



Economic growth and the harmful effects of student loan debt on biomedical research



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ABSTRACT

Modern theories of economic growth emphasise the key role of human capital and technological progress in determining a society's standard of living. In some advanced countries, however, higher education costs and the level of indebtedness among graduates have increased dramatically during recent years. This phenomenon is particularly evident in the United States, and within the biomedical sciences sector. In this paper, we develop a basic model of economic growth in order to investigate the effects of biomedical graduate indebtedness on the allocation of human resources in R&D activities and hence on the growth process. In particular, we derive a 'science-growth curve', i.e., a relation between the share of pure researchers and the economy's rate of growth, and we find two possible effects of student indebtedness on economic growth: a composition effect and a productivity effect.

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1. Introduction

Modern theories of economic growth emphasise the role of technological progress in determining a country's standard of living (Jones and Vollrath, 2013). Technological progress, in turn, is ultimately driven by new ideas, generated within research and development (R&D) activities (Weil, 2012). As improvements in knowledge depend heavily on the intellectual efforts of the human capital involved in R&D (NSB, National Science Board, 2012), both the endowment and the quality of pure and applied researchers are crucial factors in explaining differences in per capita income across countries and over time (Meek et al., 2009).

The influence of R&D on economic growth has become even more important over the past two decades, with the advance of so-called 'knowledge-based economies' (OECD, Organisation for Economic Co-operation and Development, 1996). One of the key pillars of economies based upon the production, distribution and use of knowledge is the 'biomedical sciences sector' – i.e., the complex system of interactions among higher education, scientific research, industrial production, and health care services. The role of biomedical sciences as an engine of economic growth is growing rapidly in both developed and developing countries (Bedroussian et al., 2011).

In some developed countries, however, education costs have increased dramatically in recent years. During this period the rate of

growth of college tuition and fees has been, on average, substantially higher than that of the median family disposable income (Johnstone and Marcucci, 2010). This phenomenon is particularly evident in the United States (Callan, 2008), where graduate and postgraduate education is also usually financed by means of student loans (Lee, 2013). As a result, the level of indebtedness among U.S. students and graduates has been increasing sharply for years (Cochrane and Reed, 2012). Nowadays, the causes and consequences of rising student debt burdens are sources of concern for academics and policymakers (Gale et al., 2014; Li, 2013).

In particular, questions have been raised about the negative influence of this phenomenon on a variety of economic outcomes, such as education and career choices, household formation and homeownership, retirement savings decisions, entrepreneurship, and new business formation, among others (CFPB, Consumer Financial Protection Bureau, 2013). Although concerns about the potential harmful effects of increasing student indebtedness are widespread throughout U.S. colleges and universities, the problem seems to be especially troubling for medical schools (Fresne and Youngclaus, 2013; Jolly, 2005) and, more generally, for the actual and future situation of tuition and indebtedness within biomedical sciences as a whole (Garrison et al., 2005). In this paper, we develop a basic model of economic growth in order to investigate the effects of biomedical graduate indebtedness on the allocation of human resources in bio-based R&D activities and, as a result, on the process of economic growth.

The remainder of the paper is structured as follows. The next section briefly outlines the standard Romer endogenous growth model (Romer, 1990) and applies it to a simplified 'biomedical' knowledge-based

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economy. Section 3 attempts to improve the model by introducing the difference between pure and applied research. Section 4 first illustrates the ‘science–growth (SG) curve’ – i.e., the relationship between the share of pure researchers and the economy’s rate of growth – and, second, makes use of this basic tool to investigate some possible consequences on economic growth of increasing student debt burdens. The last section concludes with a few suggestions for further research on the long-run macroeconomic implications of student loan debt in the biomedical field.

2. Economic growth in a biomedical-based economy

The importance of human capital, both as a condition and as a consequence of economic growth, has been deeply investigated during recent decades (Mincer, 1984). In particular, the interest in education as a source of economic growth dates back to the early developments of Solow (1956)’s model (Denison, 1967; Nelson and Phelps, 1966). Since then, the analysis of the interactions between investments in human capital and economic growth has played a key role in a number of seminal contributions (see, e.g., Lucas, 1988; Barro, 1991; Mankiw et al., 1992) and has given rise to a large body of scholarly literature (Acemoglu, 2009).

