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Will Automation and Robotics lead to more inequality?

Elise S. Brezis* and Amir Rubin**

Abstract

This paper presents a new framework for analyzing automation, robotics, and high-tech, which differs from the canonical model of technological progress by incorporating the higher education system. The main difference is that there is not just one type of skilled workers, but two types, and there is not one type of education but two - elite universities and standard ones. The gap between these two types of education is called 'elitism gap'.

The 'elitism gap' in the higher-education sector enables a separation of individuals by their abilities. Since the economy is divided between low-tech and high-tech sectors, the elitism gap leads to a separating equilibrium in which, high-ability workers graduating from top universities work in the high-tech sector, while low-ability workers, graduate from standard universities and work in the low-tech industries. In consequence, human capital in both industries is different, which leads to wage inequality.

We then analyze the effects of an increased use of robotics on inequality. We show that robots affect the “matching effect” between abilities and education, and in consequence, inequality increases. We also show that wages and productivity gaps between high-tech and low-tech sectors are fueled by the elitism gap in higher education. This leads to heterogeneity in human capital, and therefore to an increase in wage inequality.

We develop an index of the elitism gap, and show a positive correlation between the index of elitism gap and inequality in OECD countries.

Keywords: ability, skills, productivity, duality, higher education, robots, wage premium, international leadership

JEL classification: I26, J24, O14, O4.

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I. Introduction

Robots are one of the main inputs in the production of goods, affecting the employment sector by assisting workers or even replacing them. Therefore, the literature on automation and robots has focused primarily on frameworks comprising the labor and the production sectors, without mentioning the education sector. Although these models mention the fact that skilled workers are part of the production, the education sector per se is absent, and the specificity of the education of these skilled workers is not mentioned at all.

The purpose of this paper is to incorporate the higher education sector in a model analyzing robots, and inequality. Why to do so? This paper will show that including how technical changes affect the education of the future workers allow us to present new insights on the relationship between robots and inequality. The focus on higher education allows us to analyze changes in technology and robotics in a framework in which skilled workers are nonhomogeneous.

Recall that in the literature on automation, 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.

Although in most research, higher education is seen as one single element, in fact, higher education institutions are different in their quality. Higher education is heterogeneous and consists of two channels: graduating from a prestigious and top university or graduating from a standard one.¹ This paper uncovers 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, and good labs and infrastructure. Second, recruitment for elite universities is highly selective. The gap between universities will be termed as elitism gap. It measures the differences between the elite universities and the standard ones.

This paper shows that the elitism 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 elitism gap allows us to get a separating equilibrium, in which high ability students graduate from a top university, others from standard ones.

¹ Community colleges are included in the standard higher education. In some countries, recruitment can be different: in Israel, recruitment to the high-tech sector in Israel is through a very specific channel: having been a soldier at the special high-tech unit of the army - 8200.

Why is this elitism gap important for the economy and how is it linked to robotics and technological changes? The answer lies in the production sector. The economy is composed of high-tech and non-tech goods. The main differences between these two sectors stand in the intensity of capital but mainly that in the high-tech, the productivity of workers having graduated from an elite university and having received education at the frontier of knowledge is higher than if they would have graduated from a standard university.

Undeniably, the main difference between sectors is in the ‘fit’ 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 consequence, each sector will hire only one type of human capital, even if both types are perfect substitutes, and this separation of abilities affects the difference in labor productivity between sectors. In other words, 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 robotics and inequality.

How do we define inequality? We define inequality as the wage premium between workers in high-tech and low-tech industries. We show that inequality increases when the introduction of robots, automation and AI magnify the “match 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 inequality.

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

II. Related Literature

1. Heterogeneity in higher education

The 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 Lindahl, 2001; and Benhabib and Spiegel, 1994). The main path to explain these weird results is that human capital is defined as a homogenous factor, and this assumption leads to a bias in the effects of education on economic

growth. Indeed, research must take into consideration that education and human capital are heterogeneous. 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 (2006) 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. Dustmann (2021) raises doubt about the effect of heterogeneity on productivity since in Germany, the apprenticeship system helps workers respond flexibly to shocks in technology, and the author claims that Germany performs as well as countries with duality in higher education. However, *the Economist* (August 19, 2023, p.10) wrote: "Europe's biggest economy has gone from a leader to a laggard.... Germany lacks the talent it needs". Duality in higher education is lacking in Germany.

