Egalitarian versus Elite: a Higher–Education Policy Comparison of Education Regime Types*

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June 21, 2011

Abstract

I consider the efficiency and equity effects of a novel higher–education policy control variable I call an education regime. The education regime affects the relative difficulty of education for agents of differing ability but may also determine the relative productivity of their human capital. Using numerical analysis within an overlapping generations framework, I find that egalitarian regimes – those benefitting low– relative to high–ability students – are associated with higher output and less inequality than other regimes. When the choice of regime also affects the relative productivity of human capital, egalitarian regimes are associated with even lower levels of inequality.

1 Introduction

As in other countries, New Zealand's public policy environment plays host to recurrent debates regarding how best to fund and allocate resources within the higher education sector (e.g. Kerr, 2008; New Zealand Union of Students' Associations, 2010). In particular, policy makers and commentators have recently shown interest in employing tertiary education to improve New Zealand's economic performance and lift the education participation and achievement rates of students from disadvantaged socio-economic and cultural backgrounds (New Zealand Ministry of Education, 2010(a)).

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Given evidence of significant private and social returns to higher education (Psacharopoulos, 2008), governments have been called on to take a role in securing those social returns and extending access to those private returns to as many individuals as possible. These suggestions reflect much of the discussion on efficiency and equity in the education economics literature.

However, the literature presents suggests no consensus on the best policy approach to higher education. Psacharopoulos (2008) explains that the subsidization of higher education is inequitable because of its resource distribution regressivity: university graduates tend to come from high–income households that pay a lower proportion of their income as tax than low–income households that do not necessarily make use of or benefit from education subsidies. De Fraja (2002), however, finds that the pursuit of efficiency in the presence of market failures – such as credit constraints and externalities – by way of taxation and subsidization must come at the cost of equity in precisely the way that Psacharopoulos describes. Garcia–Penalosa & Walde (2000) show that both efficiency and equity are hampered by traditional tax and subsidy funding systems. Yet Trostel (1996) shows that the distortionary effect of income taxation on human capital investment and accumulation renders education subsidies efficiency improving.

Despite these disagreements, much of the education economics literature follows the same investigative pattern: once market failures of interest to the author are identified, the efficiency and equity effects of various government tax, subsidy, provision, and credit market interventions are analyzed. However, in its preoccupation with how higher education should be paid for, and by whom, the literature has paid very little attention to the form of the education system itself. Specifically, it has ignored the way in which human capital is created by way of the education sector's transformation of unskilled individuals into skilled individuals. This suggests a slow reaction of the literature to the increasing interest of policy makers and commentators, particularly in New Zealand, in directing tertiary institutions to address the various academic interests, skills and needs of heterogeneous students while sticking to tight public–education budgets (New Zealand Ministry of Education, 2010(a)).

In the current paper, the issue of the propriety of government intervention in higher education is eschewed in favour of investigating the effect of the manipulation of the form of the process of human capital production. This process is characterized by what I refer to as an education regime whereby, contingent on the type of regime chosen, students of differing ability can experience variations in both their ease of access to education and the pro-

ductivity gains of the human capital they acquire. I demonstrate that the manipulation of an economy's education regime can affect both efficiency (as proxied by economic output) and equity. Under a specific set of assumptions, education regime types that I refer to as egalitarian – those in which low–ability students find human capital easier to acquire than under the status quo – are associated with greater levels of economic output and less inequality of income and lifetime resources than alternative education regime types. Moreover, when a policy maker's choice of education regime affects both the ease of access to and the productivity of the human capital acquired via education, egalitarian type regimes are more effective at improving equity than when a policy maker can only influence the ease of access to education.[1] Conversely, elite education regimes – those in which high–ability students find human capital easier to acquire than under the status quo – are shown to be efficiency and equity decreasing.

The remainder of the paper is organized as follows. Section 2 explains the intuition behind the notion of an education regime as it is used in this paper. Section 3 sets out the model of the economy. Section 4 describes the choice of model parameters. Section 5 discusses the numerical analysis method used to investigate the model. Section 6 analyzes the model with respect to changes in the education regime and the interaction of human capital and the production process. In Section 7 I discuss the results presented in Section 5 in more detail by linking them to existing literature and considering limitations and possible extensions of the model. Section 8 concludes.

2 Education Regimes

2.1 An Explanation of Education Regimes

Insofar as the economic effects of the manipulation of education regimes are the primary focus of this paper, an exposition of the concept of an education regime is required. I refer to an economy's education regime as a policy instrument that affects the way in which agents of differing ability accumulate human capital at educational institutions. An important assumption, made for simplicity, is that the manipulation of the policy instrument is costless but can have two distinct effects on those individuals who choose to become

[1] Because changes in the production function change the unit of measurement for output, the efficiency effects of a policy-maker's decision in this environment are unknown.

educated.[2]

First, the manipulation of an economy's education regime can influence the ease of access to education conditional on an agent's level of ability. Because education is more or less difficult to complete for agents of lesser and greater ability respectively, agents who choose to acquire education suffer an ability–varying disutility from it. The choice of an education regime, then, can influence the relative disutility of education for agents of differing ability, affecting the ease with which different agents can access it in order to accumulate human capital.

Second, the manipulation of an economy's education regime can influence the productivity of the human capital accumulated by different agents. Agents accumulate human capital when they use education to build on their underlying ability, hence, the productivity of that human capital is ability dependent.[3] The choice of education regime, then, can influence the relative productivity gain of human capital accumulation between agents of differing ability.

I assume that the manipulation of the education regime directly affects the disutility of education, but that productivity of human capital is not necessarily affected. Rather, one of two possibilities may explain the effect of a policy maker.s choice of education regime on the economy. According to what I refer to as the Independence Hypothesis, the education regime affects only the relative disutility of education, not the relative productivity gains of human capital accumulation for agents of different ability. In this situation, the ease of access to and productivity benefits of education are independent.

Alternatively, according to what I refer to as the Interdependence Hypothesis, the education regime affects both the relative disutility of education and the relative productivity gains of human capital accumulation. Moreover, where the choice of regime improves the ease of access to education for agents of a certain level of ability, it also increases the productivity of the human capital they acquire. Although the benefits accruing to agents of low (high) ability with respect to the ease of access to education could be associated with benefits accruing to agents of high (low) rather than low

[2]For example, the government's education budget and methods of taxation may be independent of the choice of education regime type. This is appropriate given that many policy makers are interested in manipulating the higher education system with limited means at their disposal (see New Zealand Ministry of Education, 2010).

[3]Of course, this ignores the possibility that the signalling or sorting hypotheses explain education and human capital accumulation (see Weiss, 1995). However, a discussion of these issues is beyond the scope of the current paper.

(high) ability with respect to the productivity of human capital acquired, this seems intuitively implausible, hence, I do not investigate this possibility here.

Importantly, this paper focuses only on relative differences between agents of varying ability in the ease of access to and productivity benefits of education. However, it is possible that education regimes affect the average level of productivity of educated agents. This raises the possibility of a 'dumbing–down' effect whereby increases in the ease of access to education are associated with decreases in education standards and thus quality, reducing the overall productivity of the human capital acquired via education. This presents a significant concern for education policy makers; however, space constraints prevent me from addressing it here.

In Section 6.3, I show that whichever hypothesis is assumed to characterize the economy, the direction of the effect of the choice of education regime on economic outcomes is the same, though the magnitude of the effect of an education regime type on inequality is larger under the Interdependence Hypothesis.

2.2 The Characteristics of Regime Types

Irrespective of the hypothesis that most appropriately describes the economy, I assume that a policy maker can choose from what I refer to as benchmark, egalitarian or elite regime types. Under a benchmark regimeffected, the disutility of education and the productivity of human capital are directly proportional to an educated agent's level of ability.

An egalitarian type regime is such that low–ability agents find it easier to complete their education and may acquire more productive human capital than is the case under the benchmark regime. A policy maker may implement an egalitarian regime for equity reasons. Low–ability agents begin life with a less valuable endowment than high–ability agents do because higher levels of ability are associated with lower disutilities of education and possibly higher levels of productivity of human capital. An egalitarian regime may be implemented, then, in order to mitigate differences in the ease of access to and productivity benefits of education between high– and low–ability agents.

An elite type regime is such that high–ability agents find it easier to complete their education and may acquire more productive human capital than is the case under the benchmark regime. Policy makers may argue that such a regime is justified on efficiency grounds. Since high–ability agents

have a greater level of productivity associated with their human capital than low–ability students do and elite education regime types may improve the productivity of human capital of high–ability agents, as per the Interdependence Hypothesis, there may be increases in economic output.

However, in anticipation of the results discussed in Section 6.1, while the implementation of an egalitarian type regime results in equity improvements via decreases in the level of income and resource inequality, elite regime types are not associated with increases in economic output relative to benchmark or egalitarian regime types. One reason for this is that the model used here does not describe an outside option for high–ability agents with returns comparable to those provided by education because agents can only earn either a skilled wage or an unskilled wage that is independent of ability. Since incentives designed to encourage high–ability agents to become educated are largely unnecessary due to a lack of market failures in the model, no increase in efficiency is gained by making education relatively easier to acquire for high–ability agents.[4]

2.3 Real–World Education Regime Analogues

In this paper, I describe an economy's education regime as a policy instrument available to manipulation by policy makers. However, to what extent is this instrument analogous to real-world policy options? The following examples illustrate how differences in education regimes may be implemented in reality.

First, policy makers may control the distribution of (a fixed level of) government education–budget funds across students of differing ability. For example, the amount of funding per student may vary across students with differing needs. In New Zealand, for example, more tertiary education funding per student is granted to Maori, Pacific and disabled students than others (Tertiary Education Commission, 2009). This resembles an egalitarian type regime where low–ability students receive a disproportionate allocation of resources relative to high–ability students. If employed effectively, the distribution of resources under an egalitarian regime is such that the difficulty of higher education is reduced for low–ability students relative to a situation in which no redistribution of educational resources occurs. In contrast, an elite

[4]Although the presence of market failures such as adverse selection or moral hazard may render such incentives necessary for efficiency improvements, they are beyond the scope of this paper. Nevertheless, such issues would provide an interesting extension to the model presented here.

regime would concentrate a disproportionate level of resources in students of high ability, for example by providing resources for extension programmes or advanced qualifications that only high–ability students are capable of undertaking.