Relative to this considerable amount of knowledge about the effects of human capital on economic growth, much less is known about the possible consequences of student loan debt on people’s investment in human capital and employment decisions. What we know on these issues comes primarily from empirical investigations. In particular, there is evidence that debt tends to affect college major choice, driving students away from fields with lower expected wages (Rothstein and Rouse, 2011). Researchers also find a negative relationship between postgraduate education and student debt; that is, students with loan debt, ceteris paribus, seem to be less likely to apply to graduate school (Akers, 2013; Millett, 2003). Furthermore, in the labour market, high student debt appears to be the main impediment against a career in the public or not-for-profit sectors, where wages are typically lower than those in business sectors (Field, 2009; Rothstein and Rouse, 2011).

So far, however, there has been little attention on the influence of student loan debt on economic growth. In particular, to our knowledge, there is a lack of theoretical grounding. This paper should be considered as an introductory attempt to fill this gap. We aim to develop a simple but coherent model in order to investigate the possible harmful effects of the burden of student debt on long-run macroeconomic performance, focusing in particular on the biomedical sciences sector.

2.1. Romer’s approach

Let us consider a simple knowledge-based economy in which goods and new ideas are the result of production processes that combine knowledge and highly skilled labour. In this economy, there are two sectors: a consumption goods sector that produces output and an R&D sector that produces new knowledge.¹

Specifically, at each point in time, output (Y_t) is produced by using knowledge and labour, according to the following aggregate production function:

$$Y_t = A_t \times L_{Yt} \tag{1}$$

where A_t denotes the stock of existing ideas and L_{Yt} is the number of workers (for example, physicians). Because ideas are nonrivalrous, the stock of existing knowledge is also used in the R&D sector, together

with biomedical researchers (L_{At}), in order to produce new ideas, according to the following aggregate production function:

$$\Delta A_t = z \times A_t \times L_{At} \tag{2}$$

where Δ is the ‘change over time’ operator, so that ΔA_t measures the flow of new knowledge produced during period t (i.e., $\Delta A_t = A_{t+1} - A_t$), and z is a parameter that denotes labour productivity (that is, the average number of new ideas generated per researcher). In contrast to ideas, labour is rivalrous: although the available stock of high skilled workers (L) can be freely allocated to either of the two sectors, the same worker cannot simultaneously be allocated to both (output and research) sectors. Therefore, the economy is subject to the following resource constraint: $L_{Yt} + L_{At} = L$ (where L is also equal to the total population, which we consider to be constant).

In this simplified biomedical-based economy, researchers produce new ideas and physicians produce health care (such as diagnoses, medical treatments and disease prevention). To begin, we assume that researchers are a constant fraction (q) of the total labour force, so that $q \times L = L_{At}$. This leaves the economy with $(1 - q) \times L = L_{Yt}$ workers allocated to the consumption goods sector. As a result, the production functions for output and ideas become, respectively:

$$Y_t = A_t \times (1 - q) \times L \tag{3}$$

$$\Delta A_t = z \times A_t \times q \times L \tag{4}$$

This means that, for a given sectoral allocation of the labour force, workers in the goods sector produce an amount of output per capita that depends on the stock of existing knowledge. Dividing the new production function for the output sector – i.e., Eq. (3) – by total population (L) gives:

$$Y_t/L = [A_t \times (1 - q) \times L]/L \rightarrow y_t = A_t \times (1 - q) \tag{5}$$

where, given q , the average level of output per person ($Y_t/L = y_t$) is proportional to A_t . More specifically, output per capita increases with the flow of new ideas invented by the people involved in the research activity, but because the number of researchers is constant, Eq. (5) also shows that:

$$g_y = g_A + g_{(1-q)} \rightarrow g_y = g_A \tag{6}$$

The rate of growth in output per capita (g_y) will be approximately equal to the rate at which researchers generate new ideas, g_A . Finally, Eq. (4) indicates that, over time, the accumulation of new ideas proceeds at a rate equal to:

$$\Delta A_t/A_t = (z \times A_t \times q \times L)/A_t \rightarrow g_A = z \times q \times L \tag{7}$$

that is, the growth rate of knowledge is constant and exogenously determined by the parameters z , q and L . However, since $g_y = g_A$, the rate of growth in output per capita ($\Delta y_t / y_t = g_y$) is also constant and equal to the product zqL . In other words, economic growth is driven by technological progress resulting from R&D.