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 (2017) 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 the basic models of technological changes.

2. Robotics

There is a vast literature on the effects of automation on employment and on wages. Over time, the empirical literature starts to be more homogeneous in their conclusions, that at the micro-level, automation may lead to a displacement of workers, but at the macro level, employment and wages are not affected.

On the micro level, the literature has followed mainly the methodology of Acemoglu and Restrepo (2018, 2020) showing that each robot could displace between four to ten workers.² The Acemoglu-Restrepo methodology has been applied to several other countries. Chiacchio et al.

² Indeed, Acemoglu and Restrepo (2020) stresses that the job destruction effect of automation at the micro level dominates. They analyze the effect of the increase in industrial robot usage between 1990 and 2007 on US labor markets. Using within-country variation in robot adoption they estimate the local labor market effects of robots by regressing the change in employment and wages on the exposure to robots. They find that one more robot per thousand workers reduces the employment to population ratio by about 0.2 percentage points and wage growth by 0.42 %, while productivity increases, and labor share decreases. According to their estimates, each robot installed in the US replaces six workers.

(2018) finds a displacement effect between three and four workers per robot in six European countries, but do not point to robust and significant results for wage growth.

Aghion et al. (2019, 2020) find a displacement effect of ten workers per robot on French administrative data. However, using German data, Dauth et al. (2018) report a null effect of exposure to robots on aggregate employment. For low and mid skilled workers, they report lower wages, while at the aggregate level the use of industrial robots contributes to the fall in the labor share.

It should be noted that there are some empirical works who do not find displacement at the micro-level. For instance, Mann and Püttmann (2018), who measure automation using patent data, paint a different picture. Moreover, Krueger, 1993, Autor et al., 1998 and Bresnahan et al., 2002 who use the measure of computers or IT as a proxy do not find displacement.³

On the macro-level, most papers stress that an increase in productivity due to automation does not reduce employment through spillover effects. Indeed, automating firms become more productive, which enables them to lower their prices and therefore to increase the demand for their products; the resulting increase in market size translates into higher employment in the economy. The decline in manufacturing employment is thus offset by positive employment spillovers on other local industries in the service sector (Dauth et al., 2018; Mann and Püttmann, 2017; Gregory et al., 2016).

In other words, this literature shows that robot densification is associated with increases in both total factor productivity and wages, and with decreasing output prices. Using the same measure on a panel of fourteen European countries, Klenert et al. (2020) find that robot use is correlated with an increase in total employment.

The intuition underlying the reverse effect between micro and macro-economics is that the productivity effect may contribute to the crowding-out of non-automating firms by automating firms. Since the productivity effect inside the automating firm causes an increase in product demand, the market share of the firm goes up at the expense of its non-automating competitors.

In conclusion, automation is not an enemy of employment. By modernizing the production process, automation makes firms more competitive, which enables them to win new markets and therefore to hire more employees in a globalized world. Firms that automate more become more productive, and they obtain larger market shares than their competitors. The resulting gain in market share prompts those firms that automate to produce at a larger scale, and therefore to hire more employees.

³ The local exposure to robots is an indirect measure of robot penetration at the local level, which is based on the rise in the number of robots per worker in each national industry on the one hand, and on the local distribution of labor between different industries on the other hand. Linking automation patents to industries and labor markets, they find a positive effect of automation on employment.

3. Heterogeneity of workers, tasks and skills

Related, but separate from the debate about the nature of direct and indirect effects of automation on employment, there is a debate about the types of jobs that are created or destroyed and the distribution effects of automation. The economic literature has long considered technological change to be labor augmenting and favorable to skilled workers, but a substitute for low-skill workers. This literature puts an emphasis on parameters such as tasks, skills, occupation, and industrial composition as main elements affecting distribution effects.

In the wake of the IT and computer revolution in the 1990s, the emphasis was given to the skill-biased technological change hypothesis. This hypothesis indeed supported the idea of complementarity between technology and skilled workers (see Acemoglu and Autor, 2011, for an overview). Technological change would result in the polarization of the job market, i.e., the slower increase in mid-wage occupations compared to both high-wage and low-wage occupations.

