparity between universities is referred to as the "duality gap", and it measures the distinctions between elite and non-elite universities in quality, budgets as well as tightness of students' recruitment.

In the empirical part of the paper, we check the relationships developed in the theoretical model. To do so, we develop an index of the duality gap both in quality and tightness of recruitment for 17 OECD countries. The data indeed show a positive correlation between the indices of duality gap, leadership in technology, and inequality among OECD countries.

Keywords: ability, heterogeneity, productivity, duality gap, higher education, quality of education, wage premium, international leadership, tightness of students' recruitment.

JEL classification: I26, J24, O14, O4.

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I. Introduction

Perspectives on inequality tend to swing like a pendulum, alternating between periods when the gap between capital and labor incomes is seen as significantly affecting citizens' well-being, and periods when this inequality seems less important and falls off the radar of economists and the media.

The era following the publication of *Das Kapital* by Karl Marx was clearly a time when the ratio of profits to labor income became a key issue in economic policy. Similarly, the release of *Capital in the Twenty-First Century* by Piketty reignited debate over the impact of inequality between capital and labor. Since then, however, the pendulum has swung back, with some suggesting that Piketty's claims were overstated.

Yet, income inequality is not limited to the divide between profits and wages. Recent literature on economic growth has shifted the focus toward the inequality between skilled and unskilled workers. This paper highlights a different driver of inequality, which may become increasingly prominent in many countries: the inequality between skilled workers graduating from elite universities and those from standard institutions.

This paper emphasizes that duality in higher education is a key factor in understanding both inequality and technological leadership. It introduces a new framework for analyzing economic growth, inequality, and leadership in technology, diverging from traditional innovation models by incorporating the concept of duality in higher education. The paper shows that a disparity between elite and standard universities not only contributes to inequality but also fosters technological leadership. This disparity is referred to as the "duality gap."

This paper shows that countries with a high 'duality gap' in higher education are the countries with high inequality, and leadership in technology, while countries with a low duality gap have low inequality and low leadership in technology.

The essential element in this research is the heterogeneity of the higher education system. While in the literature on inequality and economic growth, higher education is characterized as one single element, in fact, higher education institutions are heterogenous and consists of two channels: graduating from a prestigious and elite university or graduating from a standard one.

This paper uncovers theoretically and empirically two main differences between standard and elite universities. First, knowledge disseminated in elite universities is at the frontier of technology, since due to high budgets, they can afford top scholars, good labs and infrastructure. Second, recruitment for elite universities is highly selective. This double gap between universities will be termed as duality gap. It measures the differences between the elite universities and the standard ones. It is different among countries, as shown in the data, and this will explain the difference in leadership and inequality among countries.

Recall that in the literature on inequality and technology, the workers are divided into two categories: skilled and unskilled, but the skilled workers are seen as one single category of homogenous workers. In this paper, we depart from this assumption and in our model skilled workers are heterogenous.

Workers are heterogeneous in two aspects. First, individuals are heterogeneous in their abilities – some are abler than others. Second, and more important, skills are acquired through institutions which are different in their quality. Considering this double heterogeneity --in ability and in quality-- will affect the whole equilibrium of the economy. It will affect leadership in technology and inequality among workers.

The model presented in this paper stresses that the duality gap between elite and non-elite universities enables the differentiation of individuals with high and low ability, so that only high ability students graduate from top universities. This is the first proposition of the paper, i.e., the duality gap in higher education allows us to get a separating equilibrium, in which high ability students graduate from a top university, others from standard ones.

Why is this dichotomy important for the economy and how is it linked to inequality and leadership in technology? The answer lies in the production sector. The economy is composed of high-tech and non-tech goods, as in the literature, but in this model, the productivity of workers working in the high-tech sector and having graduated from an elite university by having received education at the frontier of knowledge is higher than if they would have graduated from a standard university.

Indeed, the main difference between sectors is in the 'match' between the type of education, the ability of the worker and the good produced. Productivity of workers who graduated from an elite school is higher than if they would have graduated from a standard university. In other words, there is a better *match* between high-tech industry needs and the knowledge acquired in top schools, with better labs, top teachers, and knowledge at the frontier of technology. We term this the 'productivity match' in the high-tech sector.

Following our first proposition about abilities of workers, our second proposition stresses that skilled workers with a standard university education, which are with low-ability, are not working in the high-tech sector, while students graduating from an elite university, and who are with high-ability, are. In other words, each sector will hire only one type of human capital, even if both types are perfect substitutes, and this separation of abilities affects inequality, and the difference in labor productivity between sectors. In consequence, there exists a disparity in human capital between the two industries, allowing ex-post, to develop a 'tractable' model.

The logic of this model is that top universities are at the frontier of knowledge and disseminate this knowledge to the best, who can then use this knowledge in the sector which needs it most – the high-tech sector. This is the main message of this paper. It is the match between high ability, top education and high-tech sector, a sector which is a perfect match for the high-level of education, which is essential for analyzing leadership and inequality, as presented in the third proposition of this paper.

Proposition 3 shows that the level of duality of the higher education system affects inequality and leadership in technology: a greater duality gap is related to higher inequality and higher leadership in technology, when inequality is the gap between skilled workers in elite and standard universities, and leadership is defined by the relative productivity of the leading sector. .

In conclusion, this paper relates duality in higher education to leadership in technology and to inequality. This paper shows that inequality is the price of having leadership in technology. A country which only adopts technology and is not at the technology frontier may avoid having duality in the higher education and having inequality. But a country which desires to be "at the frontier of knowledge", must have top universities, in which the entry is through meritocracy, leading to income inequality. There is a trade-off between inequality and leadership.

This paper is divided into two main parts: a theoretical model and an empirical section. The model is relatively simplified, and helps clarify the relationship between three key elements: the duality gap in higher education, technological leadership, and income inequality. As a reminder, the duality gap consists of two components: a quality gap driven by budget disparities, and a gap in the selectivity of student recruitment.

The paper is divided into five sections. In the next section, we review the literature. The model is presented in section III. Section IV displays the empirical analysis.

The empirical section introduces new data. To the best of our knowledge, no one has previously developed an index measuring the duality gap across various OECD countries. This paper presents such an index for 17 OECD countries. A summary of the data can be found in Section IV and in the appendices. We create indices for duality in higher education, as well as an index for technological leadership. Our analysis shows positive correlations between the duality gap, technological leadership, and inequality in OECD countries. Section V concludes.

II. Related Literature

2.1 Leadership in technology

Determining a country's leadership in technology involves considering various indicators and data points. In the literature, there is no single metric that definitively establishes technological leadership, and many indices are used as indicators to assess a country's prowess in the technology sector. A synthesis of the literature can be found in Fernando and Fabien (2016). The main index is the contribution of technology-related industries to a country's gross domestic product, which reflects its economic reliance on and leadership in the technology sector.

Another strategy is to focus on Research and Development (R&D) spending. Some work focuses on total R&D spending, while others focus on main sectors (see Huang and Sharif, 2015 and Nelson and Wright, 1992). There are also researches focusing on number of patents granted, since a high volume of patents suggests a strong focus on technological development (see Nelson, 1990). There is a literature developing various global indices, such as the Global Innovation Index (GII)[1] and the Global Competitiveness Index (GCI) [2], which assess, and rank countries based on their innovation and technology capabilities.

Some research, such as Jaunee (2016), focuses on venture capital (VC) activity and investment in startups which indicate a thriving technology ecosystem. Indeed, countries with a high level of VC funding often foster innovation and entrepreneurship. Similarly, the presence and growth of technology startups, particularly in sectors like artificial intelligence, biotechnology, and information technology, are key indicators of technological leadership. Similarly, the existence of innovation hubs, technology parks, and incubators that support the growth of technology companies and startups is a positive indicator.

An opposite view is to focus not on startup but on established and big companies and analyse the Global Tech Company Headquarters. The presence of global technology giants headquartered in a country is a sign of its influence in the tech sector. Another index of leadership could be to focus on Advanced information and communication technology (ICT) infrastructure since widespread connectivity contribute to a country's technological leadership, enabling the adoption of emerging technologies.