3. Pure and applied biomedical research

In economics and science policy, it is often useful to distinguish between basic and applied research (Roll-Hansen, 2009). We introduce this distinction in the model by assuming that the R&D sector includes two main activities. The first is a curiosity-driven research process, undertaken primarily to acquire new knowledge of general interest, without regard to particular applications. The second is a practical-driven

¹ For the sake of simplicity, following Jones (2011) and Weil (2012), we focus only on the basic elements of Romer (1990)’s model. We therefore present the model in a simplified version, without discussing its microeconomic foundations.

research process, devoted to transform this pure scientific knowledge into a collection of blueprints in order to produce consumption goods (OECD, 2002).

In particular, the curiosity-driven research activity generates a flow of new fundamental (i.e., scientific) ideas (ΔR_t), by using the stock of existing basic knowledge R_t and the efforts of L_{Rt} pure biomedical researchers, according to the following production function:

$$\Delta R_t = \pi_R \times R_t \times L_{Rt} \quad (8)$$

where π_R is a parameter that indicates the average labour productivity in the pure research sector. In the same way, the practical-driven research activity generates a flow of new applied (i.e., technological) ideas (ΔD_t) by combining the stock of existing technological knowledge D_t with the efforts of L_{Dt} applied biomedical researchers, according to the following production function:

$$\Delta D_t = \pi_D \times D_t \times L_{Dt} \quad (9)$$

where, again, π_D is a productivity parameter that measures the number of new blueprints produced per applied researcher. Finally, the stock of blueprints accumulated by society is also utilised within the output sector to produce health care, according to the following aggregate production function:

$$Y_t = D_t \times (1 - q) \times L \quad (10)$$

where, as in the previous section, $(1 - q)$ denotes the share of total labour force (L) allocated to the consumption goods sector and thus $(1 - q) \times L$ measures the number of workers (i.e., the number of physicians).

Now let us assume that, at time t , a fraction of researchers equal to β_t are involved in basic research. Because the economy's total endowment of researchers is qL , this means that $\beta_t \times qL$ and $(1 - \beta_t) \times qL$ measure the number of researchers employed to produce the flows of fundamental and applied knowledge, respectively. Hence, the production functions of the R&D sectors can be rewritten as follows:

$$\Delta R_t = \pi_R \times R_t \times \beta_t qL \quad (11)$$

$$\Delta D_t = \pi_D \times D_t \times (1 - \beta_t) qL \quad (12)$$

and, consequently, the rates at which the economy is able to generate the flows of new basic (g_R) and applied (g_D) knowledge become:

$$\Delta R_t / R_t = (\pi_R \times R_t \times \beta_t qL) / R_t \rightarrow g_R = \pi_R \times \beta_t qL \quad (13)$$

$$\Delta D_t / D_t = [\pi_D \times D_t \times (1 - \beta_t) qL] / D_t \rightarrow g_D = \pi_D \times (1 - \beta_t) qL \quad (14)$$

That is, given the productivity parameters (π_R and π_D) and exogenous variables q and L , the growth rates of pure and applied ideas depend on the sectoral allocation of researchers between the discovery of new fundamental and technological ideas (g_R and g_D are both, *ceteris paribus*, a function of β).

3.1. Interactions between pure and applied biomedical research

The basic and applied research processes, however, are related by a complex set of interactions (Nelson, 1993). In general, science and technology tend to reinforce each other. The progress of science expands the knowledge base for the advancements of applied research, and the evolution of technology opens up new possibilities for improvements in fundamental research. Basic and applied research, in fact, represent the extreme points of a continuum, on which the former informs the latter and vice versa (Flynn et al., 2012).