In the 2000s, following the critic of Card and DiNardo (2002), and the seminal paper of Autor et al. (2003), the academic consensus shifted to a labor-replacing view of automation in routine tasks. According to this idea, “traditional” automation replaces routine jobs, and creates more demand for non-routine jobs that cannot be performed by machines. Several studies have documented the disappearance of manufacturing and routine jobs (Autor et al., 2003; Jaimovich and Siu, 2012; Autor and Dorn, 2013; Charnoz and Orand, 2017; Blanas et al., 2019).

It is interesting to note that using Canadian data, Dixon et al. (2019) document a polarization effect: investments in robotics are associated with shrinking employment for mid-skilled workers, but with increasing employment for low-skilled and high-skilled workers, notably managerial activities. This shift from low-skilled to high-skilled workers may also contribute to boosting productivity (Humlum, 2019; Acemoglu et al., 2020).

A new approach is to focus on the effects of technological changes on the dynamic changes in the type of occupations and tasks (with new job titles), instead of focusing on substitution or complementarity.⁴ Robots and automation is then modelled as the (endogenous) expansion of the set of tasks that can be performed by capital, replacing labor in tasks that it previously performed. This takes the form of the introduction of new, more complex versions of existing tasks, and it is assumed that labor has a comparative advantage in these new tasks. In the following model, we take this perspective on automation, and we focus on the innovation process itself which takes place at the level of universities.

⁴ See Acemoglu and Restrepo, 2020.

III. The model

3.1 Introduction

This model introduces the higher education sector into the "regular" models of robots and technological progress. 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 elitism 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.

This paper stresses a specific aspect of the effects of robots on inequality. While most research focus on the robots as a factor of production, this paper put the emphasis on two other features of robots-AI-IT. One is about the final good, and the other is related to higher education.

About the final good, we assume that the economy produces two goods: High tech goods, which include also robots and AI consumed by individuals, and 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).⁵ 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.⁶ 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.

⁵ In Israel, the duality is coming from the recruitment in the army.

⁶ 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.

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 robotics on inequality.

3.3 Acquiring skills -The Higher Education sector.

a. The selection and 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.⁷ 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 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:

⁷ 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. But in Israel, the most important signaling effect for entering the high-tech sector is having worked in the 8200 unit of the IDF as a soldier.

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

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

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 being in 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.⁸

This knowledge will diffuse to the standard universities over the years, but for some 5-10 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 robotics, AI and IT 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, let us define this externality as $\lambda = \lambda(R)$, R being the new development in the research of technology in AI and robots, which enhances the level of productivity of the top students at the top universities by the "enhancement effect, λ ". Students from elite universities are therefore more productive in the high-tech sector.

3.4 The two goods in the economy

There are two sorts of goods in the economy, high-tech goods, T and traditional, non-high tech 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:

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

⁸ The same effect takes place in the 8200 unit in Israel.

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:

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

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. We denote the ‘productivity match’ as λ (which is affected by the level of robotics).

So the tech sector has the following production function

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

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.

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

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:

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

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 tech sector, and individuals with low ability will work in the non- tech sector.

Proof

From Lemma 1, workers in the tech sectors are with education of type H_E . From Proposition 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:

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

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

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

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

This separating equilibrium enables us to simplify the “canonical model”. This equilibrium also allows us to analyze inequality between the two types of skilled workers which characterize today the inequality between middle and top classes. The inequality is within skilled workers – workers with very good education, and workers with education in colleges, which do not permit them to work in the high-tech sector.

I have no doubts, that the discrepancy between wages of unskilled and skilled workers is also very important. But this is not the main story of generations y-z even if this inequality has also increased.

This separating equilibrium leaves us with equations (6) and (7) which allow us to calculate inequality, as in the following corollary.

Corollary

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

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

In consequence, inequality in wages is:

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

Proof

The proof is presented in Appendix 3.

Proposition II allowed us to simplify equations 2 and 3, and define the world economy by equations (6) and (7). It allowed us to calculate the wage premium, when workers with different abilities work in different sectors.⁹ In appendix 3 we calculate the various wages, and we obtain that:

$$\omega_3 = \frac{W_S^h}{W_S^l} = \left(\frac{\lambda a^h}{a^l}\right)^\alpha \left(\frac{H_E}{H_{NE}}\right)^{\alpha-1} = \lambda^\alpha \delta^\alpha \sigma^{\alpha-1} > 1 \quad (8)$$

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 will go to work in the non-tech sector. For high ability workers, they will graduate from elite universities, and work in the high-tech sector. This separation equilibrium permits us to calculate the wage premium, when workers with different abilities work in different sectors as presented in equation (8).