More indices that are common in the literature are "Exports of high-tech out of total exports", and "percent of scientists in the population" (Nelson and Wright, 1992 use both indices), "Human development index" (Kleinknecht et al, 2002) and "Ratio of researchers in R&D" (Nelson and Wright, 1992). Most indices are quite ad-hoc and new indicators may emerge as defining the notion of leadership and technology advances. It could be that AI may change the whole notion of leadership. But as for today, the list we presented is a good description of the various indices which exist in the literature.

Table A2 presents the various variables susceptible of being a good index for leadership in technology, and Table A3 exhibits the correlation between these various indices.

2.2 Heterogeneity in higher education

The previous empirical literature on education has cast doubt on the positive effect of an increase in human capital on economic growth (see Pritchett, 2001; Krueger and Lindhal, 2001; and Benhabib and Spiegel,1994). These results were due to the fact that human capital is defined as a homogenous factor and leads to a bias in the effects of education on economic growth.

[1] https://www.wipo.int/global_innovation_index/en/2023/
[2] https://databank.worldbank.org/metadataglossary/

Research must take into consideration that education and human capital are heterogenous. For instance, Hanushek and Woessmann (2008, 2012) and Barro (2013) stressed the importance of school quality and cognitive skills rather than school quantity. Similarly, Altinok and Aydemir (2016) show that the effect of school quality on growth differs across regions and by the economic level of countries. Brezis and Crouzet (2018) show that differences of quality and recruitment among universities lead to the adoption of different types of new technologies, which affect the level of economic growth.

The duality in higher education, i.e., elite vs. standard universities, has been mainly emphasized in relation to social mobility and inequality, and not to differences in technology. Brezis and Hellier (2018) show that a dual higher-education system characterised by the concomitance of both standard and elite universities generates permanent social stratification, high social immobility and self-reproduction of the elite. Moreover, Kerckhoff (1995) suggests that the effect of family backgrounds could be magnified when the education system is highly stratified and selective. This argument has been confirmed by several empirical works (Hanushek and Woessmann, 2006; Pfeffer, 2008; Dronkers et al., 2011). The model presented in the next section is introducing the heterogeneity in higher education in a model of technological leadership.

In the following model, we link all these elements in order to analyze leadership in technology, inequality and the increase in human capital due to higher education.

III. The model

3.1 Introduction

This model introduces the higher education sector into the conventional models of technological progress, innovations and economic growth. This model is compact and draws on production functions similar to the ones depicted in the literature, as in Autor and Dorn, (2013). However, the model differs in the assumption that human capital is nonhomogeneous. In order to understand the main mechanism of this model, we present a stylized economy with three key features related to the heterogeneity of workers.

(i) Firstly, there is heterogeneity in the ability of individuals, i.e., individuals are not equal in their ability. (ii) There is duality in the higher education market, i.e., all universities are not equal in their quality: There are elite and standard universities; and (iii) There are two goods, and the production functions of traditional non-tech goods and high-tech goods are not similar in the way they make use of human capital.

About the final good, we assume that the economy produces two goods: High tech goods, which include digital economy, computers, electronic, and AI consumed by individuals, and the non-tech goods. The factor of productions of high-tech and non-tech goods are capital, unskilled as well as skilled labor, since workers can either acquire higher education, be ‘skilled’, with human capital H, or without university education, then they are ‘unskilled workers’ denoted L.

Higher education is not homogenous since there is duality in the type of universities. Individuals can either receive education in a top university, (H_E for elite universities) or learn in a standard university (H_{NE} for non-elite). We assume that the type of education the individual acquires is common knowledge since it is acknowledged on his diploma. The assumption on a duality in higher education is not commonly used in models of technological progress and leadership.[3] This is the specificity of this model.

We start the presentation of the model by defining the effect of heterogeneity in the ability of individuals, and in the education market, then we turn to the utility and production section.

3.2 Ability

We assume that individuals are born with different abilities, either high denoted a^h, or low denoted a^l. For sake of simplicity, we assume that $a^h = \delta a^l$ where $\delta > 1$. We also assume that the ratio of high ability workers over low ability workers is σ.

This difference in ability of individuals affects the economy through two channels. First, smarter people learn more rapidly, and therefore for getting the same grade or diploma, they have to invest less effort than an individual with low ability. Obviously. the ability affects their results on entry exams to universities.

The second channel is through the labor market. Ability affects the productivity of individuals: individuals with high ability will have a higher productivity at work, which affects the efficiency of workers. These two channels are essential for understanding the effects of education on leadership in technology and inequality.

3.3 Acquiring skills -The Higher Education sector.

a. The recruitment process

There are elite universities, in which when graduating, the student acquires a human capital of type H_E; and there are standard universities, in which the student acquires human capital of type H_{NE}.

There are exams for entry to the different universities, and the grades on the entry exam to gain access to the elite universities, are much higher than the grades to enter standard universities.[4] In consequence, we get the following partition: Students with high grades on his entry exam will get access to elite universities and acquire human capital of type H_E. Students with lower grades (but

[3] See for instance, Acemoglu and Autor (2011); Autor and Dorn (2013), and all seminal papers in this field by Acemoglu, Aghion, Autor, Dorn et al.

[4] In the various countries, the exam is slightly different. In the US, it is SAT, in France the “prep exams”. See Brezis and Crouzet (2006) for more details.

with a high school diploma) will register to a standard university and will acquire human capital of type H_{NE}. Finally, individuals who did not graduate from high school will stay unskilled, and display a factor of production, L.

Individuals who have graduated from high school can register to classes which are helping them to improve their score on the entry exams. The cost for taking these exams is the cost per hour of these classes, P, multiplied by the number of hours necessary for preparing for these exams. Individuals whose ability is low need plenty of time for the acquisition of the knowledge (i.e., he needs to invest high effort, e^l), whereas individuals whose ability is high need low investment (e^h). For matters of simplicity, we assume that efforts are inverse to the ability level, so that $e^h = 1/a^h$ and $e^l = 1/a^l$.

So the costs for each individual for entering elite universities are:

$$C_h = P.e^h = \frac{P}{a^h} \quad \text{for individuals with high ability} \tag{1}$$

$$C_l = P.e^l = \frac{P}{a^l} \quad \text{for individuals with low ability} \tag{2}$$

and we get that $C_l > C_h$

We assume that the costs for entering standard universities are 0 for high-ability individuals while the costs for low-ability is low but not zero, and we assume it is: $c = P/\gamma a^l$ with $\gamma > 1$ and $\delta > \gamma/(\gamma - 1) > 1$.

b. The externality effect of an elite university: world technology frontier in skills and tasks

What is the specificity of graduating from an elite university? In an elite university, scholars teach at the frontier of knowledge, which will affect the new skills in the economy. Technological changes are a suite of changes, either by creative destruction, or by additive knowledge. Most of them are based on new knowledge taught at the top universities directly, but also indirectly through the peer effect. Indeed, the literature on peer effect highlights that in top universities, since smart people meet other smart people, there is, on top of a better education, an externality of being in the elite school.

This knowledge will diffuse to the standard universities over the years, but for many years, only students at the top universities will get this knowledge which will permit to develop the new skills needed in the development of the high-tech sector.

In this paper, we focus on the science & engineering departments in elite universities, which based on new knowledge in robotic, and technology, give to their students a lead in these skills: the students get the newest knowledge, and they are on the frontier of world technology.

For sake of simplicity, we define this externality as $\lambda = \lambda(I)$, I being the investments in labs and scholars. Students from elite universities are therefore more productive in the high-tech sector, since budgets, I invested in elite universities are higher.

3.4 The two goods in the economy

There are two types of goods in the economy, high-tech goods, T and traditional, non high-tech goods, NT. Consumers want them both, (in different countries, the relative demand is different), and we assume an elasticity of substitution of 1 between these goods, so the utility function will take a Cobb-Douglas form such as:

$$U(T, NT) = T^{\frac{\pi}{1+\pi}} NT^{\frac{1}{1+\pi}} . \qquad (3)$$

π is the ratio of the demand of high-tech over non-tech goods.

3.5 The non-tech production function.

The tech sector as well as the non-tech one uses three factors of production: L, H and K. We assume a CES function between H and L, so that skilled and unskilled workers are substitute factors of production, and we assume that workers (skilled and unskilled), and capital K have a constant rate of substitution of 1. These assumptions are quite common and can be found in the literature on wage premium (see for instance Autor and Dorn, 2013).