Second, policy makers may stipulate the focus of the curricula taught at educational institutions. In mandating the kind of education required to be taught by an institution, policy makers can influence the relevance of the skills taught given students' abilities. In addition, this could affect the productivity of the human capital that those students gain. This describes the intent of the New Zealand Curriculum set out by the Ministry of Education (New Zealand Ministry of Education, 2010(b)). To some extent this also characterizes the purview of the New Zealand Qualifications authority, which determines the kinds of qualifications able to be granted given the skills taught at a particular institution (New Zealand Qualifications Authority, 2010). Under this interpretation, an egalitarian regime would be one in which educational institutions teach skills that are readily accessible to low–ability agents and are of productive benefit to them. An elite regime, on the other hand, would teach advanced skills that primarily improve the productivity of high–ability agents. Existing institutions reflect this distinction in ability–level educational focus. For example, universities offer advanced academic degrees that are productivity enhancing for high–ability students but that are frequently beyond the capacities of low–ability students. Non–tertiary institutions, on the other hand, often offer courses in skills more suited to those of low ability, but that are of less productive benefit to high–ability students than university degrees.[5]

3 The Model

I consider an overlapping generations model similar to that presented in Fender & Wang (2003). I employ Samuelson's (1958) simplest case, a stationary population, in which a constant number of agents are born and die each period, where this constant is normalized to unity. Each generation of agents lives for two periods and must decide whether to acquire an education when young.

[5]If this reads unpalatably, one need not interpret universities as catering only those with high–ability and non–tertiary institutions to those with low–ability. Rather, one might interpret different education institutions as catering to a variety of people with a variety of differentiable skills, some of which carry a lower marketable value than others.

Although agents' preferences are identical, agents differ in the disutility they incur while undertaking an education; a disutility that is only incurred by those who actually become educated. For simplicity, agents derive no utility from leisure but from second-period consumption only. Agents supply one unit of labour inelastically in the first period of their lives if uneducated and in the second period if educated.

The timing of agents' decisions is illustrated in Figure 1 in Fender & Wang (2003). If an agent eschews education, he or she works as an unskilled labourer when young and earns an unskilled wage that is saved. When old, the agent consumes the value of his or her savings plus interest. If an agent chooses to acquire education, when young he or she borrows to pay for education and incurs a disutility cost. When old, the agent works, earns a skilled wage, repays his or her education loan plus interest, and consumes the remainder. Note that it is assumed, for simplicity, that uneducated agents retire in the second period and simply consume what they have saved. While allowing uneducated agents to work in the second period may affect the magnitude of the changes in the model's variables, it will not affect their direction and thus does not affect the analysis presented here.[6]

The ability level of agents, denoted α, is distributed among the population uniformly between zero and one: $\alpha \sim U[0,1]$. This means that every agent is identifiable by his or her unique ability level, α. Education incurs a non–negative cost, denoted E, that is financed by an agent's borrowings in the first period and is repaid with interest in the second. Although much of the literature is concerned with borrowing constraints due, in particular, to moral hazard and adverse selection problems (e.g. Fender & Wang, 2003; Cigno & Luporini, 2009; Wigger & Von Weizsacker, 2001), I assume that agents face no such difficulties in order to focus on the education system itself rather than the market failures associated with it.

If an agent does not acquire an education they become an unskilled worker in the first period, earn a wage w^u that is common to all unskilled workers, lend this out at a real interest rate r, and consume the principal plus interest in period two. Following Lloyd–Ellis (2000), educated agents become managers or entrepreneurs of firms and as such extract all the rents from

[6]The most significant impact on the model would be that uneducated agents choose to save less in period one given that they can work in the second period. This would reduce the funds available for education loans, increasing the interest rate, causing education to become less attractive, decreasing the number of agents who choose to become educated. This would have further effects but all in the same direction that the model already predicts for other variable changes.

production. Due to the nature of the production process, outlined in more detail below, educated worker's incomes, denoted w^e_α, will vary with ability, α. Educated workers will consume w^e_α, less the education cost and interest in the second period.

The utility functions of uneducated agents is linear. For educated agents, the disutility of education enters the utility function as a scale factor on consumption. The utility functions of educated and uneducated agents respectively are

$$U^e_\alpha = \alpha^\phi (w^e_\alpha - E(1+r)) \tag{1}$$

and

$$U^u_\alpha = w^u(1+r). \tag{2}$$

Note that the educated agent's utility varies with his or her ability level: because $\alpha \leq 1$, the scale factor represents the disutility of education. The parameter ϕ is the education disutility elasticity of ability, which varies with the education regime type chosen by the policy maker.

In deciding whether to become educated, an agent will compare his or her prospective utility as an educated worker with that as an uneducated worker. This comparison will depend on the agent's ability endowment. As such, there will be a critical value of α denoted α^*, such that an agent with that level of ability will be indifferent between becoming an educated or uneducated worker. I assume that the marginal agent with ability α^* decides to become educated. Thus, α^* solves the indifference condition

$$\alpha^{*\phi}(w^e_{\alpha^*} - E(1+r)) = w^u(1+r), \tag{3}$$

where $w^e_{\alpha^*}$ is the income of the marginal educated worker with ability level α^*. Agents with an ability level in the range $\alpha \in [\alpha^*, 1]$ will become educated while those in the range $\alpha \in [0, \alpha^*)$ will not.

One perishable good is produced in the economy by firms, each of which requires one educated manager or entrepreneur and l unskilled labour.[7] A firm is identified by the ability of the educated agent who heads it; a particular firm is denoted y_α and there are $1 - \alpha^*$ firms, one for each educated

[7]Of course, the price of the good is normalized to one.

agent.[8] The production process is Cobb–Douglas and combines unskilled labour, which is a homogenous input that is unvarying in agents' abilities, and the human capital of the educated agent. Human capital is denoted α^{β}, which is given by the underlying ability of the educated agent and an educational transformation parameter β. For lack of a more concise descriptor, I call this parameter the human capital elasticity of ability, that is, the effect of an agent's ability on his or her accumulation of human capital via the education transformation process.

The production function of a firm, identifiable by the unique ability level of its manager, is given by

$$y_{\alpha} = f(\alpha, l_{\alpha}) = (\alpha^{\beta})^{1-\delta} l_{\alpha}^{\delta}, \forall \alpha \in [\alpha^{*}, 1], \tag{4}$$

where $\delta \in (0, 1)$ is the output elasticity of unskilled labour, $1 - \delta$ is the output elasticity of skilled labour, and l_{α} is firm α's demand for unskilled labour. The interaction of the output elasticity of human capital and the output elasticity of skilled labour is discussed in more detail in Section 4.2. The firm chooses the quantity of unskilled workers it hires to solve

$$\max_{l_{\alpha}} \pi_{\alpha} = (\alpha^{\beta})^{1-\delta} l_{\alpha}^{\delta} - l_{\alpha} w^{u} - w_{\alpha}^{e}. \tag{5}$$

The labour demanded by firm α is thus

$$l_{\alpha} = \alpha^{\beta} \left(\frac{\delta}{w^{u}} \right)^{\frac{1}{1-\delta}}. \tag{6}$$

As firms are perfectly competitive, firms earn zero profits with managers extracting all of the rent associated with their human capital as a salary:

$$w_{\alpha}^{e} = (1 - \delta) \alpha^{\beta} \left(\frac{\delta}{w^{u}} \right)^{\frac{\delta}{1-\delta}}. \tag{7}$$

The unskilled wage depends on the perfectly competitive, market demand and supply of unskilled labour. Total unskilled labour demand is derived by summing each of the individual firms' demand for unskilled labour, while

[8] Lloyd–Ellis (2000) notes that firms can be thought of, alternatively, as autonomous production units, projects, or plants contained within larger firms.

unskilled labour supply is given by the critical value α^*. Setting demand equal to supply,

$$\int_{\alpha^*}^{1} l_\alpha d\alpha = \alpha^*, \tag{8}$$

then substituting 6 into 8 and solving for the unskilled wage gives

$$w^u = \delta \left(\frac{(\beta+1)\alpha^*}{1-\alpha^{*\beta+1}} \right)^{\delta-1}. \tag{9}$$

Therefore, the educated worker's salary is

$$w^e_\alpha = (1-\delta)\alpha^\beta \left(\frac{(\beta+1)\alpha^*}{1-\alpha^{*\beta+1}} \right)^{\delta}. \tag{10}$$

The interest rate that obtains in the economy is the one that clears the credit and goods markets simultaneously. The goods market depends on production and consumption. Given 4, 6, and 9 aggregate production is

$$\sum_{\alpha=0}^{1} y_\alpha = \int_{\alpha^*}^{1} f(\alpha, l_\alpha) d\alpha = \frac{(1-\alpha^{*\beta+1})}{\beta+1} \left(\frac{(\beta+1)\alpha^*}{1-\alpha^{*\beta+1}} \right)^{\delta}. \tag{11}$$

Aggregate consumption is the sum of all agents' income less education costs:

$$\sum_{\alpha=0}^{1} c_\alpha = \alpha^*((1+r)w^u) + \int_{\alpha^*}^{1} (w^e_\alpha - E(1+r)) d\alpha. \tag{12}$$

Substituting 9 and 10, aggregate consumption is

$$\begin{aligned} \sum_{\alpha=0}^{1} c_\alpha \;=\; & \alpha^* \delta (1+r) \left(\frac{(\beta+1)\alpha^*}{1-\alpha^{*\beta+1}} \right)^{\delta-1} \\ & + \frac{(1-\delta)(1-\alpha^{*\beta+1})}{\beta+1} \left(\frac{(\beta+1)\alpha^*}{1-\alpha^{*\beta+1}} \right)^{\delta} \\ & - E\,(1+r)\,(1-\alpha^*)\,. \end{aligned} \tag{13}$$

Setting 11 equal to 13 produces the interest rate that prevails in the economy given the education costs that $1-\alpha^*$ agents must borrow to finance their education and the savings that α^* agents provide to do so:

$$(1+r) = \frac{\delta}{\delta - \frac{E(\beta+1)(1-\alpha^*)}{1-\alpha^{*\beta+1}} \left(\frac{1-\alpha^{*\beta+1}}{(\beta+1)\alpha^*}\right)^{\delta}}. \tag{14}$$

The critical value α^* is given by the combination of 1, 9, 10 and 14, which characterizes the general equilibrium indifference condition. However, due to the non–linearities introduced by the indifference condition and the production function, an analytical solution for α^* is unable to be found, nor can partial derivatives of the equilibrium condition be signed. Thus, in order to conduct a numerical analysis of the problem, I rearrange the equilibrium condition for the education cost:

$$E = \frac{\alpha^{*\beta}(1-\delta)\left(\frac{\alpha^*(\beta+1)}{1-\alpha^{*\beta+1}}\right)^{\delta} - \frac{\delta}{\alpha^{*\phi}}\left(\frac{\alpha^*(\beta+1)}{1-\alpha^{*\beta+1}}\right)^{\delta-1}}{\left(1+\frac{\alpha^{*\beta}(1-\delta)(1-\alpha^*)(\beta+1)}{\delta(1-\alpha^{*\beta+1})}\right)} \tag{15}$$

where the educated agent's salary described in 10 is for the marginal agent with ability α^*.