Two essential variables affect the wage-premium equation, and both are related to gap in productivity. The first element is the gap in abilities, δ ; the higher the gap, the higher the wage premium. The second element is the productivity match in the tech sector, λ influenced by change in robotics and AI.

⁹ 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.

3.8 Progress in robotics, IT and AI.

Let us assume, as it indeed happens in recent years, we witness a shift in the types of technological progress. New technologies (embedded into robots, IT and AI) enter the classroom in elite universities and affect the knowledge of students in elite universities vs. standard ones. This happens mainly in sciences.

This paper focuses on higher education in science and engineering. In social and human sciences, the teacher in a top university might have better knowledge (hopefully) than is standard ones, but the class will not be very different. In a classroom in computer science or chemistry; it will be very different.¹⁰ The classes will be equipped with the top IT and robotics. In consequence, the training of high ability students will have a match effect on the high-tech sector. What will be the effect of progress in robotics on inequality?

Proposition 3

The introduction of new robots and AI will lead to an increase in the enhancement factor λ . In consequence wage inequality increases.

Proof

We have shown that in the production function of high-tech, the enhancement effect takes the form of $\lambda = \lambda(R)$, R being the new development in AI and robots technology, which increases the level of productivity of the top students at the top universities by the match effect. From equation (8), when λ increases, then wage inequality increases.

This proposition stresses that the higher this productivity match, the higher the wage premium. This result relates automation to education since elite education leads through better labs and equipment, to an enhancement of the ability of the smart people, due to a better match between the needs of the high-tech industry and the knowledge acquired in top schools.

IV. Empirical Analysis

The model presented in the previous section has developed the notion of an elitism gap which incorporates 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, and good infrastructure. Second, recruitment for elite universities is highly

¹⁰ In Israel, it is slightly different. If you enter (don't worry, you will not) an office in 8200, it will be equipped with the top IT, AI and robotics. In consequence, the training very specific to 8200 which is linked to AI and robotics permit to the best soldiers with high ability to have higher productivity in the high-tech sector. This is the story of the high tech in Israel, although migration is also part of the high-tech success. See Brezis and Krugman (1996).

selective. An index of the elitism gap between elite and non-elite universities should incorporate these two elements.

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).¹¹ In consequence, students graduating from an elite university get a better education -- leading to higher productivity.

The second main difference between elite and standard universities is the tightness of selection. While one needs a very high grade on entry exams to enter elite universities, one needs only a high school diploma to enter a college. So the two elements that define 'elitism of higher education' are (i) the ratio of quality between elite and standard universities, and (ii) the degree of tightness of selection.

We gather data on these two elements: the tightness of recruitment and gap in budgets (which is a proxy for quality) between universities. The data enable us to generate indices of the elitism gap in higher education for each OECD country.

We then check the correlation between these elitism indices and inequality indices. We find that countries with higher elitism in higher education are the countries with higher inequality. In other words, a higher level of 'elitism', i.e., higher gap in quality of universities, and stronger selection is leading to a higher Gini index.

1. Elitism gap in quality

We develop an index of elitism based on the differences in budgets. The index is presented in Table 1, column 1. The way it is calculated is the following. For OECD countries, we gather data on total number of students per university, and budget per student at various universities. We then check which are the top universities, given by the Shanghai ranking (ARWU), and calculate the budget per student for these top universities. The index of the elitism gap is the ratio of the budget per student for top universities divided by the average budget per student.

Let us give some concrete examples. For England, while the budget per student of Cambridge University is of \$123,200, the average expenditure per student in the UK is \$25,770; So some four times the average budget. For the US, Stanford has a budget per student of \$299.900, while the average budget is of \$28,300, some 10 times the average budget.

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 an elitism index of 1.73.