Our model differs by assuming that H is not homogenous: we have in fact two different types of human capital, H_E and H_{NE} (workers graduating from elite and standard universities respectively). The two types of human capital are perfect substitute, and the producer can hire either workers graduating from elite universities or from standard universities.

The productivity of each human capital H is a function of the average ability of the skilled workers having acquired this type of education: a_1 and a_2 for non-elites and elite education respectively. So, if only high ability individuals graduate from an elite university, we get $a_2 = a^h$, but if there are equal amount of low ability and high ability graduates from elite universities then $a_2 = (a^h + a^l)/2$.

So, the production function of the non-tech good takes the following form:

$$Y_{NT} = K^{1-\beta}[(a_1 H_{NE} + a_2 H_E)^{\alpha} + (a_u L)^{\alpha}]^{\frac{\beta}{\alpha}} . \qquad (4)$$

where β, α are both between 0 and 1. The respective costs of the factor of productions of L, H_{NE}, H_E and K are: W_u, W_S^l, W_S^h, and r.

3.6 The high-tech production function.

The production function of the high-tech good is similar to the non-tech one. For sake of simplicity, we take a similar ratio in both goods (β is the same in both equations), but we assume a different substitution rate between skilled and unskilled labor, ρ (assumption which can be released. Later on we will also check the case where $\rho = \alpha$).

The main difference between these two sectors is in the 'match' between the type of education and the good produced. For producing high-tech, the productivity of the workers having graduated from an elite university and having received education at the frontier of knowledge has a higher effect than if they would have graduated from a standard university. In other words, there is a better match between the needs of the high-tech industry and the knowledge acquired in top schools. This is the 'productivity match' as λ (which is affected by the level of education in elite universities).

So the tech sector has the following production function

$$Y_T = K^{1-\beta}[(a_1 H_{NE} + \lambda a_2 H_E)^{\rho} + (a_u L)^{\rho}]^{\frac{\beta}{\rho}}. \qquad (5)$$

where β, ρ are both between 0 and 1, and $\lambda > 1$.

3.7 The Equilibrium.

Let us find out, whether there is separation between types of ability, i.e., individuals with high ability work in tech industries while individuals with low ability work in the non- tech industries.

Let us first define conditions Ia and Ib, and then present Proposition 1.

Condition Ia: $\frac{P}{a^l}(\frac{\gamma - 1}{\gamma}) > W_S^h - W_S^l > \frac{P}{\delta a^l}$ **Condition Ib**: $W_S^l - c > W_u$

Proposition 1.

Under conditions Ia and Ib, all individuals with low ability will acquire standard higher education of type H_{NE}, while individuals with high ability, will get access to elite universities and acquire human capital of type H_E.

Proof

The proof is presented in Appendix 1

We now check whether there is also duality in the labor market.

Let us define Condition II:

Condition II: $\frac{\lambda W_S^l}{a^l} > \frac{W_S^h}{a^h} > \frac{W_S^l}{a^l}$

We then get the following Lemma.

Lemma 1

Individuals with human capital of type H_E (having graduated from an elite university) will all work in the high-tech sector, and the individuals with human capital of type H_{NE} (having graduated from a standard university) will work in the traditional, non-tech sector.

Proof - The proof is presented in Appendix 2

We now turn to Proposition 2.

Proposition 2

Under Conditions I and II, individuals with high ability, having graduated from a top university will work in the high-tech sector, and individuals with low ability will work in the low-tech sector.

Proof

From Lemma 1, workers in the tech sectors are with education of type H_E. From Proposition 1 1, those with education type H_E are of high ability. In consequence, individuals with high ability work in the tech sector. Following the same reasoning, individuals with low ability will work in the non- tech sector.

Since the only skilled workers in the tech sector are of high ability and have acquired human capital of type H_E, we then get that $a_2 = a^h$, and the production function takes the following form:

$$Y_T = K^{1-\beta}[(\lambda a^h H_E)^\rho + (a_u L)^\rho]^{\frac{\beta}{\rho}} . \tag{6}$$

Following the same reasoning, the production function of the non- tech sector is:

$$Y_{NT} = K^{1-\beta}[(a^l H_{NE})^\alpha + (a_u L)^\alpha]^{\frac{\beta}{\alpha}} . \tag{7}$$

3.8 The tractable model

Most models of innovations and economic growth do not include heterogeneity of human capital, since equations (4) and (5) are not easily solvable. So, scholars prefer to assume homogenous human capital, and analyze skilled vs. unskilled workers. Out model permits to introduce heterogeneity in human capital and still have a simplified and tractable model, because we have proved that in fact there is a separating equilibrium in the economy.

This separating equilibrium enables us to simplify the "canonical model". This equilibrium also allows us to analyze leadership in technology and inequality between the two types of skilled workers, which today characterizes the inequality between middle and top classes.

We can now check the assumptions under which we obtain that this separating solution is an equilibrium.

Corollary

With production functions presented in equations (6) and (7), Condition III is sufficient to obtain Conditions I and II.

Condition III $\delta(\tau-1) > \frac{P}{W_S^l a^l} > (\frac{\gamma}{\gamma-1})(\tau-1)$ where $\tau \equiv \lambda^\alpha \delta^\alpha \sigma^{\alpha-1} > 1$

Proof

The proof is presented in Appendix 3.

Proposition 2 allowed us to simplify equations (4) and (5), and define the world economy by equations (6) and (7). It allowed us to calculate productivity and the wage premium, when workers with different abilities work in different sectors.[5]

This model stresses that the equilibrium presented in the propositions holds under the assumption that costs of learning are neither too high (so that high ability individuals will invest in acquiring education in elite universities), nor too low (to avoid that low ability students will also invest in acquiring education in elite universities). Then, we obtain that indeed the separation equilibrium is stable and no individual has incentives to deviate from this solution.

Therefore, low ability workers graduate from standard universities and go to work in the non-tech sector. About high ability workers, they graduate from elite universities, and work in the high-tech sector. This separation equilibrium permits us to define leadership and define the elements affecting the level of leadership. It also permits to calculate the various wages, as well as inequality between workers.

3.8 Duality Gap, Leadership in technology and Inequality

The two elements entering the definition of the duality gap are the tightening of the recruitment, which is given by σ (the ratio of students in elite universities over standard ones), and the gap in quality λ, which is a function of the gap in budgets.

As defined in section 2.1, and following Brezis and Krugman (1993, 1997), leadership at the level of a country is defined by the relative productivity of the leading sector, denoted as *Fd*.

[5] For simplicity matters, let us assume that $\sigma = \pi$, so that in a separating equilibrium, the demand for tech and non-tech goods is equal to the supply of these goods.

$$Fd = \frac{Y_T}{Y_{NT}} = \beta \lambda^{\alpha} \delta^{\alpha} \sigma^{\alpha - 1} \tag{8}$$

What about inequality? In appendix 3 we calculate the various wages, and we obtain the wage inequality, equation (9).

$$\omega_3 = \frac{W_S^h}{W_S^l} = (\frac{\lambda a^h}{a^l})^{\alpha} (\frac{H_E}{H_{NE}})^{\alpha - 1} = \lambda^{\alpha} \delta^{\alpha} \sigma^{\alpha - 1} > 1 \tag{9}$$

From equations (8) and (9), we see that productivity gap, Fd and the wage inequality, ω are a function of the two elements affecting the duality gap: the gap in quality due to budgets, λ and the gap in tightness of recruitment, σ (a lower σ means less openness of recruitment, i.e., higher tightness of recruitment).

A higher gap in quality due to a gap in budget, λ leads to higher wage inequality and to an increase in leadership. A lower openness of recruitment σ (which means an increase in tightness) leads to an increase in wage inequality and in leadership.

In conclusion, both elements of the duality gap (quality and tightness) lead to higher leadership. This effect increases over time since the development of innovations magnifies the "matching effect" of education in elite universities. In consequence, the 'productivity match' leads to an increase in the productivity of these workers, and to an increase in leadership in technology. So, we get the following proposition.

Proposition 3

An increase in the duality gap (quality and tightness of recruitment) leads to an increase in leadership in technology and to an increase in inequality.

Proof

Focusing on equations (8) and (9), we see that wage inequality and the leadership index are a positive function of both elements of the duality gap. (when λ increases, Fd and ω increases and when σ decreases, Fd and ω increases).