Note that since this model describes no market imperfections or government interference, the variables of interest are efficient at the equilibrium.

4 Parameterization of the Model

4.1 The Education Disutility Elasticity of Ability Parameter

Insofar as the ease of access to or difficulty of acquiring education can be affected by the policy maker under either of the Independence and Interdependence Hypotheses, the parameterization of the education disutility elasticity of ability, ϕ, is important.

Table 1 contains values for ϕ for several education regime types along with the signs of the first and second derivatives of the utility function with respect to those values. Figure 1 shows the utility multiplier – that is the value by which an educated agent's utility is tempered – for an educated agent given his or her ability and the value of ϕ associated with a particular education regime.

Table 1: The Education Disutility Elasticity of Ability

Education Regime	Education Disutility Elasticity of Ability (ϕ)	$\frac{\partial U^e}{\partial \alpha}$	$\frac{\partial^2 U^e}{\partial \alpha^2}$
Egalitarian one	0	0	0
Egalitarian two	0.5	> 0	< 0
Benchmark	1	> 0	0
Elite	2	> 0	> 0

The value of ϕ associated with the first egalitarian regime type implies that the disutility of education does not vary with ability. The second egalitarian regime type implies that agents of low ability benefit from the regime as their marginal disutility of education is decreasing faster in ability than agents with high ability.[9] The benchmark regime is one in which the disutility of education for an agent is proportionate to his or her ability. The elite regime implies that agents of high ability benefit from the regime as their marginal disutility of education is decreasing faster in ability than agents with low ability.[10]

4.2 The Human Capital Elasticity of Ability Parameter

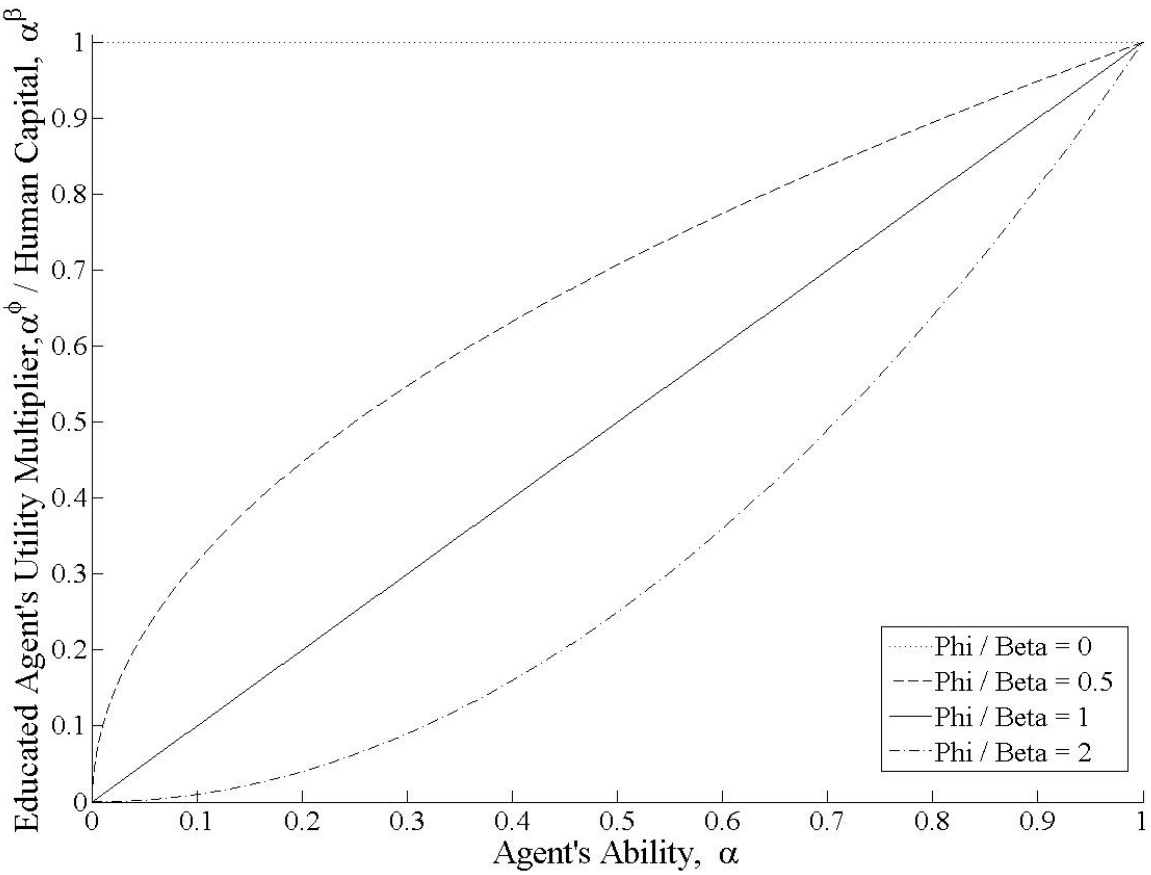
The value of the human capital elasticity of ability parameter, β also has an effect on economic outcomes. Moreover, if the Interdependence Hypothesis appropriately characterizes the economy, a policy maker's choice of education regime affects the productivity of the human capital accumulated via education. For these reasons, the parameterization of β is important.

The human capital elasticity of ability reflects the interaction of the transformation of an agent's ability into human capital with the production pro-

[9] That is, there is diminishing marginal utility in ability.

[10] That is, there is increasing marginal utility in ability.

Figure 1: Educated Agent's Utility Multiplier and Human Capital



cess. However, the form of the production function is such that the human capital elasticity of ability interacts with the output elasticity of skilled labour in determining the overall effect of human capital on productivity. For example, if δ is large the output elasticity of skilled labour is low, dampening the productivity effect of education's transformation of ability into human capital because skilled workers have a relatively unimportant role in the production process.

Nevertheless, the focus here is on the human capital transformation process' effect on productivity and thus I am interested in changes in the value of β. In reality, human capital may affect the productivity of skilled workers in a variety of ways; hence, I consider four representative values of β. These cases are described in Table 2, which contains values for β with the signs of the first and second derivatives of the production function with respect

to them across the range of δ values. In addition to depicting an educated agent's utility multiplier given his or her ability, Figure 1 shows an educated agent's level of human capital given the values of the human capital output elasticity of ability shown in Table 2 and the agent's level of ability.

Table 2: The Human Capital Elasticity of Ability

Human Capital Elasticity of Ability (β)	$\frac{\partial y_\alpha}{\partial \alpha}$	$\frac{\partial^2 y_\alpha}{\partial \alpha^2}$
0	$= 0, \forall \delta \in [0, 1]$	$= 0, \forall \delta \in [0, 1]$
0.5	$> 0, \forall \delta \in [0, 1)$ $= 0, \delta = 1$	$< 0, \forall \delta \in [0, 1)$ $= 0, \delta = 1$
1	$> 0, \forall \delta \in [0, 1)$ $= 0, \delta = 1$	$< 0, \forall \delta \in (0, 1)$ $= 0, \delta \in \{0, 1\}$
2	$> 0, \forall \delta \in [0, 1)$ $= 0, \delta = 1$	$> 0, \forall \delta \in [0, 0.5)$ $= 0, \delta = 0.5$ $< 0, \forall \delta \in (0.5, 1]$

A zero value for the human capital elasticity of ability represents an environment in which the gains in productivity associated with human capital are independent of an agent's ability. This case is reminiscent of the signalling hypothesis in the economics of education literature where education acts as a signal for some unobservable characteristic, but does not result in ability–dependent human capital productivity gains (Arrow, 1973; Layard & Psacharopoulos, 1974; Weiss, 1995).[11] β values of 0.5 and one represent production processes with a diminishing marginal productivity of ability, and thus also human capital. These cases are associated with benefits to low–ability, educated agents because their productive output is increasing in ability at a faster rate than that of high-ability agents.[12] When β is two, and δ is low – that is, the output elasticity of skilled labour is high – there are benefits to high–ability educated agents in that their productive output is increasing in ability and at a faster rate than that of low–ability educated agents.[13]

[11]Note that here I am not concerned with the signalling hypothesis in itself, only in representing a human capital-productivity interaction process that reflects the possibility that the hypothesis describes the world.

[12]Alternatively, these cases can be characterized by low-ability, educated agent's marginal product decreasing slower in ability than high-ability educated agents.

[13]Alternatively, high–ability, educated agents' marginal productivity is increasing faster than for low–ability, educated agents. When δ is high, however, the second derivative of the production function is negative and low-ability, educated agents benefit, as in the cases where β takes on values of 0.5 and one.

4.3 The Independence and Interdependence Hypotheses

As explained in Section 2.1, the Independence and Interdependence Hypotheses reflect two characterizations of the relationship between education regimes and the economy. While under the Independence Hypothesis the manipulation of education regimes affects the disutility of education only, under the Interdependence Hypothesis the education regime affects both the disutility of education and the productivity gains of human capital accumulation. Moreover, under this hypothesis, where the choice of regime benefits agents of a certain level of ability with respect to the difficulty of education for them, it also benefits them with respect to the productivity of the human capital they acquire. Table 3 illustrates the pairing of the values of ϕ and β for each regime type under each hypothesis. Any difference between the economic outcomes for each of these pairs reflects a difference in the effects of manipulating education regimes under each hypothesis.