¹¹ Desrochers, D. and J. Wellman. 2011. "Trends in College Spending 1999–2009". In Delta Project on Postsecondary Education Costs. Washington, D.C. <http://www.deltacostproject.org/>

The index presented in Table 1, col. 1 shows that countries with a high elitism index are the US, France, the UK, as well as Israel and Japan. Indeed the index takes the value of 3.9 for the US; 1.2 for Sweden and 1.7 for Finland. For Norway, the elitism index is of 1.53.

2. Elitism gap in tightness of selection

The second element having an impact on the elitism gap is the tightness of selection. 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.¹² We focus on the most popular subjects of study in the countries of the sample, which are Economics, Psychology, Computer science and Law.¹³ 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.¹⁴

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 of these universities and subjects, we checked the required admission score.¹⁵

The elitism index is calculated as the ratio in the tightness of selection between the lowest ranked university and the highest ranked one.¹⁶ In each country, and each university we focus on, 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 selection in this specific university. Let us present some examples.

¹² The countries that we intend to include in the sample are Israel, Denmark, UK, Germany, Sweden, Norway, Spain, France, US, Finland, Poland, Japan, South Korea, Portugal. In this paper, we present the results for 7 countries.

¹³ The most popular subjects: Business management and Economics, Psychology and Social Sciences, Medicine and Nursing, Law, Teacher Education and Pedagogy, Computer science and Information technology, Engineering. We used data on specific subjects of study (Economics, Psychology, Computer science and Law) because of the absence of information on admission scores, at the level of the entire academic institution. In the US there is more extensive information (on the government website <https://nces.ed.gov>) and therefore it was possible to perform a calculation at the level of the educational institution (instead of using specific subjects of study).

¹⁴ Information can be found on the government website <https://nces.ed.gov>.

¹⁵ There is heterogeneity between countries in the admission methods and grades required. There are countries that require "normalized" external tests (such as the SAT or ACT in the US), others 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 combine 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.

¹⁶ One more index was calculated in the same way, but according to a comparison between a university that is not ranked and the one that is ranked in the highest place.

In the US, Harvard University is ranked first in the Shanghai ranking. The percent of applicants who have a chance of being admitted is 5%, so the tightness of selection at Harvard is 5%. In the University of Toledo, which is a non-ranked university, 35% of applicants are accepted.¹⁷ The calculation of the elitism index for tightness of selection for the US is then 7 (35 divided by 5). The data is presented in Appendix 4.

In the UK, the top university (in Economics) is Cambridge. The score of acceptance in Economics is such that only 8% of applicants are admitted. In the non-ranked University of Nottingham Trent, the university admits 31% of applicants.¹⁸ In consequence, the index of the elitism gap in the UK is 3.9. (31/8). See Appendix 4.

In Denmark, the applicant at the Copenhagen Business School (ranked first) has a 33% chance of admission compared to a 50% chance for the unranked university, UCL Business Academy and Professional College.¹⁹ Thus, Denmark's elitism index is 1.5 (50/33), significantly lower than US or UK.

In Germany, the applicant at the Goethe University Frankfurt (ranked first) has a 12% chance of admission compared to 50% chance for the unranked University of Bielefeld.²⁰ Thus, Germany's elitism index is 4.2 (50/12).

A final example is Israel. Tel Aviv University is ranked first in Economics studies where only 8% of applicants are accepted. The non-ranked university, the College of Management accepts 56% of the applicants, and the elitism index is then 7.0 (56/8).

Table 1 lists the elitism indices that were calculated for various countries and in the various subjects sampled. In countries with a high level of inequality, such as US, Israel, and the UK, the elitism index is high (7 for US, 7 for Israel, and 3.9 for UK) and in countries with a low level of inequality the elitism index is also low, such as Denmark (1.5) and Sweden (2.0).

It is interesting to note that the index of elitism based on budgets (and quality), and index of elitism based on tightness of selection are very highly correlated. In fact, an index of elitism could and should integrate these two indices together.

We then check the correlation between the index of elitism and inequality indices. We perform this empirical test only for the elitism gap in budgets. We find a strong correlation between the indices. Indeed, the correlation between the elitism index and the Gini index before tax is of 0.22; between the elitism index and the p90/p10 index, of 0.43; and with the Gini index after tax of 0.54.²¹

¹⁷ <https://www.harvard.edu> <https://www.utoledo.edu>

¹⁸ <https://www.ox.ac.uk> <https://www.port.ac.uk>

¹⁹ <https://www.cbs.dk> <https://www.ucl.dk>

²⁰ <https://www.uni-frankfurt.de> <https://www.uni-bonn.de/de>

²¹ Note that Italy was excluded from the regression due to anomalies in the data.