IV. Empirical Analysis

This paper relates duality in higher education to leadership in technology and to inequality. The empirical analysis is divided into two main tasks. First, there is a need to develop variables on this matter, and then to perform econometric analysis. About the first task, there are no indices on the duality gap in the actual literature. In consequence we have developed an index of the duality gap. This paper also develops a leadership index.

Next, we conduct empirical analysis. Given the novelty of the data and the lack of prior knowledge regarding the relationships among these variables in the economy, we adopt the approach outlined by Corak (2013), focusing solely on correlation to gain insight into the dynamics of the variables.

To do this, we examine for OECD countries, the correlation between duality gap indices, leadership index, and the Gini index. As shown in the following section, we observe that countries with higher duality gap indices in higher education also tend to have higher leadership indices and higher levels of inequality. Our analysis begins with the development of a duality gap index.

The model presented in the previous section has incorporated two main differences between standard and elite universities. First, the gap occurs since knowledge disseminated in elite universities is at the frontier of technology, due to high budgets. Second, recruitment for elite universities is highly selective. An index of the gap between elite and non-elite universities should incorporate these two elements: a gap in quality and a gap in tightness of recruitment. We start with the gap in quality.

4.1 Duality gap in quality

There is a huge difference in the budget per student of elite universities vs. standard ones, and this budget difference leads to difference in quality of education, as emphasized in Desrochers, D. and J. Wellman, (2011).[6] As a result, students graduating from elite universities receive a better education, which leads to higher productivity. This is why we focus on differences in budgets.

The index is presented in Table 1, column 1, and is calculated as follows. For OECD countries, we identify the top universities based on the Shanghai ranking (ARWU) and calculate the budget per student for these top institutions. The duality gap index is the ratio of the budget per student at top universities to the average budget per student.

Here are some concrete examples. In England, the budget per student at the top three universities, including Cambridge, is $80,400, which is 3.12 times the national average of $25,770 per student. In the United States, the top three universities, including Stanford, have a budget per student of $111,500, while the national average is $28,300—3.94 times the average budget.[7]

The index presented in Table 1, col. 1 shows that countries with a high gap index are the US, France, the UK, as well as Israel and Japan. (The index takes the value of 3.9 for the US; 1.2 for Sweden and 1.73 for Finland. For Norway, the duality index is of 1.53).

[6] See Desrochers and Wellman, 2011.

[7] For Sweden, Uppsala University has a budget per student of $28,000 compared to $23,300 for the average budget. So, it is only 1.2 times the average budget. And to give one more example, for Finland, University of Helsinki has a budget of $30,960, compared to $17.920 average budget, so that we have a duality index of 1.73.

4.2 Duality gap in tightness of recruitment

The second element included in the duality gap is the tightness of recruitment. The aim of the index is to check the difference in the tightness of selection between the elite universities and the standard ones.

The way the index is calculated is the following: A priori, we should check the tightness of selection at the level of a university, but because of the absence of information on admission scores, at the level of the entire academic institution for most countries, we gather data on specific subjects of study. We focus on the most popular subjects of study in the countries of the sample, which are Economics, Psychology, Computer science and Law. However, for the US, there is more extensive information and therefore it was possible to perform a calculation at the level of the university, instead of using specific subjects of study.[8]

In the next step, using the Shanghai ranking, we check the universities which are ranked high in those subjects of study and those which are ranked low. For all these universities and subjects, we checked the required admission score.[9]

The duality gap index is calculated as the ratio in the tightness of selection between the average ranked university and the highest ranked one. In each country, and each university, we check the lowest grade needed to be accepted at the university. Given the distribution of students' grade on exams, we can calculate the percent of students who are accepted from the population of students. We denote this percent as the tightness of recruitment in this specific university. Let us present some examples.

In the US, Harvard University is ranked first in the Shanghai ranking. The percent of applicants who are admitted is 5%, so the tightness of recruitment at Harvard is 5%. In average in the US higher education system, we get that 28 % of applicants are accepted. The calculation of the duality index for tightness of recruitment for the US is then 5.6 (28 divided by 5). The data is presented in Appendix 4. [10]

Table 1, column 2 presents the index of the duality gap in tightness of recruitment. In countries with a high level of inequality, such as US, Israel, and the UK, the gap index is high (5.6 for US, and 3.6 for UK) and in countries with a low level of inequality the duality index is also low, such as Denmark (1.1) and Sweden (1.4).

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[8] Information can be found on the government website https://nces.ed.gov.

[9] See Appendix 4 for more details.

[10] In the UK, the top university is Cambridge. The average score of acceptance is such that only 13.8% of applicants are admitted. In the median-ranked University of Fribourg, the university admits 49.2% of applicants. In consequence, the index of the duality gap in the UK is 3.6. (49.2/13.8). See Appendix 4.
In Denmark, the applicant at the University of Copenhagen (ranked first) has a 56% chance of admission compared to a 61% chance for the median-ranked university, Aalborg University. Thus, Denmark's duality index is 1.1 (61/56), significantly lower than the US or UK.

It is interesting to note that the index of duality gap based on budgets (and quality), and the index of duality gap based on tightness of selection are very highly correlated.

4.3. The International Leadership index in Technology

Based on Fernando and Fabien (2016), the leadership index we use is the ratio of the output of the five high R&D intensity industries over total manufacturing in the various OECD countries. According to Fernando and Fabien (2016), OECD Taxonomy of Economic Activities Based on R&D Intensity, those are the industries with high R&D intensity: I. In Manufacturing activities, they are: Air and spacecraft and related machinery (ISIC code 303), Pharmaceuticals (21), Computer, electronic and optical products (26). II. In Non-manufacturing activities, they are: Scientific research and development (72), Software publishing (582).

In Table A1 in the appendix, we present the data for these five industries. The index of technological leadership is calculated as the ratio of production in industries with high R&D intensity over the total production.

The leadership index is presented in column 8, and in Table 1, column 4.

In section 2.1 of the related literature, we have shown that there are other possible indices. They are presented in Table A2. Is there a correlation between all these indices? In Table A3, we present the correlations of these various indices among them, and we also present the correlation with the duality index and the Gini index. The leadership index we present is the one most related to equation (8) in which the leadership index is defined as the ration of high-tech industries over non-tech.

4.4. Correlations between income inequality and international leadership in technology

The data for the various indices are presented in Table 1. Figure 1 shows the correlation between the leadership index and the duality gap based on differences in quality. We find a positive correlation, indicating that duality in higher education, in terms of budget and quality, influences leadership.

In Figure 2, we present the correlation between the leadership index and the duality gap based on recruitment selectivity. Again, we find a positive correlation, meaning that duality in higher education regarding the selectivity of recruitment impacts leadership. These two effects are highlighted in equation (8), which demonstrates that gaps in quality and recruitment selectivity influence a country’s leadership.

Figures 3 and 4 show the correlations between the Gini index and the duality gap based on differences in quality and recruitment selectivity, respectively. We observe a positive correlation, suggesting that duality in higher education—both in terms of budgets and recruitment selectivity—contributes to inequality. These factors are accounted for in equation (9), which analyzes wage inequality.

In Figure 5, we present the correlation between leadership and inequality. Since the gap between elite and standard universities affects both leadership (equation 8) and inequality (equation 9), it is not surprising that there is a positive correlation between leadership and inequality. Countries at the forefront of technology require a heterogeneous higher education system, which inevitably leads to wage inequality among skilled workers. There is no 'free lunch' in building leadership in high-tech.

V. Conclusion

There are many sorts of income inequality going from the gap between capital and labor income, the gap between unskilled and skilled labor, and the gap between skilled workers emerging from a top university to skilled workers from a standard one. This paper focuses on the last type of inequality

This paper shows that a nation implementing a public education policy, which establishes a significant dichotomy between top-tier universities and standard ones, may stimulate innovations and leadership, at the price of income inequality among skilled workers.

The initial finding of this paper is that the duality gap contributes to higher productivity and income inequality by directing high-ability workers toward sectors where high ability significantly influences productivity. In countries with a high gap, a distinction arises among students, resulting in a separating equilibrium. This means that only students with high abilities graduate from top universities, while skilled workers with lower abilities are admitted to standard universities. Conversely, in countries with low duality, there is no separating equilibrium, and no alignment occurs between students' abilities and the universities they attend.

In this paper, the primary distinction between high-tech and low-tech sectors lies in the match between education type, worker ability, and the nature of goods produced. In the high-tech sector, the productivity of workers educated at the forefront of knowledge is higher than if they had graduated from a standard university.