Table 3: Education Regime Characteristics by Hypothesis

Education Regime	Independence Hypothesis	Interdependence Hypothesis
Egalitarian one	$\beta = 0, \phi = 0$	$\beta = 1, \phi = 0$
Egalitarian two	$\beta = 0.5, \phi = 0.5$	$\beta = 1, \phi = 0.5$
Benchmark	$\beta = 1, \phi = 1$	$\beta = 1, \phi = 1$
Elite	$\beta = 2, \phi = 2$	$\beta = 1, \phi = 2$

5 The Numerical Analysis Methodology

Rather than employ numerical analysis to obtain precise numerical solutions to the equilibrium equation, I use it to investigate the way in which economic outcomes vary across the parameter space. Thus, while there are inaccuracies associated with the use of numerical analysis due to computation and approximation errors (Smyth, 1998), they do not affect the nature of the results presented here.[14]

[14]Indeed, Microsoft Excel's Goalseek is not particularly accurate. The algorithm often has trouble converging on unique solutions to equations if the value from which it begins searching is very different to the solution value. Moreover, in solving equation 15 for α^*, Goalseek occasionally fails to converge when previous similar inputs suggest the solution is very close to one. In the cases where this occurs, I take one to be the solution value.

I use the simple Goalseek algorithm in Microsoft Excel to solve equation 15 for α^* given the parameter values specified in Table 4. I then use the set of values associated with each α^* to calculate the proportion of uneducated agents, the unskilled wage, the average skilled wage, and the interest rate, as defined in Section 3. I also calculate several other variables of interest. Gross aggregate output is the sum of the productive output of the firms in the economy. Net aggregate output is gross aggregate output less the total cost of education incurred by educated agents and reflects the total level of resources available for consumption in the economy.[15] The ratio of net education costs to the average skilled wage describes the proportion of income that educated agents have left to consume after paying for the cost of financing their education, including interest payments. Finally, I calculate the Gini coefficients (see Appendix D) for wage income and lifetime resources available for consumption for agents in the economy.[16]

Table 4: Model Parameter Values

Parameter		Values
E	Cost of Education	$[0.00, 0.05, \ldots, 1]$
δ	Output Elasticity of Unskilled Labour	$[0.1, 0.9]$
β	Human Capital Elasticity of Ability	$\{0, 0.5, 1, 2\}$
ϕ	Education Disutility Elasticity of Ability	$\{0, 0.5, 1, 2\}$

[15] I do not include the interest rate cost associated with financing education in net aggregate output as this is incurred by educated agents but paid to uneducated agents in the economy who save. The overall level of resources available for consumption is not reduced by the interest rate because others in the economy consume interest payments.

[16] The Gini coefficient is a value between zero and one, where zero describes absolute equality and one describes a single individual in the population earning all of the economy's income. Note that I calculate the Gini coefficient using a discrete distribution of income across the population due to the computational difficulty of calculating a continuous distribution. Although this produces noticeable kinks in the Gini coefficient curves in the graphs presented in this paper, this does not affect the general nature of the results.

6 Analysis of the Model's Results

6.1 Comparison of Education Regimes

In manipulating the economy's education regime, a policy maker influences agents' education disutility elasticity of ability, ϕ, affecting agents' ease of access to, and thus incentive to acquire, education. This affects the proportion of educated agents in the economy, a crucial determinant of every other variable in the model. I illustrate the differences in education regimes by comparing the variables of interest for the four values of ϕ described in 1. In order to do this I hold the output elasticity of unskilled labour, δ, and the human capital elasticity of ability, β, constant, at the values 0.5 and one respectively, so as not to confuse changes in the production function with effects generated by changes in the education regime.[17] Egalitarian and elite regimes contrast in their effects on economic outcomes, hence for brevity, I discuss the effect of implementing an egalitarian type regime relative to the benchmark case and it can be inferred that elite regime types produce the opposite effects. Note that figures 4 through 19 are relegated to the appendices B and C.

Egalitarian type regimes, represented by low values of ϕ, make the return to acquiring education more attractive relative to the return to unskilled labour for low–ability agents because the disutility of education is less for them than under the benchmark regime. As a result, a greater proportion of agents choose to become educated, as shown in Figure 4. However, this only holds when education costs are low; as E rises, the attractiveness of education diminishes and the difference between the regime types disappears. Nevertheless, at low values of E, the lower disutility of education for low–ability agents associated with egalitarian type regimes leads to a smaller number of unskilled workers per skilled worker in the production process. Thus, there are more skilled agents in the economy who have a higher marginal product than unskilled agents. Furthermore, there are a greater number of firms, each with fewer unskilled workers, where the last worker hired has a greater marginal product. Consequently, the level of gross aggregate output is somewhat greater, as illustrated in Figure 11, though there is little difference in net aggregate output, as per Figure 12.

As more agents choose to become educated under egalitarian type regimes, there are fewer agents competing in the unskilled labour market, resulting

[17]Note, I also investigate the impact of changes to the value of δ that is assumed. See Appendix A for a summary.

in a higher unskilled wage than under the benchmark regime, as depicted in Figure 5, though, again, the difference is decreasing in E. However, the average skilled wage is not greatly affected by the choice of education regime, as shown in Figure 6.[18]

The greater number of agents choosing to become educated results in an increase in the demand for loans and a decrease in the supply of loans as there are fewer unskilled workers saving. The interest rate is thus slightly higher than under the benchmark regime, as per Figure 7. Consequently, the proportion of the skilled wage consumed by the cost of financing education is higher, as illustrated in Figure 8.

As a result of these effects, the implementation of an egalitarian education regime is associated with less inequality. While the problems associated with the discretization of the Gini coefficient calculation, discussed in Section 5, result in a somewhat ambiguous ranking of wage inequality for some values of the education cost in Figure 9, lifetime resource inequality is clearly lower than it is under the benchmark regime, as shown in Figure 10.

These results reflect the impact of a policy maker's manipulation of the economy's education regime under the Indepedence Hypothesis. Most significantly, egalitarian regimes result in a greater level of gross aggregate output and lower levels of inequality relative to the benchmark or elite regimes. Therefore, improving the ease of access to education for low–ability agents by reducing the difficulty of acquiring human capital can bring about both efficiency and equity improvements relative to no intervention on the part of the policy maker.

6.2 Comparison of Production Processes

The way in which human capital interacts with the production process, as captured by the human capital elasticity of ability, can also affect economic outcomes. Moreover, if the Interdependence Hypothesis describes the influence of education regimes on the economy appropriately, the effect of changes in the human capital elasticity of ability add to the effects of a policy maker's manipulation of the education regime, described in the previous section.

In the following, I explain the effect of differences in human capital interactions with the production process by comparing the variables of interest

[18] I omit a sensitivity analysis where δ takes the values 0.4 and 0.6. As δ changes, skilled wages remain relatively unaffected by the education regime implemented.

for the four values of β described in Table 2. In doing so I hold the output elasticity of unskilled labour, δ, and the education disutility elasticity of ability, ϕ, constant, at the values 0.5 and one respectively, so as not to confuse changes in the education regime with the differing effects of human capital on the production process.[19]

Note that the gross and net output of the economy cannot be directly compared across values of β because changes in it result in changes in the production function and thus the production possibility frontier of the economy meaning that the units of measurement for output are different across different values of β.

When β takes a low value, the marginal productivity of a low–ability educated agent relative to a high-ability educated agent is typically higher than when β is high.[20] Hence, the input of educated agents with low ability into the production process is greater and thus the rents available for extraction from production are larger relative to the returns to unskilled labour for those agents. As a result, a larger proportion of the population chooses to become educated when β is low, as shown in Figure 13, though this effect is decreasing in E.

Consequently, there are fewer agents competing in the unskilled labour market, resulting in higher unskilled wages when β is low, as depicted in Figure 14. Additionaly, there is a greater proportion of educated agents in the economy, each managing fewer unskilled workers in their production units from which they can extract surplus, returning a lower average skilled wage, as per Figure 15. Since a greater number of agents choose to become educated, there is an increase in the demand for loans and a decrease in the supply of loans due to fewer unskilled workers saving. Hence, the interest rate is generally higher when β is lower, as in Figure 16. As a result, the proportion of the skilled wage consumed by the cost of financing education is higher when β is low, as illustrated in Figure 17.

It might seem odd that a lower average skilled wage, where a higher proportion of that wage is consumed by the cost of financing education, is associated with a greater proportion of agents becoming educated. However, low values of β are associated with higher levels of productivity of human capital for low-ability agents. This increases the relative return of education for low–ability agents when compared to the benchmark case, inducing them

[19]Holding ϕ and δ constant at other values does not alter the results of the analysis presented here.

[20]Recall, from Table 2, that when β is two, the marginal productivity of ability is increasing in ability only when δ is less than 0.5.

to acquire education, while high-ability agents become educated by default (see Section 2.2).

A further consequence of low values of β is less inequality. Though the wage income Gini coefficient values suffer from the calculation discretization problem discussed in Section 5, wage income inequality is generally lower for low values of β, as shown in Figure 18, and lifetime resource inequality is unambiguously lower relative to the benchmark β value, as per Figure 19.

6.3 The Interdependence Hypothesis

Under the Interdependence Hypothesis, the policy maker's manipulation of the education regime influences both the difficulty and human capital productivity benefits of education for agents of the same ability level. Hence, the effects on economic outcomes described in Section 6.1 add to those described in Section 6.2. Following the ϕ and β parameter value pairings described in Table 3, Figures 2 and 3 illustrate the differences in income and lifetime resource inequality between the Independence and Interdependence Hypotheses.