One way of modelling these interdependences within R&D processes is to suppose that the productivity of applied researchers (π_D) is

positively influenced by the rate of growth in pure knowledge, as follows:

$$\pi_D = z_D + \alpha \times g_R \rightarrow \pi_D = z_D + \alpha \times (\pi_R \times \beta_t qL) \quad (15)$$

where z_D indicates the autonomous component of the average labour productivity in the development sector, while α is a constant, between 0 and 1, that measures the efficiency by which new scientific ideas are transferred into technical expertise (and where g_R is here replaced by its expression from Eq. (13)). This standard 'basic to applied' model of innovation, however, captures only one aspect of the complex process of knowledge discovery in the health care sector (Andras and Charlton, 2005). In particular, biomedical research is a demand-driven process, largely characterised by a problem-solving approach, with feedback mechanisms across all components of the research system (Rees, 2004).

We therefore complete the model by adding the positive effects of applied research to the productivity of basic researchers. On the one hand, we assume that z_D has a corresponding parameter in the production function of basic knowledge z_R , which measures the autonomous component of the labour productivity of pure researchers. On the other hand, we assume that z_R is strengthened by z_D , by supposing that the full productivity parameter in the basic research sector (π_R) is the product of z_D multiplied by z_R . Therefore, it is really:

$$\pi_R = z_D \times z_R \quad (16)$$

representing the average productivity of researchers who work to broaden the economy's stock of fundamental knowledge.

As in the standard Romer model developed in the previous section, economic growth is again led by the generation of new ideas. In fact, by dividing the final goods production function – Eq. (10) – by the total population (L), we obtain a new expression for the level of output per capita:

$$Y_t / L = [D_t \times (1 - q) \times L] / L \rightarrow y_t = D_t \times (1 - q) \quad (17)$$

In addition, because q is still constant, the growth rate of output per capita is equal to the rate of growth in knowledge, particularly of technological knowledge, $g_y = g_D$. If the progress of applied knowledge ceases, so will per capita output growth. Therefore, to compute the growth rate of the economy, it suffices to solve the model for g_D , which, in turn, is determined by the production functions of pure and applied knowledge as well as by their interactions.

More specifically, by substituting in Eq. (14) the productivity parameter of applied research (π_D) with its expression from Eq. (15), the rate of growth in applied knowledge becomes:

$$g_D = [z_D + \alpha g_R] \times (1 - \beta_t) qL \rightarrow g_D = [z_D + \alpha \times (\pi_R \times \beta_t qL)] \times (1 - \beta_t) qL \quad (18)$$

Finally, by using Eq. (16) to include the positive effects of applied to pure research productivity, we obtain:

$$g_D = g_y = [z_D + \alpha \times (z_D z_R \times \beta_t qL)] \times (1 - \beta_t) qL \quad (19)$$

where g_y is entirely written as a function of the exogenous parameters of the model. Eq. (19) has a nice interpretation. The growth rate of applied knowledge, and thus the growth rate of the economy, depends on four key factors, namely 1) the labour productivity of both kinds of researchers, z_D and z_R ; 2) the efficiency of scientific knowledge transfer, α ; 3) the total labour force, L ; and 4) the allocation of L between workers and pure or applied researchers, q and β .

In particular, given qL and β – that is, given the number of researchers and their allocation to R&D activities – the economy's rate of growth becomes a function of the ability of its researchers to discover

new ideas and of the efficiency of the technology transfer mechanism. In other words, g_y will be greater: 1) the more productive are both kinds of researchers, and 2) the greater is the fraction of new pure ideas transferred into technical expertise. It is worth noting that the autonomous component of applied researchers' productivity has both a direct and an indirect effect on the growth rate of output per capita (through its influence on g_D and g_R , as shown in Eqs. (15) and (16), respectively). As a result, a given increase in z_D has a stronger effect on g_y than an equal increase in z_R . Finally, the interactions between the productivity of the two kinds of researchers – the product $z_D \times z_R$ in Eq. (19) – tend to reinforce the key role of technology transfer. In other words, an efficient transfer mechanism generates a virtuous cycle within R&D activities.

4. An SG curve

The solution of the modified model developed in the previous section allows us to analyse some comparative statics. In particular, Eq. (19) shows that, for a given value of all other parameters, the growth rate of per capita income depends on the distribution of researchers between the discovery of new fundamental and technological ideas (that is, g_y is a function of the coefficient β).