Top universities, being at the forefront of knowledge, play a crucial role. Having the best students directed towards sectors utilizing this knowledge more efficiently leads to technological progress, and to technological leadership. In countries with a high duality gap, there is differentiation among students, ensuring that the best universities impart this knowledge to more capable students who can then apply it in sectors with rapid technological progress, such as the high-tech sector.

In essence, a large duality gap leads to higher worker productivity, by channelling the top workers to the sectors where high ability affects productivity very much. In consequence, countries with heterogeneous higher education can reach the frontier of leadership in technology but at the price of higher inequality, while countries without this dual higher education will not develop high tech sectors and sectors where productivity is high. The choice of the high education policy affects productivity growth.

Another aspect explored in this model is the inequality among skilled workers. This paper argues that inequality is the cost of achieving technological leadership and driving productivity growth. In other words, inequality is a consequence of being at the forefront of technological advancement.

A relevant question arises: does this form of inequality impact citizens' well-being more than the income inequality between capital and labor? While this is an important issue, it lies beyond the scope of this paper.

In the empirical section, we compile data on both the leadership index and the duality gap index, which consists of two components: a quality gap and a recruitment selectivity gap. We show that, in OECD countries, there is a clear correlation between technological leadership, inequality, and the duality gap.

A country that primarily adopts existing technologies without pushing the technological frontier may avoid significant heterogeneity in its higher education system and, consequently, wage inequality. However, a nation aiming to lead in knowledge and innovation must establish elite universities where admission is based on meritocratic exams, which inevitably leads to increased inequality.

An interesting case for future research could be China, which is not an OECD country and is not included in our sample. In China, much of the inequality does not stem from the capital-labor divide, as most capital is state-owned. Nonetheless, inequality is high and continues to rise, largely due to inequality among skilled workers, which is precisely the focus of this paper.

Indeed, China’s higher education system is strongly shaped by its entrance exam to universities, the *gaokao*, suggesting a high duality index. Moreover, the type of inequality discussed in this research has sharply increased in China over the past decade.

In recent years, China has also made significant technological advancements, with a large number of highly cited research papers and substantial investments in high-tech industries. Therefore, the relationship this paper highlights between inequality, leadership, and duality in higher education is not only relevant to OECD countries but also to any nation aspiring to lead in fields that drive economic growth.

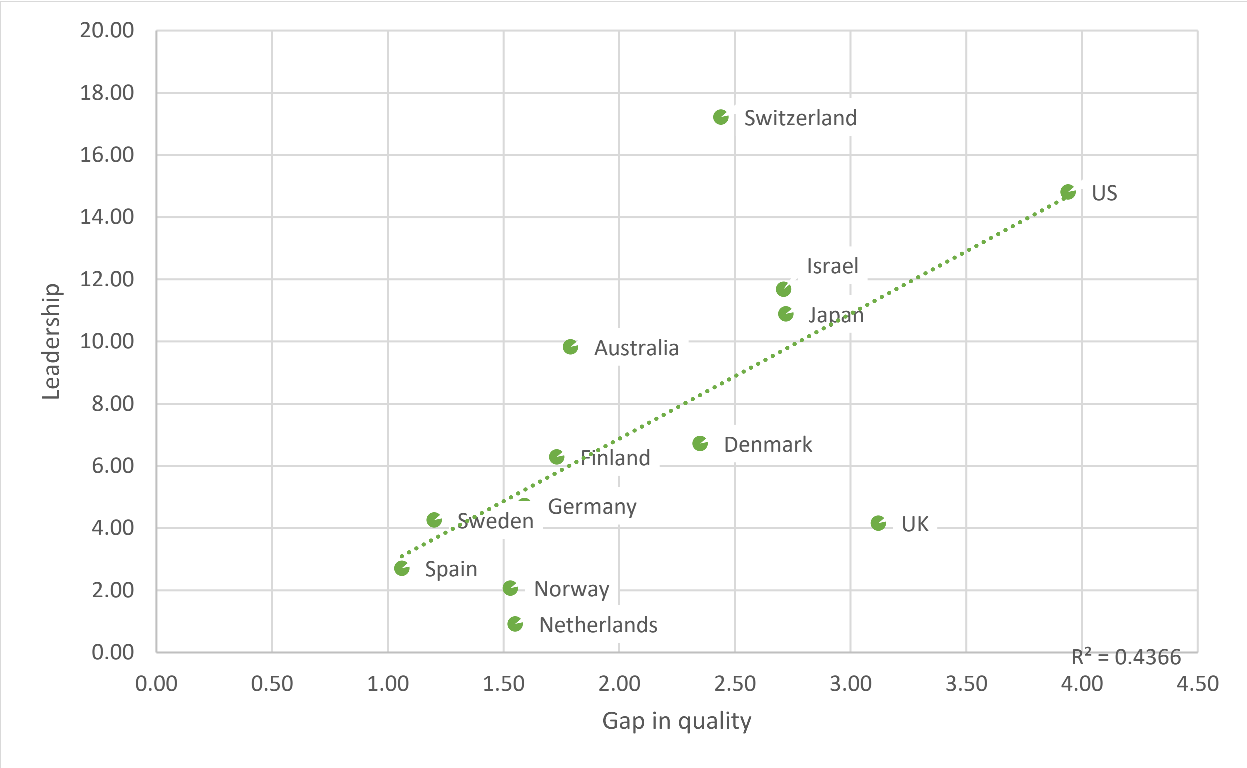
Table 1: Indices on the Duality Gap, Inequality, and Leadership in Technology.

	Index of duality gap in quality (1)	Index of duality gap in recruitment (2)	Gini index (3)	Leadership Index (4)
Australia	1.79	2.8	0.327	9.83
Canada	1.52	2.8	0.316	8.90*
Denmark	2.35	1.1	0.257	6.72
Finland	1.73	1.6	0.262	6.29
France	3.52	3.2*	0.297	6.36
Germany	1.59	2.6	0.294	4.72
Ireland	1.87	3.0*	0.301	9.68
Israel	2.71	3.9	0.350	11.68
Italy	1.02	1.9*	0.330	3.06
Japan	2.72	5.0	0.320	10.89
Netherlands	1.55	2.0	0.306	0.92
Norway	1.53	1.6	0.268	2.07
Spain	1.06	1.6	0.349	2.71
Sweden	1.2	1.4	0.266	4.26
Switzerland	2.44	1.4	0.287	17.22
UK	3.12	3.6	0.357	4.16
United States	3.94	5.6	0.389	14.81

Sources: World Bank, World Forum, and own calculations.

Notes: column (1) is the index of duality gap in quality as explained in section 4.1; column (2) is the index of duality gap in recruitment as explained in section 4.2 and elaborated in appendix 4; Column (3) is the Gini index of disposable income before taxes; Column (4) is the percent of production in Industries with a high rate of R&D, as presented in the appendix Table. A1, column III. * Data to be updated.

Figure 1: The technological leadership index and Duality gap in Quality



Source: own calculation

Figure 2: The leadership index in technology and Duality gap in tightness of selection