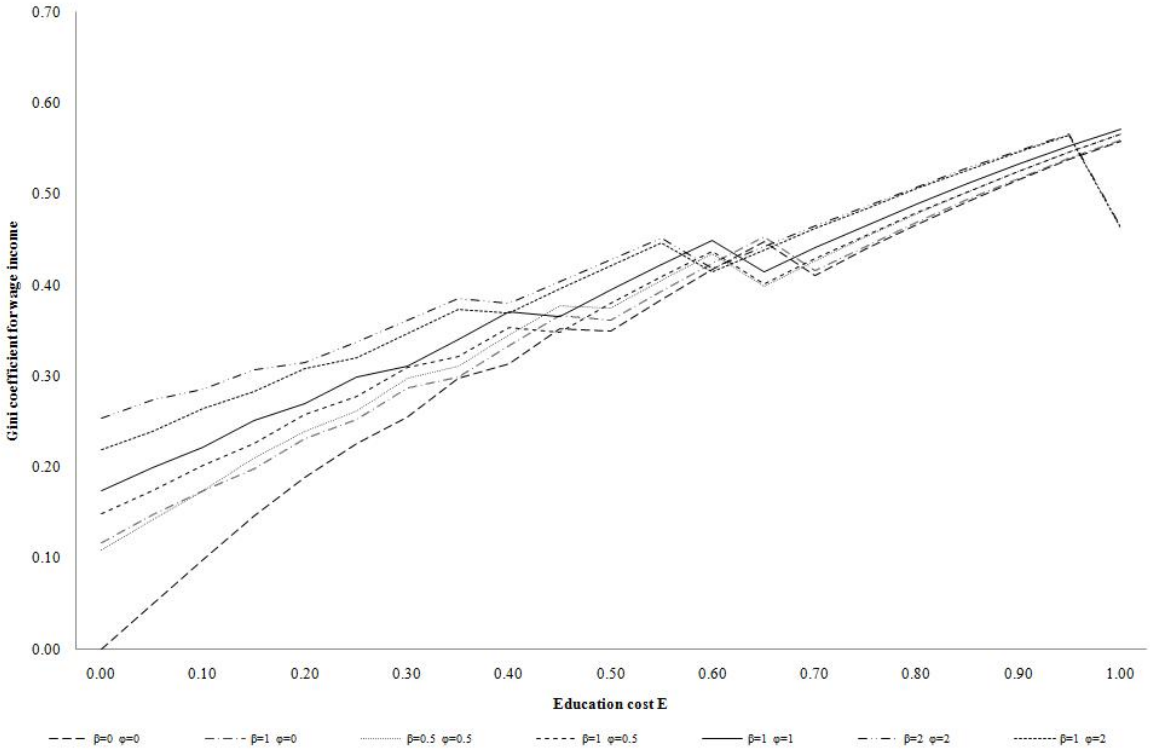
For most values of the education cost parameter, E, the implementation of egalitarian regimes under the Interdependence Hypothesis results in less inequality than under the Independence Hypothesis. Conversely, the elite regime results in more inequality. These findings are most clearly illustrated in Figure 3. Hence, the policy maker's ability to affect equity via the manipulation of the economy's education regime is more pronounced when both the ease of access to and productivity benefits of education can be influenced.

7 Discussion of the Model's Results

7.1 Implications of the Results

Psacharopoulos (2008) writes that we might conceptualize education policymaking behaviour as maximizing a social welfare function in which efficiency and equity are the arguments. He and others (e.g. Garcia–Penalosa & Walde, 2000) note that traditional education policies, such as taxation and subsidization, often trade off economic output against equality. For example, De Fraja (2002) finds that the presence of credit constraints, positive educa-

Figure 2: Gini Coefficient for Wage Income



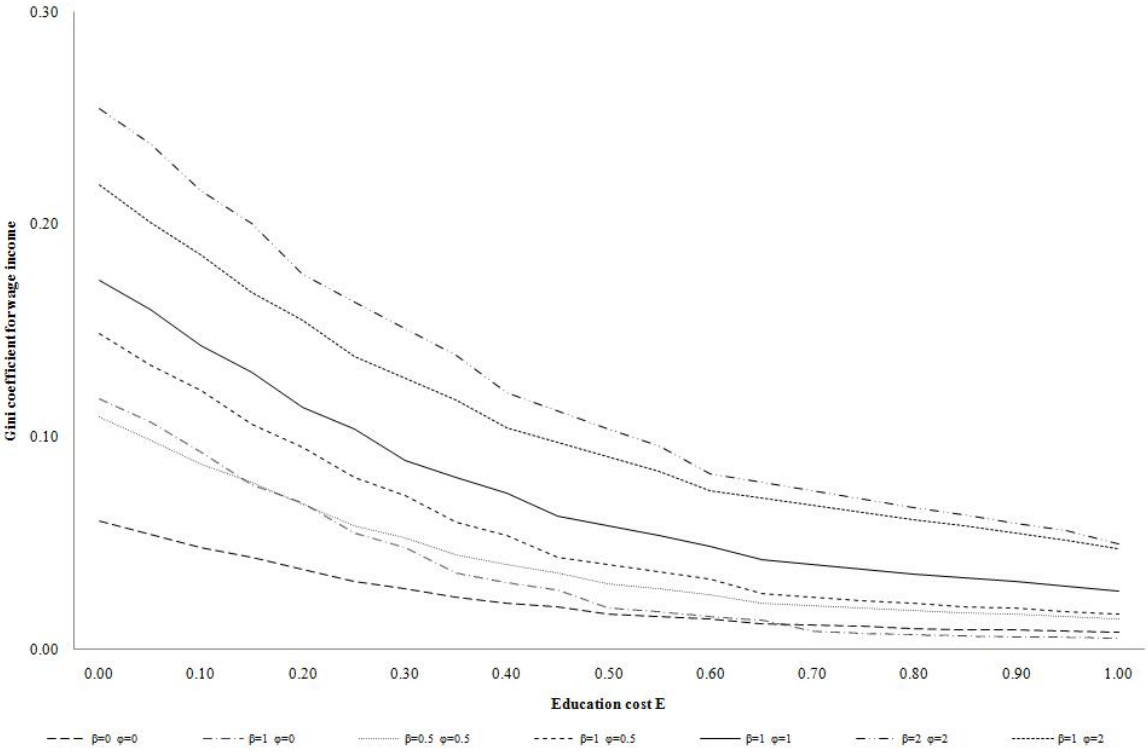
tion externality, and redistribution concerns result in the optimal education policy being such that

> The difference in educational achievement between bright and less able children is greater than it would be if education were only provided privately... Higher ability individuals are subsidized by the taxpayer and by the households whose children are less able, and wealthier households contribute less to the overall education budget than poorer households (De Fraja, 2002, p.438).

Hence, the setting of optimal policy in the face of market failures makes the pursuit of equality difficult.

The current paper presents an alternative policy instrument that, under certain conditions, avoids such a trade off. The results of the model show that when education costs are low, the manipulation of the education regime can improve both economic output and equality of income and lifetime resources available for consumption. Under the Independence Hypothesis, the implementation of an egalitarian type regime improves the ease of access to educa-

Figure 3: Gini Coefficient for Lifetime Resources



tion for low-ability agents relative to a benchmark regime and consequently increases the proportion of the population that chooses to become educated. This increases the marginal productivity of low–ability agents while reducing the number of unskilled workers per skilled worker, which results in an increase in the marginal productivity of the marginal unskilled worker hired by each firm and a consequent rise in aggregate output. The greater proportion of educated agents is associated with a higher proportion of agents earning skilled wages greater than unskilled wages. Moreover, the greater marginal productivity of unskilled workers increases their wage. Overall, this is associated with a fall in income and resource inequality. Therefore, the policy maker's adoption of an egalitarian education regime results in both efficiency and equity improvements relative to the status quo benchmark case. In addition, note that the decline in output and rise in inequality associated with the elite regime relative to the benchmark case suggests that such a regime type decreases efficiency and equity.

Under the Interdependence Hypothesis, the pursuit of equity is even more effective than under the Independence Hypothesis. While the choice of an

egalitarian education regime improves the ease of access to education for low–ability agents, it also increases the productivity of the human capital that those agents acquire. As such, relative to the benchmark regime, low–ability agents take up education in greater numbers, receiving an income greater than that provided by the unskilled wage, and the return to that education is larger because of the higher–value human capital received, leading to a more even distribution of income and resources in the economy.

7.2 Relevance of the Results to the Literature

Though the current paper holds a somewhat different focus than many of those in the education economics literature, many of the results of the model presented here are supported by similar findings in the literature.

The model suggests, as shown in 4 and 13, that increases in the cost of education are associated with decreases in the proportion of the population that chooses to become educated. From the literature, Savoca (1990) finds, using United States data, that the probability of a student applying for college is negatively affected by the cost of attending. Moreover, using Canadian data, Neill (2009) shows that increases in university tuition fees are associated with decreases in student enrolment rates after controlling for endogenous factors such as concurrent rises in student financial support and changes in the size of the population's cohort eligible for university entrance.

I also find that when the parameters E, δ and ϕ take low rather than high values, a larger proportion of the population becomes educated and this is associated with higher levels of aggregate output.[21] The connection between education and economic output is of central importance in endogenous growth theory in the macroeconomics literature. Consequently, there is a range of evidence suggesting that increases in education are associated with higher levels of growth (Krueger & Mikael, 2001; Barro, 1991; Stevens & Weale, 2004).

In my model, decreases in the value of δ are associated with increases in the level of both wage and lifetime resource inequality in the economy (see Appendix A). This occurs because a decrease in δ reflects an increase in the output elasticity of skilled labour relative to unskilled labour, which

[21]Note that while low values of β are also associated with higher proportions of the population educated than high values, aggregate output cannot be compared across values of β because of its effect on the production function.

causes a readjustment of the relative supply and demand of skilled and unskilled workers, increasing and decreasing the skilled and unskilled wage, respectively. This result reflects Topel's (1997) discussion of the link between education and income in the United States.

> Rising wage inequality is one of the most important social changes in modern economic history. The weight of empirical evidence is that this change in the wage structure is demand–driven, emanating from technical changes that have favoured skilled labor in production (Topel, 1997, p.72).

Moreover, he notes that there is evidence that college enrolments in the United States have responded positively to this increase in skilled labour demand. This is just as the model presented in this paper suggests; increases in the output elasticity of skilled labour are associated with higher proportions of the population choosing to become educated.

Topel also argues that there is some evidence to suggest that increases in education will mitigate rising inequality caused by increasing demand for skilled workers. This is also one of the results of my model. Variable changes that increase the proportion of educated agents in the economy, such as the adoption of an egalitarian rather than elite type education regime, result in decreases in both wage and lifetime resource inequality.

Walde (2000), concentrating on cross–country differences in income inequality, presents a paper in which egalitarian education systems reflect equality of the quality of education across skill–levels and elite systems reflect higher quality education at higher skill–levels. Though his underlying model is different, consistent with my findings, he shows that under elite systems technological change increases the demand for skilled relative to unskilled workers, causing increases in wage inequality. Moreover, since egalitarian systems are associated with less marked differences between the productivity of skilled and unskilled workers, as is the case in my model, technological change increases the demand for all workers, causing wage inequality to fall.

Reflecting the funding allocation mechanism interpretation of education regimes discussed in Section 2.3, Keller (2010) finds that countries with high concentrations of resources in low-skill students (i.e. primary and secondary school students) have more equal income distributions than countries with high concentrations of resources in high-skill students (i.e. university students). She also shows that increasing enrolment rates in education alone is not enough to reduce income inequality. This lends support to my finding that when policy can affect more than just the ease of access to education

such as by influencing the productivity of the fruits of that education, as is the case under the Interdependence Hypothesis, the pursuit of equity will be much more effective. Following the discussion in Section 2.3, this also suggests that the manipulation of the curriculum taught by education institutions may be more effective at improving the equality of income than simply reallocating funding across students of differing ability.