The relation between g_y and β (ceteris paribus) is illustrated in Fig. 1, where the fraction of pure researchers is measured on the horizontal axis, while the growth rate of output per capita is measured on the vertical axis. If all researchers were employed in the development sector (i.e., if $\beta = 0$), the economy's rate of growth would be $g_y = z_D \times qL$ (point A) and the model would reduce to the standard Romer result depicted in Eq. (7), with the only difference using z_D instead of simply z as the measure of labour productivity. By contrast, if all researchers were dedicated to the discovery of new scientific ideas (i.e., if $\beta = 1$), then $(1 - \beta_t)qL = 0$; as a result, the growth rate of the economy would be $g_y = 0$ (point E). In other words, with no applied researchers, there is no progress in the stock of technological knowledge ($\Delta D_t = 0$) that enters into the output production function, hence $g_D = g_y = 0$.

In between these extreme allocations, an increase in the share of pure researchers, on the one side (i.e., in the research sector), leads to an increase in g_R and thus to an increase in g_D – through the transfer of scientific knowledge, as described in Eq. (15) – while, on the other side (i.e., in the development sector), this leads to a decrease in g_D due to the decrease in the number of applied researchers. Starting from point A in Fig. 1, and reallocating researchers from the development to the research sector, the economy's growth rate increases until the

former effect is greater than the latter. Therefore, as β increases toward one, the function $g_y = f(\beta)$ rises, reaches a maximum (at point C) and then declines to zero.

The specific shape of this SG curve depends on the features of the production process of new pure and applied ideas and thus – given q and L – it depends on the determinants of the parameters z_D , z_R , and α . Different values of these parameters shift the curve upward or downward and affect the slope of its increasing and decreasing sections.² Overall, however, given our assumptions, the curve has three main characteristics. First, the same rate of growth in income per capita (for example, g_y°) may arise from different researcher compositions such as, for example, β_1 or β_2 (points B and D in Fig. 1, respectively). Second, given the total number of researchers (qL), the optimum mix of pure and applied researchers – i.e., the level of β that maximises g_y , (β^*) – increases as z_R and α rise, shifting the maximum (point C) to the right; that is, the more productive are pure researchers and the more efficient is the process of knowledge transfer, the greater is the optimal level of β . Third, β^* tends to 0.5 as the product $\alpha z_R \times qL$ grows (as shown in the Appendix).

4.1. Student debt and economic growth

The choice to work as a pure or an applied researcher is likely to be influenced by different factors (e.g., personal preference and aptitude, social conditioning, education costs and potential earning, among many others). In general, however, the educational process to become a biomedical researcher requires great efforts for several years and a substantial investment in human capital. If individuals finance their studies largely by means of education loans, as college costs increase over time faster than average wages, future researchers will use a rising proportion of their disposable income to repay the biomedical school loan. This economic dimension may, therefore, play an important role in explaining researchers' preferences toward pure or applied knowledge discovery as a professional career.

In order to examine this issue, let us assume that both pure and applied researchers have to follow the same higher education core curriculum in biomedical sciences. Regardless of the differences in tuition and fees between the various U.S. institutions, we also suppose that all researchers incur about the same total (implicit and explicit) cost of attending their graduate and postgraduate programmes. In the labour market, however, basic research is typically undertaken in universities as well as other not-for-profit centres supported by the government and is mainly financed through public funds. Moreover, academic researchers usually receive both low pay and low benefits compared with applied researchers, who are most frequently employed in biomedical business-oriented organisations (GECD, Global Education and Career Development, 2012; Palmer and Yandell, 2013).

We therefore assume that the expected return on education for L_R is, on average, lower than that for L_D . This means, on the one hand, that pure researchers tend to be more exposed to the consequences of indebtedness than applied researchers and, on the other hand, that the wage gap between pure and applied research activities and the rising burden of student debt may have a crucial influence on the composition of the researcher workforce.