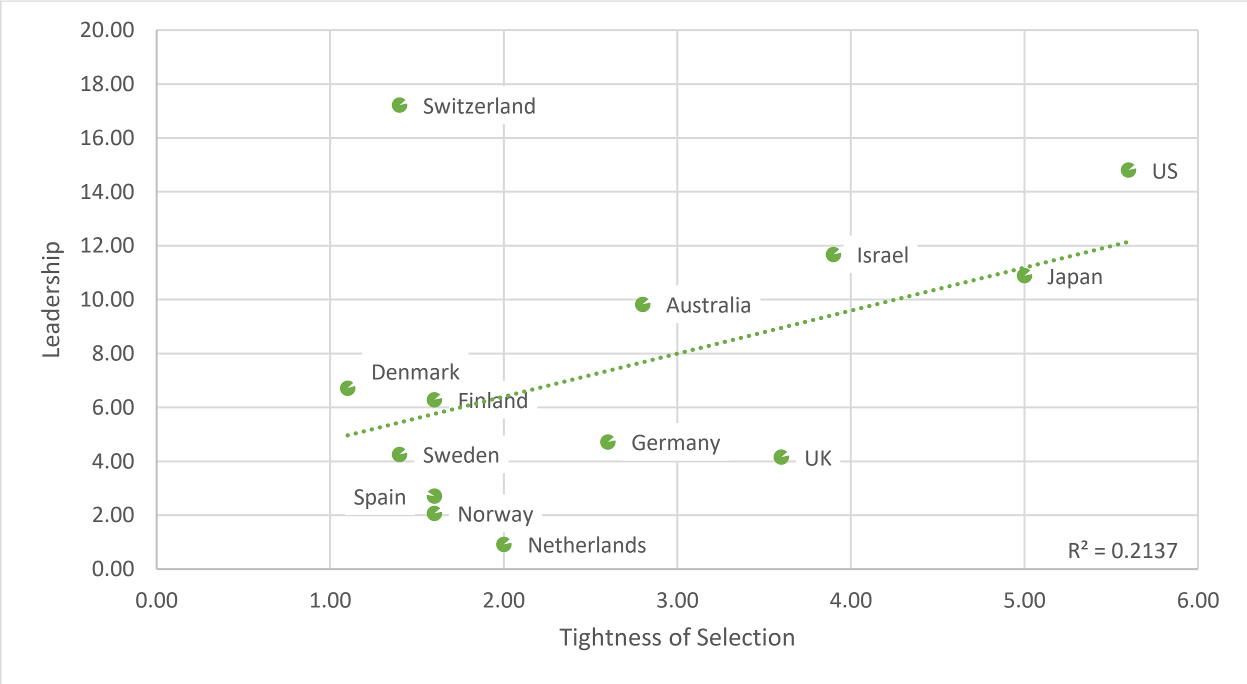
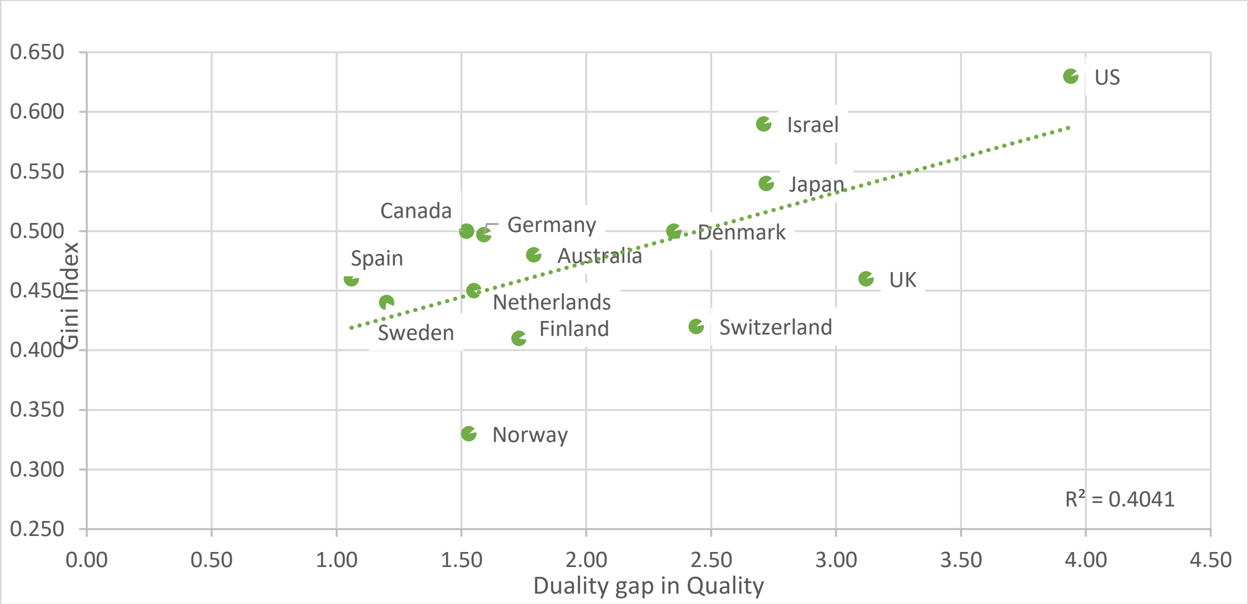
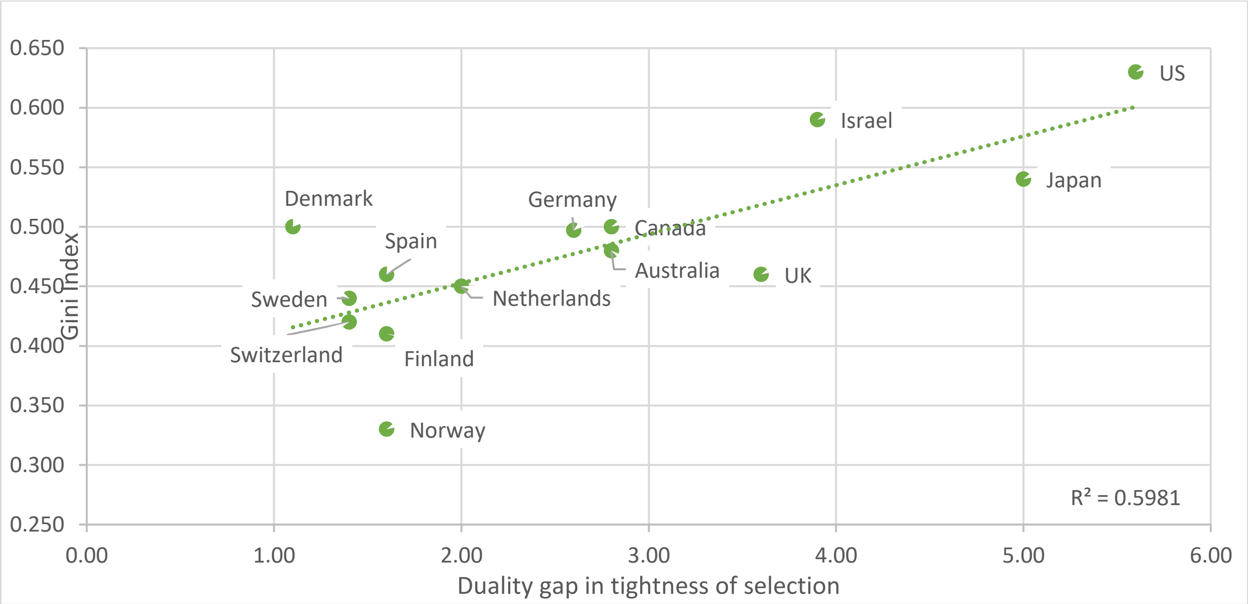


Figure 3: The Gini Index and the Duality gap in Quality



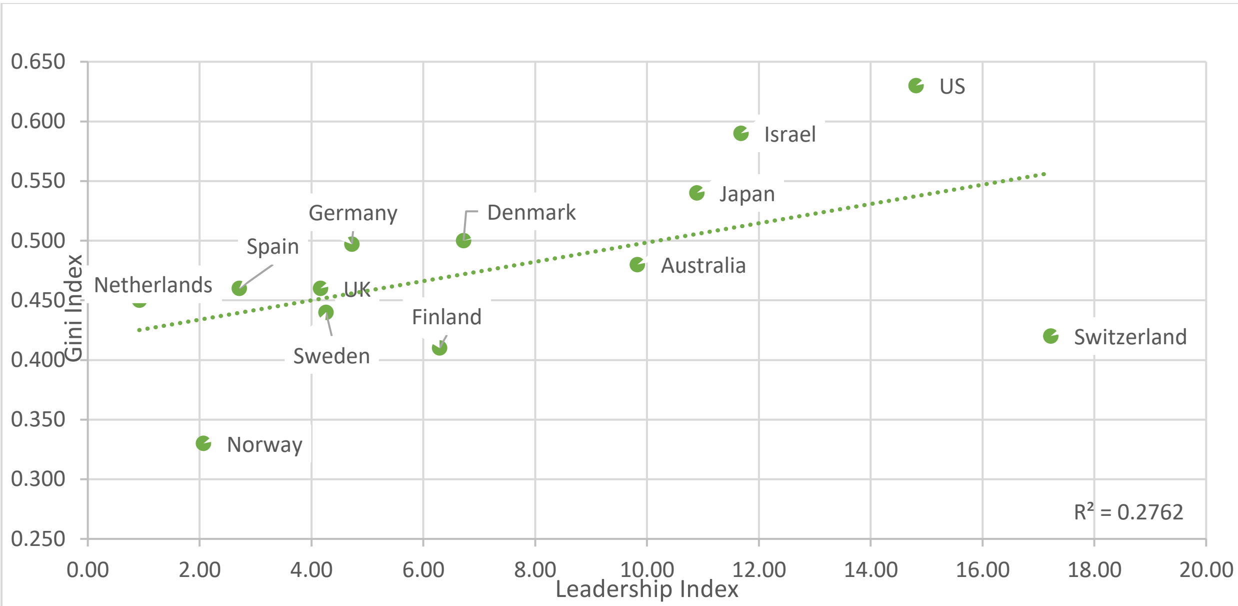
Source: own calculation and The World Bank.