7.3 Limitations and Extensions of the Model

There are several limitations to the model presented here. First, my model lacks physical capital. This affects the credit market where there is a lack of competition in the demand for loanable education funds. The interest rate is thus likely to be lower than it would be if the economy employed physical capital, which means the cost of financing education is too low and a larger proportion of agents choose to become educated for any given set of parameter values than should be the case.

Second, in this model scarce resources are not used up in the production of education. That is, agents are not required to supply labour to the education sector in order to teach students and produce human capital. If scarce resources were consumed in the production of education, net aggregate output would be lower than my model suggests because the resources required to produce education would detract from the total resources available for consumption. This would affect the impact of education regimes on efficiency. Moreover, educated agents would be required to work as teachers, which would introduce competition for skilled workers between the education and other sectors of the economy. This could increase skilled workers' wages, distorting the results concerning inequality presented here. This change to the model would affect the ability of a policy maker to manipulate the education regime with such unambiguous changes in output and inequality. Further investigation of this issue is therefore warranted.

Third, the implementation of a policy that aims to ease access to education for agents of a certain level of ability would be difficult if information about ability was private or unknown. Recall that the education regime type can be interpreted as reflecting a policy maker's decision about how to allocate resources within the education sector among agents of differing abilities. However, when there is a noisy signal about agents' abilities, or no signal at all, universities will have difficulty identifying differences between agents. Brezis & Crouzet (2004) show that even when supposedly meritocratic screening processes are used for the purposes of enrolment, such as the

Scholastic Aptitude Test (SAT) employed by colleges in the United States, "elite schools and universities have a tendency to recruit in a non-diversified way, resulting in certain classes being over-represented" (Brezis & Crouzet, 2004, p.3). They find that recruitment processes that aim to identify the most able students irrespective of social background rely on imperfect signals that are biased towards the over-identification of students from what the authors describe as elite backgrounds. This would certainly distort the results of the model presented in the current paper.

However, this suggests an interesting extension to the model. The inclusion of uncertainty or asymmetry of information about agents' ability is likely to affect the outcomes of the implementation of the different regime types if education regimes are simply funding allocation mechanisms, as described in Section 2.3. On the other hand, if education regimes determine education institutions' curricula, uncertainty over an agent's ability is less of a problem because educational institutions simply offer certain courses of study that students of any ability may choose to undertake. If the Independence and Interdependence Hypotheses reflect resource allocation and curricula determination respectively, the addition of asymmetric information would enable a more thorough investigation of the relative effectiveness of the pursuit of equity via the manipulation of the education regime under the conditions described by each hypothesis.

To some extent, the distinction between the focus of elite and egalitarian education regimes, as interpreted by the curricula manipulation example, may be seen in the difference between existing tertiary and non-tertiary institutions. As such, further work could analyze existing institutions under the elite-egalitarian education regime framework presented here.

8 Conclusion

Previous academic debates regarding the role of the government in higher education have concentrated heavily on the efficiency and equity improvements that can be made when market failures are addressed. However, such discussion has neglected policy maker and commentator interest in the form of the education system itself.

In light of this gap in the literature, this paper investigates the effect of a policy maker's manipulation of the education system, where that manipulation can affect the ease of access to and productivity benefits of education. A

policy maker can choose from a range of education regime types, such as egalitarian and elite, which have comparative benefits for low- and high-ability students respectively. I demonstrate that under certain conditions the implementation of an egalitarian type regime is associated with efficiency and equity improvements, as measured by aggregate economic output and the Gini coefficient of income and lifetime resource inequality respectively, relative to no intervention on the policy maker's part. Conversely, an elite type regime is associated with efficiency and equity losses.

I also show that where the manipulation of the education regime affects both the ease of access to and productivity benefits of the human capital acquired via education, as opposed to affecting the ease of access to education only, equity is generally more effectively pursued. This suggests that education policy makers should aim to influence both education access and productivity gains, rather than access alone. The New Zealand Ministry of Education's control of the New Zealand Curriculum and the New Zealand Qualification Authority's oversight of qualifications present possible examples of such policies. Further research is required to investigate the extent to which the impact of these institutions reflects the effects of the manipulation of education regimes presented in this paper.

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Appendix A

Consider the impact of an increase in the output elasticity of unskilled labour, δ, for a given value of E. As δ rises, unskilled labour becomes more productive. This results in an increase in gross and net aggregate output. The increase in productivity also causes an increase in the unskilled wage. Moreover, as δ rises, skilled labour becomes less productive and thus the share of income from production accruing to skilled agents declines: the average skilled wage falls. This increase and decrease in the unskilled and skilled wages, respectively, lowers the relative return to education. Hence, a greater proportion of the population chooses not to become educated when δ is high.

When fewer agents choose to become educated, there are more unskilled agents working and saving. This increases the supply of loans, which decreases the interest rate. Interestingly, the lower interest rate associated with higher values of δ outweighs the lower average skilled wage resulting in a lower ratio of education costs to average skilled wages. Intuitively, agents should have a greater incentive to acquire education. However, the higher unskilled wage is relatively more valuable to low-ability agents whose productivity of human capital and thus skilled wage, should they choose to become educated, would be low.

The higher unskilled wage and lower skilled wage caused by an increase in δ leads to a decrease in wage income inequality. Moreover, these effects dominate the effect of lower interest rates on skilled and unskilled agents' lifetime resources available for consumption resulting in lower resource inequality.