More particularly, past increases in higher education costs affect today's level of indebtedness among all researchers (qL), and a high stock of debt accumulated during university years implies, ceteris paribus, a decrease in the current level of consumption and savings due to loan repayments. Therefore, for actual society's workforce of pure researchers $\beta_t qL$, whose salaries are lower compared with their

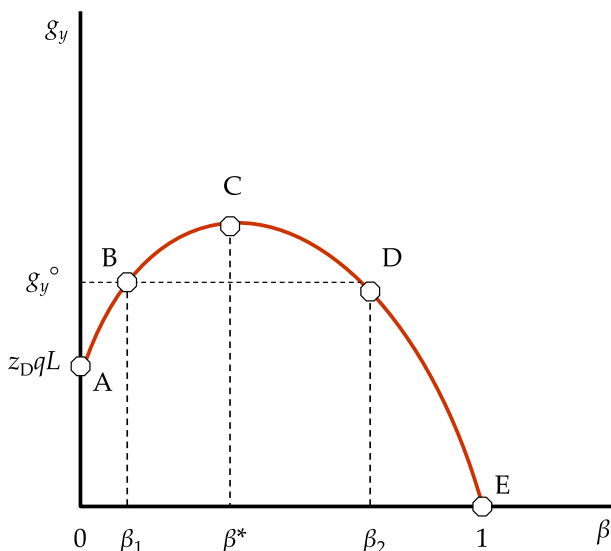


Fig. 1. The science–growth curve.

² Many other factors may influence the curve's slope and position. For instance, some processes of knowledge discovery simply duplicate already existing knowledge and thus they do not generate really new ideas. In this case, only a fraction of the total flows of pure and applied ideas increases the economy's stock of fundamental and technological knowledge and thus affects the growth process.

applied counterparts $(1 - \beta_i)qL$, this represents an incentive to leave university for more gainful positions as technological researchers in biomedical-related industries.

Overall, the sectoral allocation of high skilled workers has important implications for economic growth (Murphy et al., 1991). Likewise, changes in the composition of the economy's researcher workforce may also affect the growth rate of output per capita. By using the SG curve, we are able to show that a process of researcher reallocation between bio-medical R&D activities due to the burden of student debt has two main consequences on economic growth: a 'composition effect' and a 'productivity effect'.

The 'composition effect' refers to a change in the mix of researchers, and it corresponds to a movement along a given SG curve – for example, a decrease in β (from β_2 to β_1) that pushes the economy from points D to B on the SG curve, as shown in Fig. 2. A decreasing share of pure researchers has a positive influence on the output growth rate only if the economy is operating to the right of point C (i.e., only if the current level of β is greater than β^*). Otherwise, a reduction in β , because of researcher indebtedness, has a negative effect on growth: the number of scientists and thus the flow of new fundamental ideas become too small to support the economy's potential growth rate, given its endowment of resources and knowledge.

The 'productivity effect' refers to a change in the average labour productivity of pure researchers, and it corresponds to a shift in the SG curve – for example, from SG to SG', in Fig. 2. Specifically, if the difficulty repaying their college debts turns highly talented researchers away from pure science, the intellectual level of the academic community will gradually deteriorate. Hence, as universities and other not-for-profit centres lose the brightest minds, the autonomous component of pure researchers' labour productivity (z_R) tends to decrease, shifting the economy's SG curve downward. As a result, this phenomenon decreases the output rate of growth, for any given mix of pure and applied researchers – i.e., for any value of β (for example, in Fig. 2, g_y falls from points D to F or from B to E, corresponding to β_2 and β_1 , respectively).

Moreover, the 'productivity effect' may be exacerbated in the presence of substantial differences in education costs among universities. Top ranked institutions have typically both the lowest acceptance ratio and the highest tuition fees. The brightest students – who will probably be the most productive future scientists – usually apply to colleges with the highest academic reputation. Thus, expected low starting wages and slow income growth may push the best future researchers away from the curiosity-driven research curriculum in order to abate the expected pressure of student debt on their future living standards.

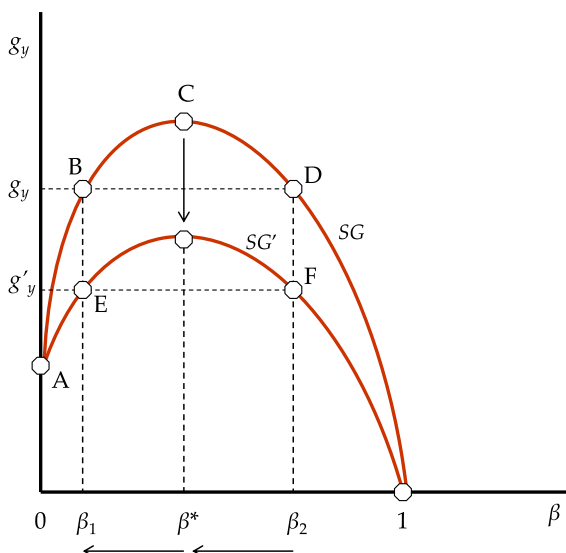


Fig. 2. Composition effect and productivity effect.