Figure 4: The Gini Index and the Duality gap in tightness of selection



Source: own calculation and The World Bank.

Figure 5: The leadership index in technology and the Gini Index



Source: own calculation and The World Bank.

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Appendix 1

Let us assume that indeed all individuals of high ability acquire H_E, and individuals with low ability go to learn in standard universities. We show that this is an equilibrium, i.e., no individual wants to diverge from this equilibrium.

a).

For a high ability person, from the right-hand side of Condition Ia, it is easy to show that we get the following inequality:

$W_S^h - C_h > W_S^l$

This inequality means that high ability individuals get a higher income from investing in education in elite university than from getting a degree in standard university (remember that costs for high ability individual to learn in standard university are 0). In consequence we have shown that indeed high ability individuals prefer to learn at elite universities.

b).

For a low ability person, from the left-hand side of condition Ia, we get the following inequality (remember that for low-ability individual, cost of learning in standard university is c):

$W_S^l - c > W_S^h - C_l$

which means that a low ability person is better off going to a standard university than to an elite university.

Moreover, from condition Ib, i.e., $W_S^l - c > W_u$, we get that a low ability individual having a high school diploma prefers to enter a standard university than not to get higher education. In consequence low ability individuals enter a standard university.

This lemma states that under Conditions Ia and Ib, we get that the duality in higher education leads to a separating equilibrium: individuals with high ability acquire H_E and individuals with low quality acquire H_{NE} .

Appendix 2

(i) Let us first analyze the tech sector. From the production function displayed in equation (5), human capital of types H_E and H_{NE} are perfect substitute. In consequence the producer will employ the type which is the cheapest for him for producing the same amount of output.

One worker of type H_E (which we know from lemma 1 that he is of high ability) is producing λa^h at cost W_S^h, while the worker of type H_{NE} is producing a^l at cost W_S^l .

It is less expensive to hire workers having graduated from elite universities if:

$\frac{W_S^l}{a^l} > \frac{W_S^h}{\lambda a^h}$ which is equivalent to the left hand side of condition II.

(ii) About the non- tech sector, from equation (4), a worker of type H_E (being of high ability) is producing a^h at costs W_S^h, while the worker of type H_{NE} is producing a^l at cost W_S^l .

It is less expensive to hire workers having graduated from standard universities if:

$\frac{W_S^h}{a^h} > \frac{W_S^l}{a^l}$ which is equivalent to the right hand side of condition II.

Appendix 3

In order to prove the Corollary, let us find out the wages: W_u , W_S^l , W_S^h.

The marginal products of H_E and L are equal to their wages, so:

$$W_u = \frac{\partial Y_T}{\partial L} = \beta K^{1-\beta} L^{\beta-1} a_u{}^{\rho} [(\lambda a^h \frac{H_E}{L})^{\rho} + (a_u)^{\rho}]^{\frac{\beta-\rho}{\rho}} . \quad \text{(A1)}$$

and:

$$W_S^h = \frac{\partial Y_T}{\partial H_E} = \beta K^{1-\beta} H_E{}^{\beta-1} (\lambda a^h)^{\rho} [(\lambda a_h)^{\rho} + (a_u \frac{L}{H_E})^{\rho}]^{\frac{\beta-\rho}{\rho}} . \quad \text{(A2)}$$

So that the wage premium of education of type H_E is:

$$\omega_1 = \frac{W_S^h}{W_u} = (\frac{\lambda a^h}{a_u})^{\rho} (\frac{H_E}{L})^{\rho-1} . \quad \text{(A3)}$$

From the non-tech function of production, the marginal products of H_{NE} and L are equal to their wages, so:

$$W_u = \frac{\partial Y_{NT}}{\partial L} = \beta K^{1-\beta} L^{\beta-1} a_u{}^{\alpha} [(a^l \frac{H_{NE}}{L})^{\alpha} + (a_u)^{\alpha}]^{\frac{\beta-\alpha}{\alpha}} . \quad \text{(A4)}$$

$$W_S^l = \frac{\partial Y_{NT}}{\partial H_{NE}} = \beta K^{1-\beta} H_{NE}{}^{\beta-1} a^{l\,\alpha} [(a^l)^{\alpha} + (a_u \frac{L}{H_{NE}})^{\alpha}]^{\frac{\beta-\alpha}{\alpha}} . \quad \text{(A5)}$$

And the wage premium of education of type H_{NE} (solving as in the case of high-tech) is:

$$\omega_2 = \frac{W_S^l}{W_u} = (\frac{a^l}{a_u})^{\alpha} (\frac{L}{H_{NE}})^{1-\alpha} \quad \text{(A6)}$$

From (A3) and (A6), we get that the wage premium of education of type H_E vs. type H_{NE} is:

$$\omega_3 = \frac{W_S^h}{W_S^l} = (\frac{a^l}{a_u})^{-\alpha} (\frac{H_{NE}}{L})^{1-\alpha} (\frac{\lambda a^h}{a_u})^{\rho} (\frac{H_E}{L})^{\rho-1} \quad \text{(A7)}$$

If we make the simplifying assumption that $\rho = \alpha$, then:

$$\omega_3 = \frac{W_S^h}{W_S^l} = (\frac{\lambda a^h}{a^l})^{\alpha} (\frac{H_E}{H_{NE}})^{\alpha-1} \quad \text{(A8)}$$

Remembering that the ratio of high ability individuals vs. low ability is σ , then we get:

$$\omega_3 = \frac{W_S^h}{W_S^l} = (\frac{\lambda a^h}{a^l})^{\alpha} (\frac{H_E}{H_{NE}})^{\alpha-1} = \lambda^{\alpha} \delta^{\alpha} \sigma^{\alpha-1} \quad \text{(9)}$$

Two conditions to check:

a).

Remember that condition II is : $\frac{\lambda W_S^l}{a^l} > \frac{W_S^h}{a^h} > \frac{W_S^l}{a^l}$

which given equation (9) is equivalent to:

$$\lambda\delta > \lambda^{\alpha}\delta^{\alpha}\sigma^{\alpha-1} \quad \text{and} \quad \text{(10)}$$

$$\lambda^{\alpha}\sigma^{\alpha-1} > \delta^{1-\alpha}$$

And since we have that $\lambda, \delta, \gamma, > 1$ and $\alpha < 1$, then equation (10) holds, when we assume that: $\lambda^{\alpha}\sigma^{\alpha-1} > \delta^{1-\alpha}$. (For instance, if $\alpha = .5$, and $\sigma = 1$, this condition is equivalent to $\lambda > \delta$).

b).

Regarding condition Ia: $\frac{P}{a^l}(\frac{\gamma-1}{\gamma}) > W_S^h - W_S^l > \frac{P}{\delta a^l}$

Since $\tau = \lambda^{\alpha}\delta^{\alpha}\sigma^{\alpha-1} > 1$, then Condition Ia is equivalent to Condition III.