In conclusion, this research shows that countries with higher elitism gap in higher education are the countries with higher inequality. The model we have presented permits to understand why a gap in tightness of selection and gap in budget affects wage inequality.

V. Conclusion

There is a new and diversified literature on the relationships between robots, employment, and wages. Some of the literature emphasizes that firms using automation and robots are more efficient and are therefore crowding out firms with no robots. In consequence, total productivity increases, wages increase, and since firms using robots are developing more rapidly, they don't have to lay off workers, even if robots displace them.

This paper goes in a completely different line of research and conclusions. The companies which use robotics, and particularly AI, develop more rapidly and crowd out the other firms, because they use people with higher ability, and who acquired their knowledge from the best universities.

In other words, the narrative with robots is not about robotics but about the intelligence of human beings. This is the reason why wage inequality increases. The new economy makes the differences in talent more acute. Robotics enhance human capital for the high-ability ones.

The first result of this paper is that inequality in wages between sectors increases when robots and AI affect the 'productivity match' of education in elite university. Indeed, the elitism gap leads to higher productivity, by channelling the top workers to the sectors where high ability affects productivity much. Recall that we define elitism gap as the differences between elites and non-elite universities. In countries with high elitism gap, there is a differentiation between students. Skilled workers are of high and low ability, but the elitism gap leads to a separating equilibrium so that only high ability students graduate from top universities.

This model also shows that there is a 'match' between the type of education, the ability of the worker and the goods produced. In the high-tech sector, the productivity of the workers having received education at the frontier of knowledge has a higher effect than if they would have graduated from a standard university.

Some of the literature puts the focus on the inequality between low-skilled and high skilled workers; this paper focuses on middle class vs. the top, i.e., between skilled and high-quality vs. skilled and low-quality workers. The effects of the impact of automation, robotics and AI in the economy are that an elitism gap leads to higher inequality. Moreover, this paper shows that as robotics develops over time, inequality increases.

In the empirical part, we have developed an index of the elitism gap. We show that for OECD countries, there is indeed a correlation between inequality and the elitism gap: The higher the

elitism gap, the higher the inequality. In conclusion, incorporating the higher education system into models of robotics and AI leads to different perspectives and conclusions about inequality.

Further research is necessary using this framework relating technological changes to the elitism in higher education. Indeed, in this paper, we have focused on the effects of the elitism gap on inequality. We should, in future research, focus on the effects of the elitism gap on leadership in technology.

Top universities are at the frontier of knowledge. Having the best students who are channelled to the sectors using this knowledge more efficiently leads to leadership in technology. In countries with high elitism gap, there is a differentiation between students so that the best universities disseminate this knowledge to the abler students, who can then use this knowledge in the sectors with high pace of technological changes as the high-tech sector. In consequence, countries choosing to develop dual quality education tracks can reach the frontier of leadership in technology but at the price of higher inequality.

Inequality is the consequence of being at the frontier of technology. A country which only adopts technology and is not at the technology frontier may avoid having an elitism gap in higher education and avoid wage inequality. But a country which wants to be "at the frontier of knowledge", must have top universities, in which the entry is through meritocracy and exams, leading to increased inequality. However, there is a literature stressing that inequality leads to stratification and to very narrow selection in elite universities, despite meritocratic exams.²² We therefore might get a vicious circle, so that small inequality leads to stratification, which leads to inequality. In consequence, there is room for policy intervention, but this is beyond the purpose of this paper.

This paper has shown that an elitism gap leads to inequality. When further research shows that elitism gap indeed leads to leadership, then elitism leads to a trade-off between inequality and leadership in technology. A country with high level of elitism has high level of inequality but will be also the countries with leadership in science and engineering technology.

²² See Pallais et al. (2021), Temin (1999) and Brezis and Hellier (2018).

Table 1: Indices of inequality and the Elitism index.