Finally, if the total number of pure and applied researchers is constant, the consequences on economic growth of the reallocation of human capital within R&D activities become the sum of both the composition and the productivity effects. Hence, with a decrease in β from β_2 to β_1 , for example, the economy starts at point D on the SG curve and ends up at point E on the lower SG' curve. More generally, because it is less likely that the economy operates (in the long run) to the right of point C, where $\beta > \beta^*$ – that is, with a structural excess of scientists employed in pure curiosity-driven research programmes (Sargent, 2014) – the decrease in the share of pure researchers unambiguously reduces the economy's potential growth.

5. Conclusions

Modern economies are increasingly reliant on knowledge-related economic activities. This is why human capital will play a more crucial role in determining long-run economic growth. Thus, as highlighted by Nobel Laureate Joseph E. Stiglitz, the costs of higher education and graduates' level of indebtedness represent not only a problem of equality of opportunity, but also a serious threat to the future prosperity of advanced economies (Stiglitz, 2013).

In this paper, we show that, from the standpoint of society as a whole, the high level of the indebtedness of pure researchers may have severe negative effects on economic growth. It is worth noting that our results rely upon two main hypotheses. First, a sort of brain drain from curiosity-driven to business-oriented research activities may generate a shortage of biomedical scientists and thus an upward pressure on the wages of pure researchers (Elvidge, 2013). However, if there is increasing demand for biomedical researchers and the wage rate in the pure research sector tends to be sticky because it is determined more by government budget constraints than by the forces of supply and demand, the price adjustment does not lead to a convergence of the wage rates of pure and applied researchers, maintaining the incentive for basic researchers to move into biomedical business-oriented organisations. Second, the effect of changes in productivity implies that pure and applied researchers are imperfect substitutes. However, it seems reasonable to suppose that researchers with a strong inclination toward pure speculative research are less productive if they force their talents to technological applied research in business-oriented organisations, only to repay, as fast as possible, a high student debt.

In conclusion, for a country that produces goods and knowledge, the 'composition effect' and the 'productivity effect' imply the inefficient allocation of human resources (i.e., both effects push the economy somewhere inside its production possibility frontier). However, the potential harmful effects of an increasing difference in the average growth rates of real family income and the average costs of higher education may be even more pervasive if we consider the other key roles of the biomedical sciences sector.

In U.S. society, for instance, empirical evidence supports the hypothesis that indebtedness among young medical graduates affects speciality career choices (Bazzoli, 1985; Smith, 2012). This means that, in the future, ceteris paribus, prospective students in biomedical sciences will be strongly incentivised, firstly, to choose the more remunerative career of medical practitioner instead of that of medical (pure or applied) researcher, and secondly to further sub-specialise in those fields that promise higher earnings to offset their higher loan repayments.

These perverse incentives, on the one hand, reduce the total number of both kinds of researchers and hence shift the SG curve downward. On the other hand, preferences toward highly profitable specialities may leave society with a shortage of physicians in crucial fields and areas (e.g., primary care specialists and paediatrics, in urban and rural communities). These two effects decrease the economy's growth rate directly through the reduction in the rate of technological progress and indirectly through the reduction in the outcomes of the health care system, and thus in the average population's health condition.

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Appendix A

From Eq. (19), we find the first derivative of g_y with respect to β , and we set it equal to zero:

$$dg_y/d\beta = -z_D qL + \alpha z_D z_R \times q^2 L^2 - 2\alpha z_D z_R \times \beta q^2 L^2 = 0. \quad (1A)$$

The value of β that satisfies (1A) is $1/2 - 1/(2\alpha z_R \times qL)$. Since, $d^2 g_y / d\beta^2$ is $-2\alpha z_D z_R \times q^2 L^2$, the level of β that maximises g_y is around 0.5 (i.e., it tends to 0.5 as $2\alpha z_R \times qL$ increases).

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