Appendix 4. The duality gap index in students' recruitment

We present data for all the four most relevant fields we examined. We checked the required admission score. [11] In Table 1, we present the average index.

country	Local Rank	Law	Computer Science	Psychology	Economics	Average
Australia	First- The University of Melbourne	8	14	12	10	11
	Median- Deakin University	26	46	29	23	31
	First vs median	**3.2**	**3.3**	**2.4**	**2.3**	**2.8**
Canada	First- University of Toronto	10	8	15	7	10
	Median- Carleton University	20	15	40	40	29
	First vs median	**2**	**1.9**	**2.7**	**5.7**	**2.9**
Denmark	First- University of Copenhagen	31	90	14	88	56
	Median- Aalborg University	49	90	17	88	61
	First vs median	**1.6**	**1.0**	**1.2**	**1.0**	**1.1**
Finland	First- University of Helsinki	5	10	13	5	8
	Median- University of Turku	15	10	15	13	13
	First vs median	**3**	**1**	**1.2**	**2.6**	**1.6**
Germany	First- Heidelberg University	4	4	4	5	4.3
	Median-Martin Luther University Halle-Wittenberg	8	14	9	14	11.3
	First vs median	**2**	**3.5**	**2.2**	**2.8**	**2.6**
Israel	First- The Hebrew University of Jerusalem	3	2	6	11	5.5
	Median- Ariel University. For law: Reichman University	6	10	38	32	21.5
	First vs median	**2**	**5**	**6.3**	**2.9**	**3.9**
Japan	First- The University of Tokyo	1	5	13	5	6
	Median- Miyazaki University For law: Ehime University, for psychology: Ochanomizu University *	30	30	20	40	30
	First vs median	**30**	**6**	**1.5**	**8**	**5**
Netherlands	First- University of Amsterdam	10	10	8	5	8.3
	Median- University of Groningen	20	15	10	20	16.3
	First vs median	**2**	**1.5**	**1.25**	**4**	**2.0**
Norway	First- University of Oslo	1	5	1	9	11.5
	Median- University of Stavanger. for CS and psychology: OsloMet - the metropolitan university	11	15	15	35	19.0
	First vs median	**11**	**3.0**	**15**	**3.9**	**1.6**
Spain	First- University of Barcelona*	45	45	40	60	48
	Median- University of La Laguna. for CS: first- Complutense University of Madrid, median- University of Las Palmas de Gran Canaria.	75	90	50	90	76
	First vs median	**1.7**	**2**	**1.2**	**1.5**	**1.6**
Sweden	First- Lund University	4	8	4	20	9
	Median- University of Gothenburg	7	20	4	20	12.7
	First vs median	**1.7**	**2.5**	**1**	**1**	**1.4**
Switzerland	First- University of Zurich	8	8	13	13	10.5
	Median- University of Fribourg	15	15	15	15	15.0
	First vs median	**1.9**	**1.9**	**1.2**	**1.2**	**1.4**
UK	First- University of Cambridge	15	10	20	10	13.8
	Median- University of Fribourg	56	47	47	47	49.2
	First vs median	**3.7**	**4.7**	**2.4**	**4.7**	**3.6**
US	First- Harvard University					5
	average					28
	First vs average					**5.6**

[11] There are differences between countries in the admission methods and grades required. Some countries require "normalized" external tests (such as the SAT or ACT in the US), other countries require external tests in selected subjects (such as the "A level" in the UK). There are countries where the average grades in high school are enough (such as Sweden) and there are countries that combine different indicators (such as Israel which combines the "Psychometric" test with scores from the matriculation exams) In order to be able to compare the countries and the different admission methods, the scores were converted into a uniform bar, in percentages.

Appendix 5. The Leadership Index- Tables

Table A1: The Construction of the leadership index

	Currency	High R&D intensity category						Total Manufacturing	Leadership Index
		Air and spacecraft and related machinima (303)	Pharmaceuticals (21)	Computer, electronic, and optical products (26)	Scientific research and development (72)	Software publishing (582)	Total (I)	(II)	(III)
Australia	Australian Dollar, 2010	NI	NI	30,340	127,206	14,554	172,100	1,750,320	9.83
Canada									
Denmark	Danish Krone, 2020	612	139,730	33,746	28,680	14,815	217,582	3,236,867	6.72
Finland	Euro, 2020	159	2,182	10,901	1,000	2,931	17,173	272,985	6.29
France	Euro, 2020	69,011	39,255	31,466	7,595	16,830	164,157	2,582,936	6.36
Germany	Euro, 2020	34,230	69,831	91,422	15,550	2,387	213,420	4,520,488	4.72
Ireland	Euro, 2020	35	43,686	11,493	1,481	NI	56,694	585,808	9.68
Israel	Shekel, 2017	11,586	27,079	71,395	28,209	3,767	142,036	1,215,800	11.68
Italy	Euro, 2020	12,928	26,232	18,580	269	4,692	62,702	2,048,668	3.06
Japan	Yen, 2019	1,246	8,255	22,983	NI	NI	32,485	298,429	10.89
Netherlands	Euro, 2020	NI	6,544	23,220	6,658	79	36,501	957,489	3.81
Norway	Norwegian Krone, 2020	NI	16,341	25,287	18,058	22,824	82,509	3,984,621	2.07
Spain	Euro, 2020	8,443	16,024	4,701	3,158	1,042	33,367	1,229,005	2.71
Sweden	Swedish Krona, 2020	NI	144,252	39,476	29,735	56,460	269,923	6,340,010	4.26
Switzerland	Swiss Franc, 2020	2,173	103,388	54,347	17,701	44	177,653	1,031,507	17.22
United Kingdom	Pound Sterling, 2019	28,101	30,035	21,978	27,093	3,214	110,421	2,651,623	4.16
United States	American Dollar 2017	43,916	321,783	288,256	160,362	276,234	1,090,551	7,364,070	14.81

Source: OECD- SDBS Structural Business Statistics (ISIC Rev. 4), Production by sector (https://stats.oecd.org/index). For the US: United States Census Bureau (https://data.census.gov/table) and own calculations.
Note: The data are in hundred thousand, except for Japan, that it is in millions. Column (III) = column (I)/column (II).

Table A2: The various indices of technological leadership in the literature

Country Name	Leadership Index (1)	High-tech exports/ total exports (%) (2)	Ratio of Researchers in R&D / population (per million) (3)	Human Development Index (HDI) (4)	Tertiary graduates (%) (5)	# patent / population (%) (6)	R&D / GDP (%) (7)
Australia	9.83	40.690	4532.40	0.951	20	4	1.829
Canada		17.850	4516.30	0.936	26	6	1.697
Switzerland	17.22	28.841	5551.97	0.962	24	6	3.359
Germany	4.72	26.523	5393.15	0.942	35	15	3.142
Denmark	6.72	25.608	7691.89	0.948	20	5	2.813
Spain	2.71	23.609	3109.24	0.905	20	1	1.429
Finland	6.29	21.834	7527.36	0.940	28	9	2.989
France	6.36	20.756	4926.19	0.903	20	21	2.219
United Kingdom	4.16	20.554	4683.77	0.929	25	7	2.915
Ireland	9.68	16.830	4769.14	0.945	28	1	1.131
Israel	11.68	15.991	-	0.919	23	11	5.557
Italy	3.06	15.805	2671.83	0.895	21	11	1.454
Japan	10.89	13.670	5454.68	0.925	18	115	3.296
Netherlands	0.92	13.370	5911.68	0.941	17	9	2.309
Norway	2.07	12.415	6698.84	0.961	16	7	1.938
Sweden	4.26	8.770	7930.81	0.947	19	5	3.417
United States	14.81	8.132	4821.23	0.921	24	44	3.457

Source: OECD, United Nations, World bank and own calculations.
Notes: Column (1) is the leadership index presented in Table A1, column III. It is based on the calculation of the percent of production in industries with a high rate of R&D. See section 2.2 for the sources of the other various indices.

Table A3: Pearson correlation coefficient between the various indices

	Duality Gap in quality	Gini Index	Leadership Index (1)	High-tech exports/ total exports (%) (2)	Ratio of Researchers in R&D / population (per million) (3)	Human Development Index (HDI) (4)	Tertiary graduates (%) (5)	patent/ population (%) (6)	R&D/ GDP (%) (7)
Duality index	1								
Gini Index	0.404	1							
Leadership Index	0.583	0.2762	1						
High-tech exports/ total exports (%)	-0.105	-0.151	0.137	1					
Ratio of Researchers in R&D / population (per million)	0.018	-0.565	-0.012	-0.154	1				
Human Development Index (HDI)	-0.178	-0.426	0.185	0.236	0.653	1			
Tertiary graduates (%)	0.035	0.077	0.178	0.233	-0.092	0.076	1		
patent/population (%)	0.414	0.625	0.317	-0.306	-0.024	-0.230	-0.183	1	
R&D/GDP (%)	0.458	0.304	0.455	-0.178	0.561	0.053	0.110	0.260	1

Source: own calculations.