	Index of Elitism gap in quality	Index of Elitism gap in Tightness of selection	Gini market income (before taxes)	Gini disposable income (after taxes)	P90/P10
Australia	1.79		0.469	0.329	4.3
Canada	1.52		0.421	0.3	3.5
Denmark	2.35	1.5	0.447	0.257	3.0
Finland	1.73		0.382	0.258	3.2
France	3.52			0.303	3.5
Germany	1.59	4.2	0.508	0.296	3.7
Ireland	1.87		0.505	0.287	3.4
Israel	2.71	7.0	0.441	0.342	5.1
Italy	1.02		0.563	0.335	4.6
Japan	2.72		0.458	0.316	5.2
Netherlands	1.55		0.418	0.271	3.4
Norway	1.53	3.7	0.448	0.262	3.1
Spain	1.06	1.7	0.491	0.319	5.0
Sweden	1.2	2.0	0.449	0.279	3.4
Switzerland	2.44		0.393	0.301	3.8
United Kingdom	3.12	3.9	0.474	0.305	4.3
United States	3.94	7.0	0.517	0.371	5.4

Sources: OECD ²³, Hassel (2023) ²⁴ and own calculations.

²³ OECD: P90/P10 is the ratio of the upper bound value of the ninth decile to that of the first decile.

²⁴ The Data of the Gini index, before and after tax, was taken from .Joe Hasell (2023) - "Income inequality before and after taxes: How much do countries redistribute income?". Published online at OurWorldInData.org. Retrieved from: '<https://ourworldindata.org/income-inequality-before-and-after-taxes>' [Online Resource]

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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 (3), 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:

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

(ii) About the non-tech sector, from equation (2), one 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:

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

Appendix 3 -Wages and wage premium

Let us now 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:

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

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:

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

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

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

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

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

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

$$\omega_3 = \frac{W_S^h}{W_S^l} = \left(\frac{\lambda a^h}{a^l}\right)^\alpha \left(\frac{H_E}{H_{NE}}\right)^{\alpha-1} = \lambda^\alpha \delta^\alpha \sigma^{\alpha-1} \quad (8)$$

Two conditions to check:

a).

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

which given equation (8) is equivalent to:

$$\lambda \delta > \lambda^\alpha \delta^\alpha \sigma^{\alpha-1} \quad \text{and} \quad (9)$$

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

And since we have that $\lambda, \delta, \gamma, > 1$ and $\alpha < 1$, then equation (9) 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).

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

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

Appendix 4: selectivity index of elitism

Although, we have focused only on economics as the most popular subject, in this appendix we present data for all the four most relevant fields we examined. We present the data for four countries. All the data can be found in the website.

1. US

The most popular subject in the US is Business Administration and Management (includes economics)

Local Rank	university	Local Rank	International Rank	Acceptance score in % (2021)
first	Harvard University	1	1	95
Non-ranked	University of Toledo	Unranked	Unranked	65
First vs unranked				7

2. UK

The most popular subject in the UK is business and management (includes economics), after Medicine.

Local Rank	Law		Computer Science		Psychology		Economics	
	university	score ²⁵	university	score	university	score	university	score
first	University of Cambridge	88	University of Cambridge	92	University College London	88	University of Cambridge	92
Non-ranked	Abertay University	45	Abertay University	62	Abertay University	45	Nottingham Trent University	69
First vs unranked	4.6		4.8		4.6		3.9	

3. Denmark

The most popular subject in Denmark is Economics.

Local Rank	Law		Computer Science		Psychology		Economics	
	university	score	university	score	university	score	university	score
first	University of Copenhagen	77	University of Copenhagen	50	University of Copenhagen	90	Copenhagen Business School	67
Non-ranked	Copenhagen Business School	62	Professionshøjskolen University College Nordjylland	50	Aalborg University	84	UCL Business Academy and Professional College	50
First vs unranked	1.7		1		1.6		1.5	

²⁵ One hundred minus the acceptance score (in percentages) - represents the level of difficulty to be accepted - the lower it is, the more difficult it is to be accepted.

4. Sweden

The most popular subject in Sweden is Business Administration and Economics.

Local Rank	Law		Computer Science		Psychology		Economics	
	university	score	university	score	university	score	university	score
first	Lund University	95	KTH Royal Institute of Technology	93	Karolinska Institute	96	Lund University	88
u. r	Karlstad University	90	Karlstad University	70	Umeå University	95	Södertörn University	76
First vs unranked		2.0		4.3		1.2		2.0