Appendix B

Figure 4: Proportion of Uneducated Agents

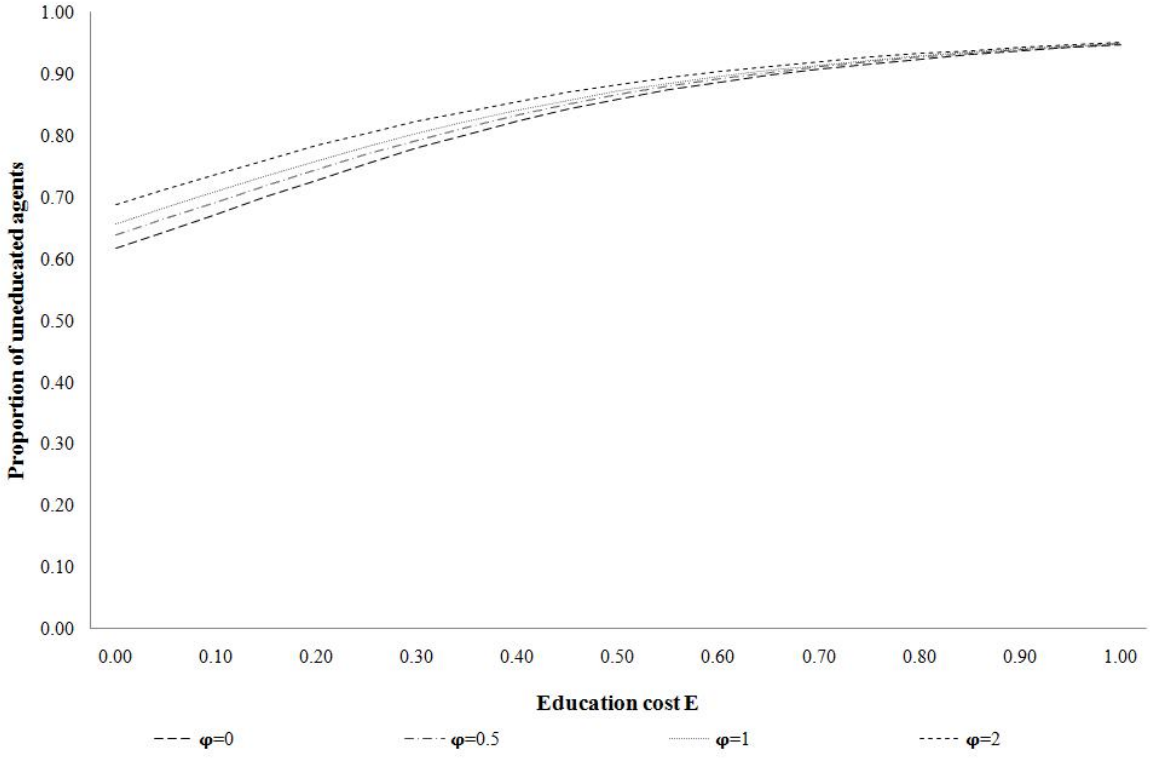


Figure 5: Unskilled Wage

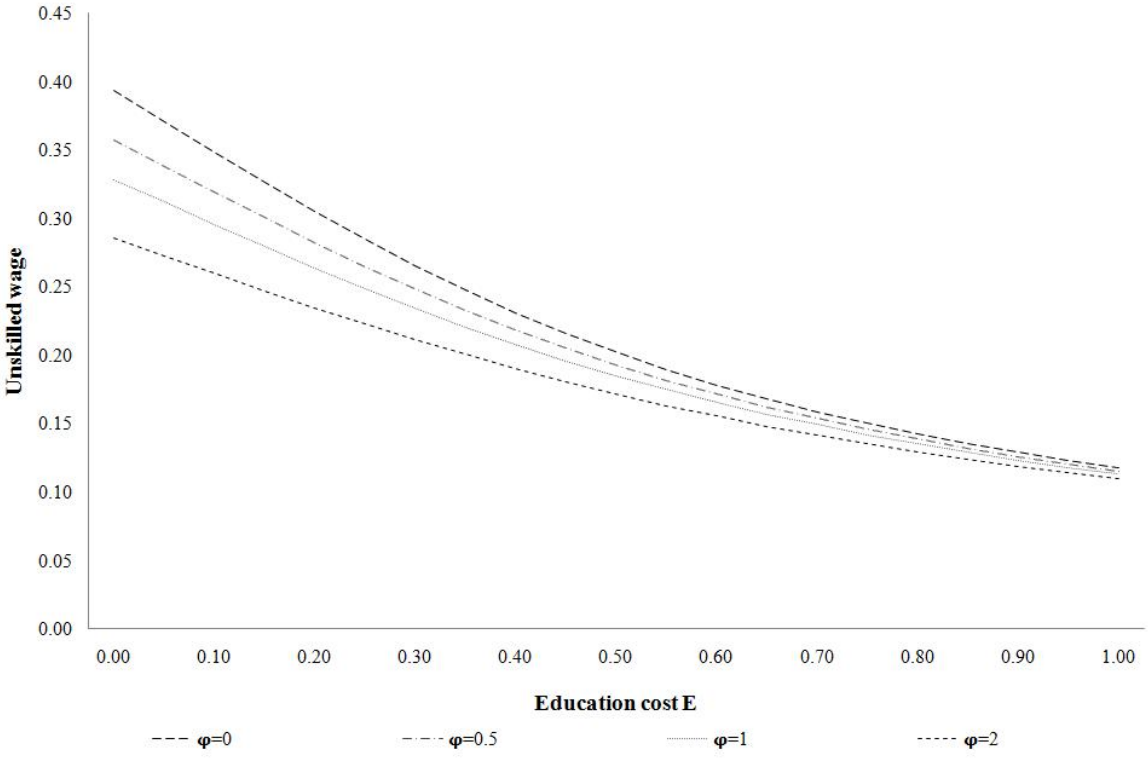


Figure 6: Average Skilled Wage

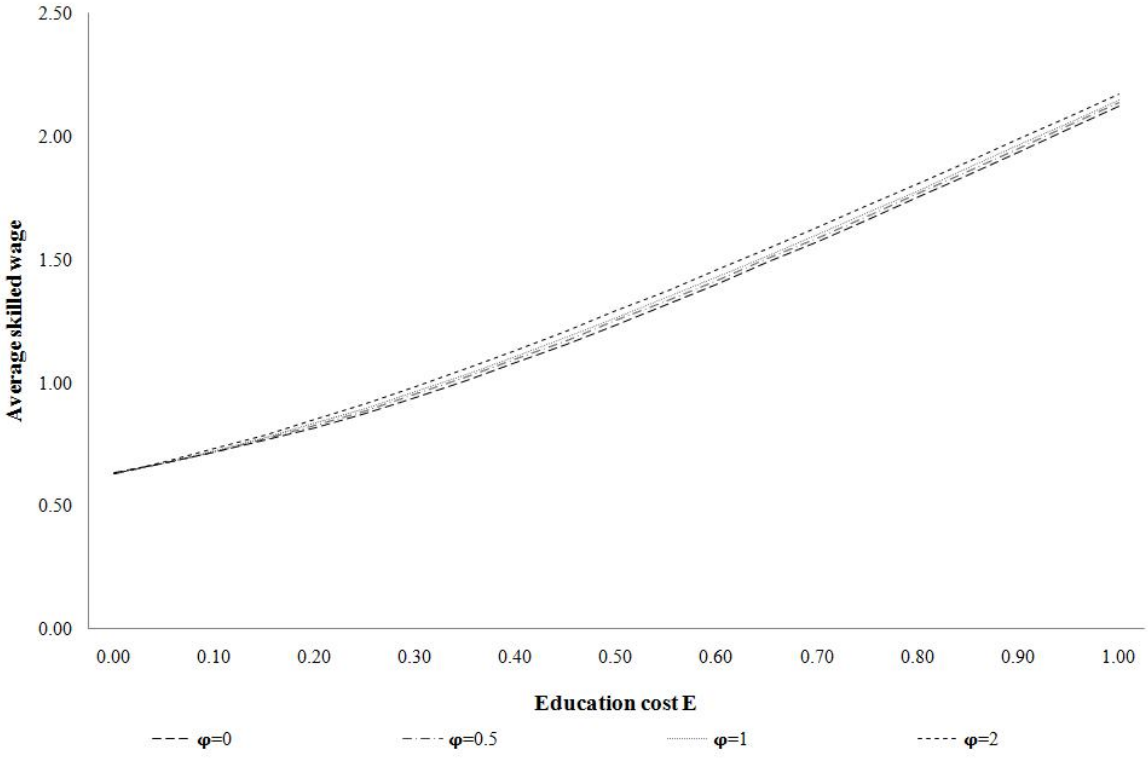


Figure 7: Interest Rate

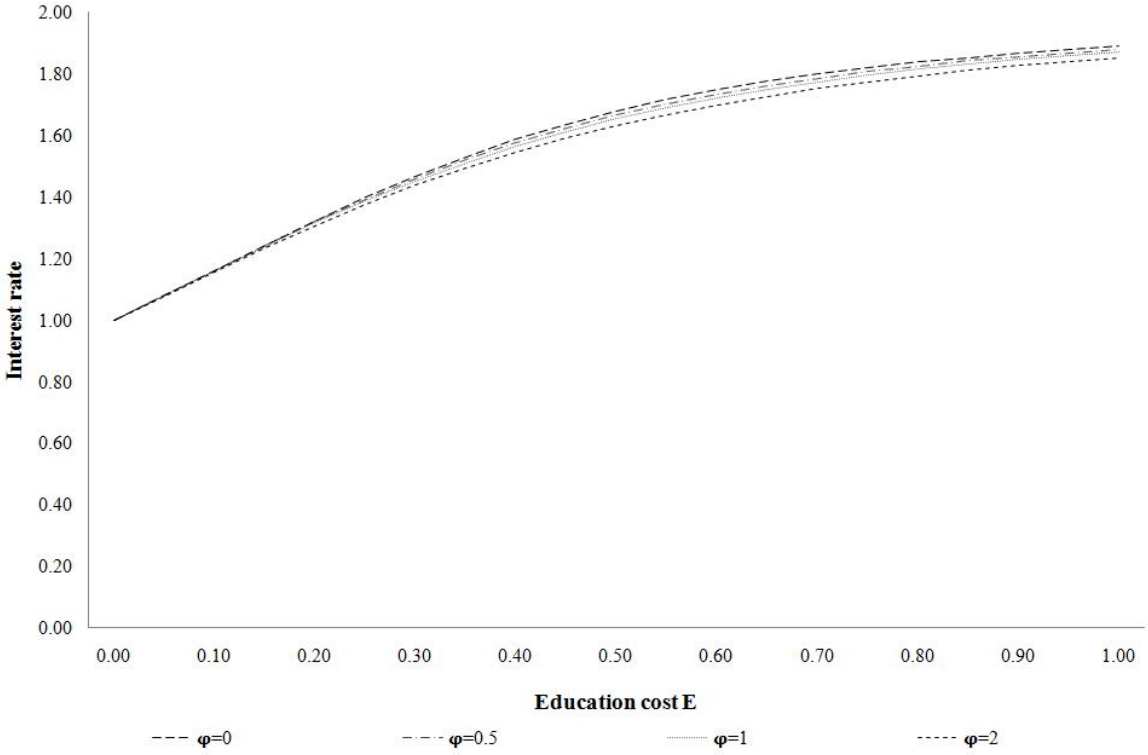


Figure 8: Ratio of Education Costs to Average Skilled Wage

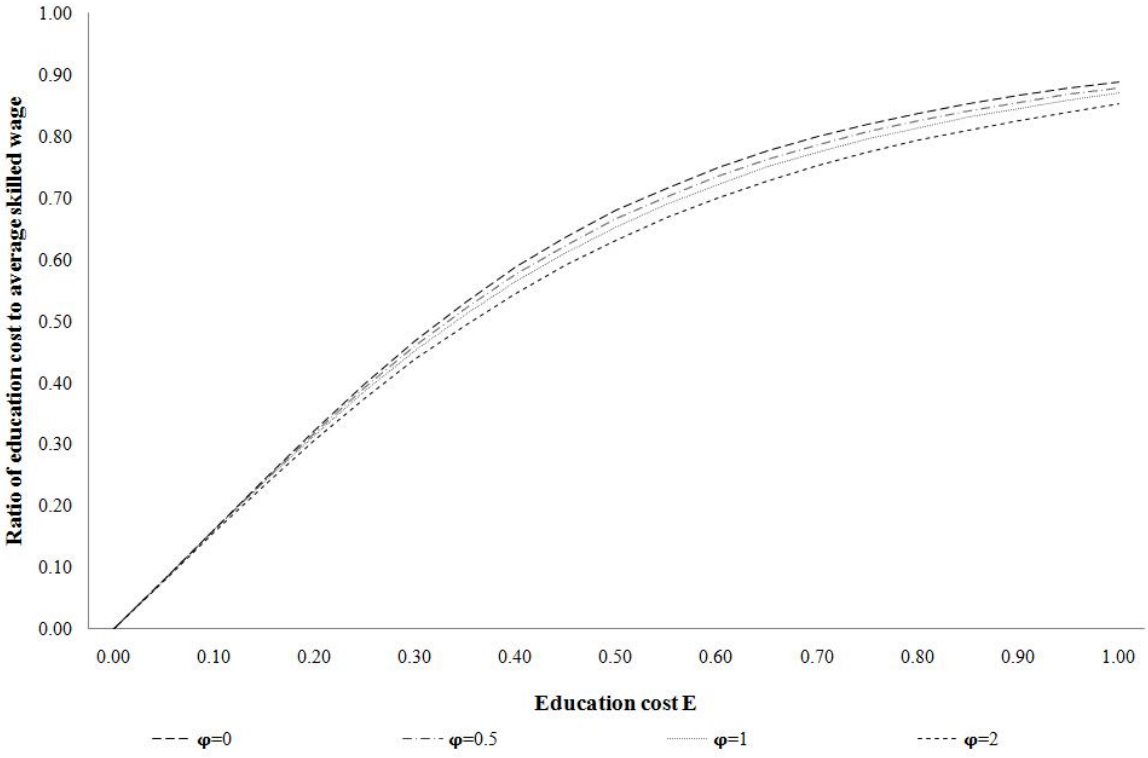


Figure 9: Gini Coefficient for Wage Income

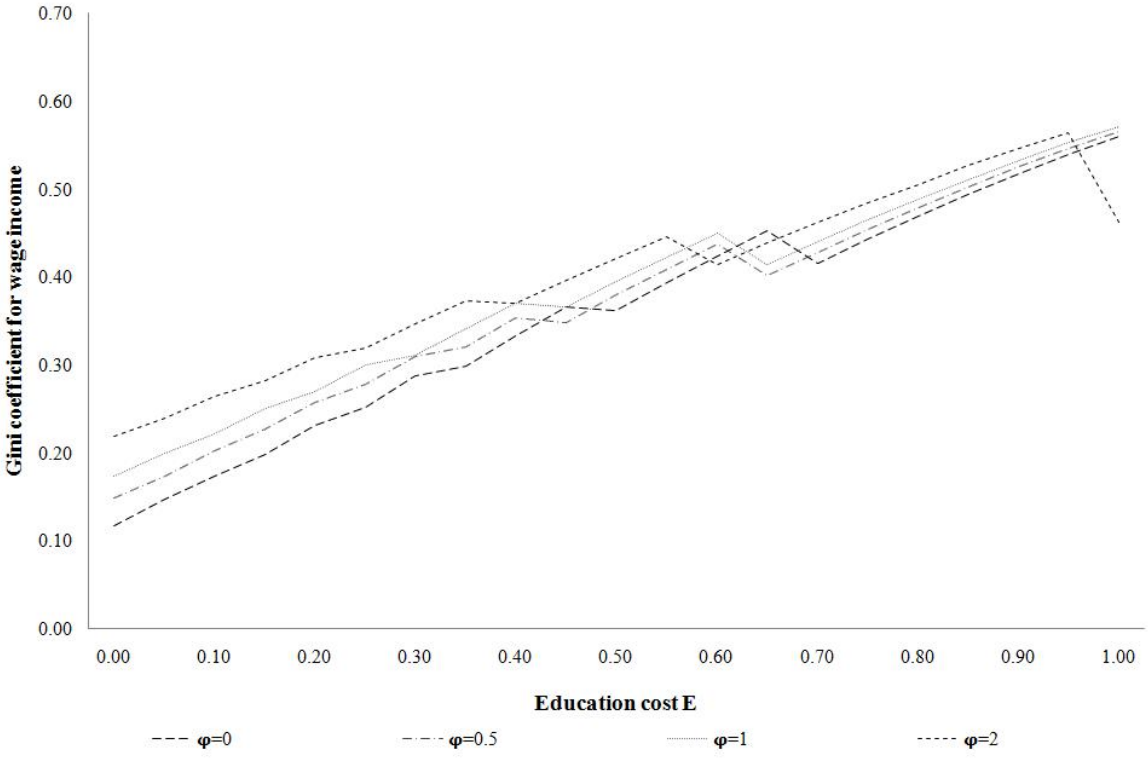


Figure 10: Gini Coefficient for Lifetime Resources Available for Consumption

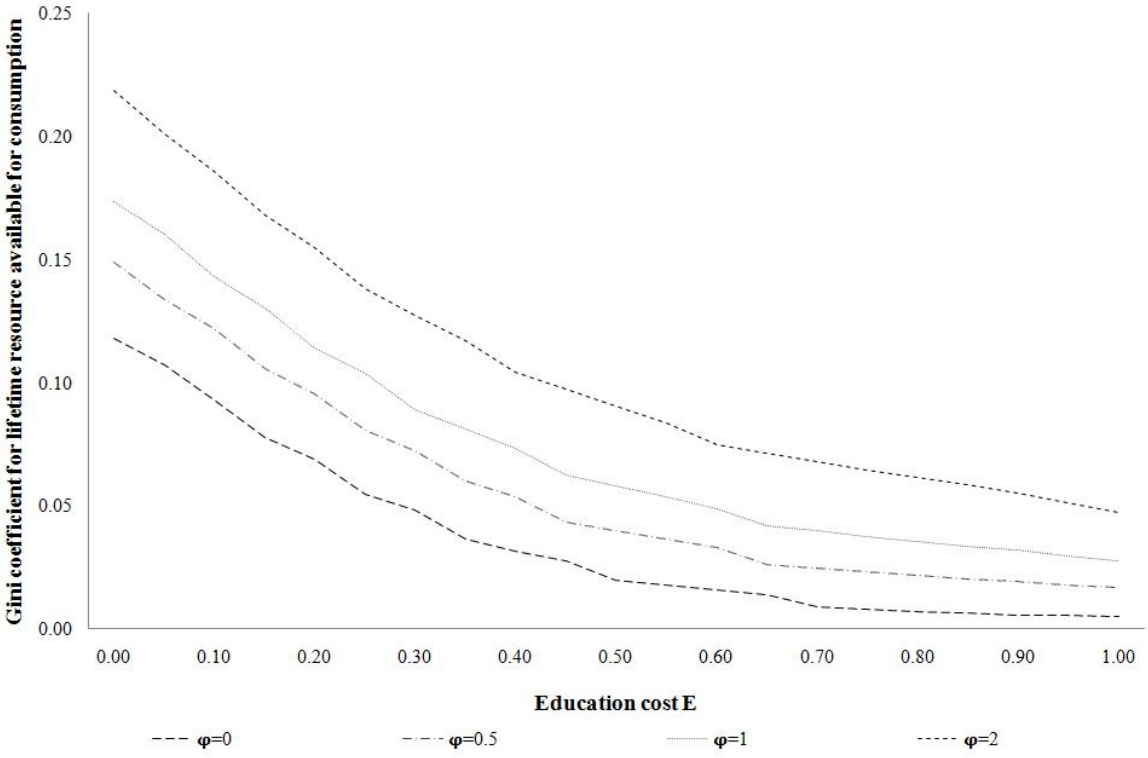


Figure 11: Gross Aggregate Output

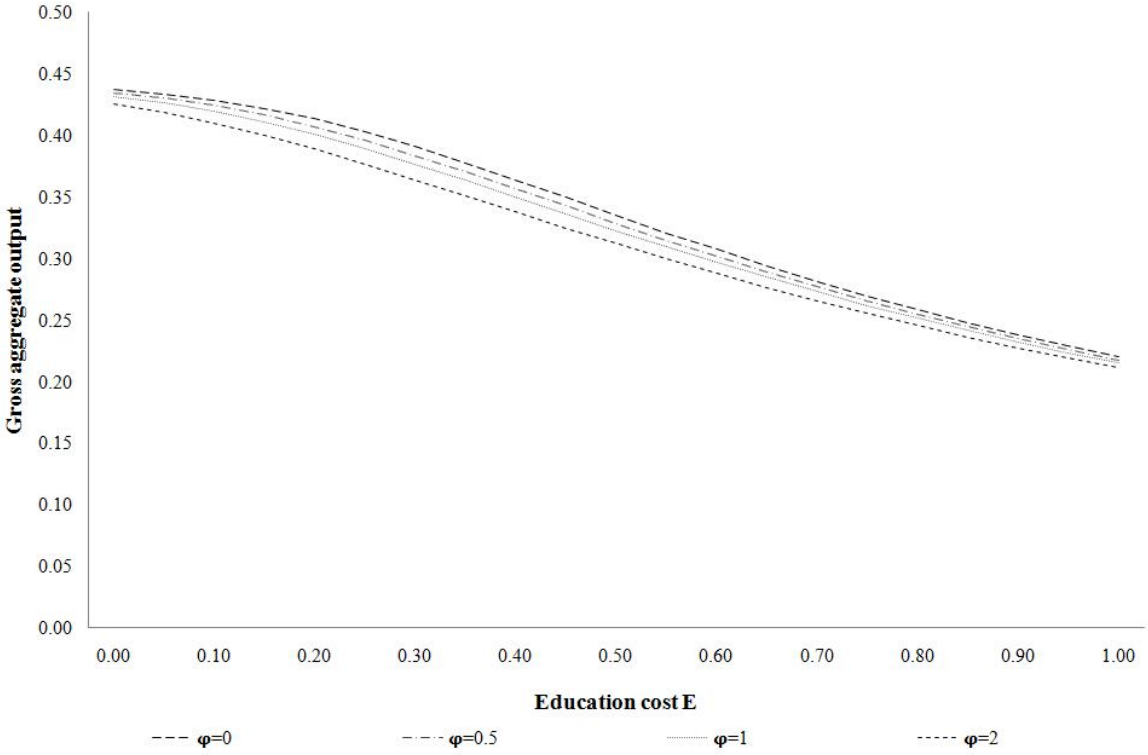
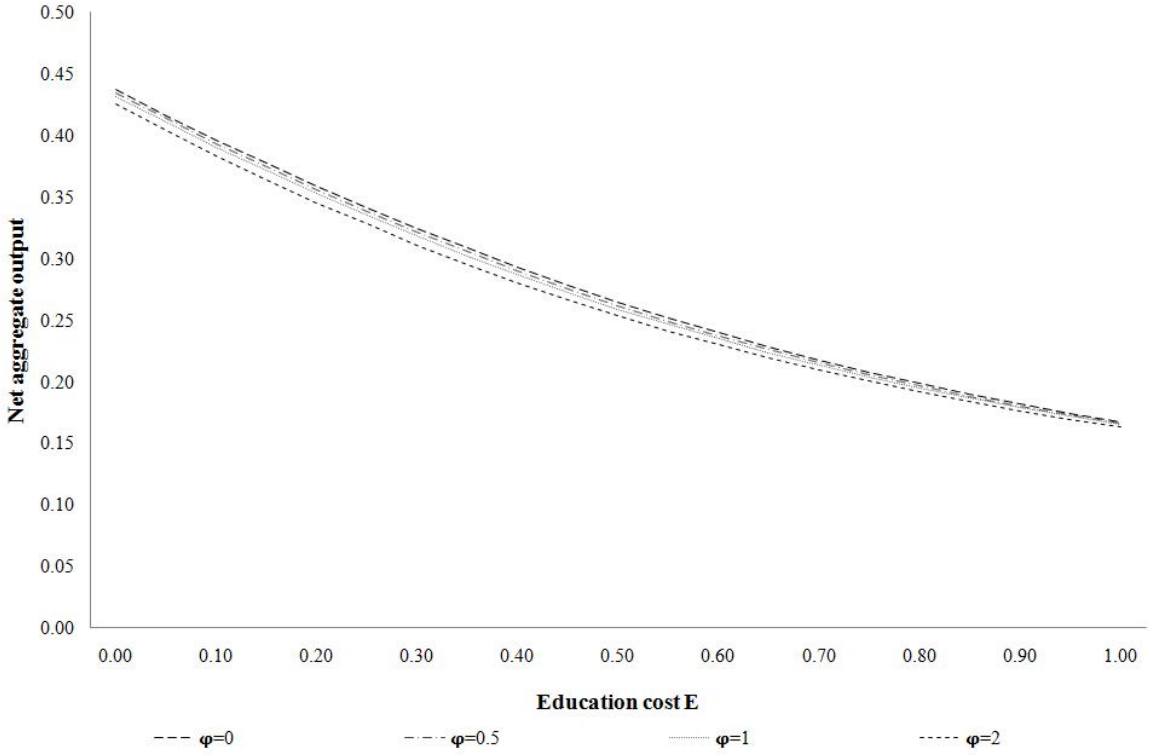


Figure 12: Net Aggregate Output



Appendix C

Figure 13: Proportion of Uneducated Agents

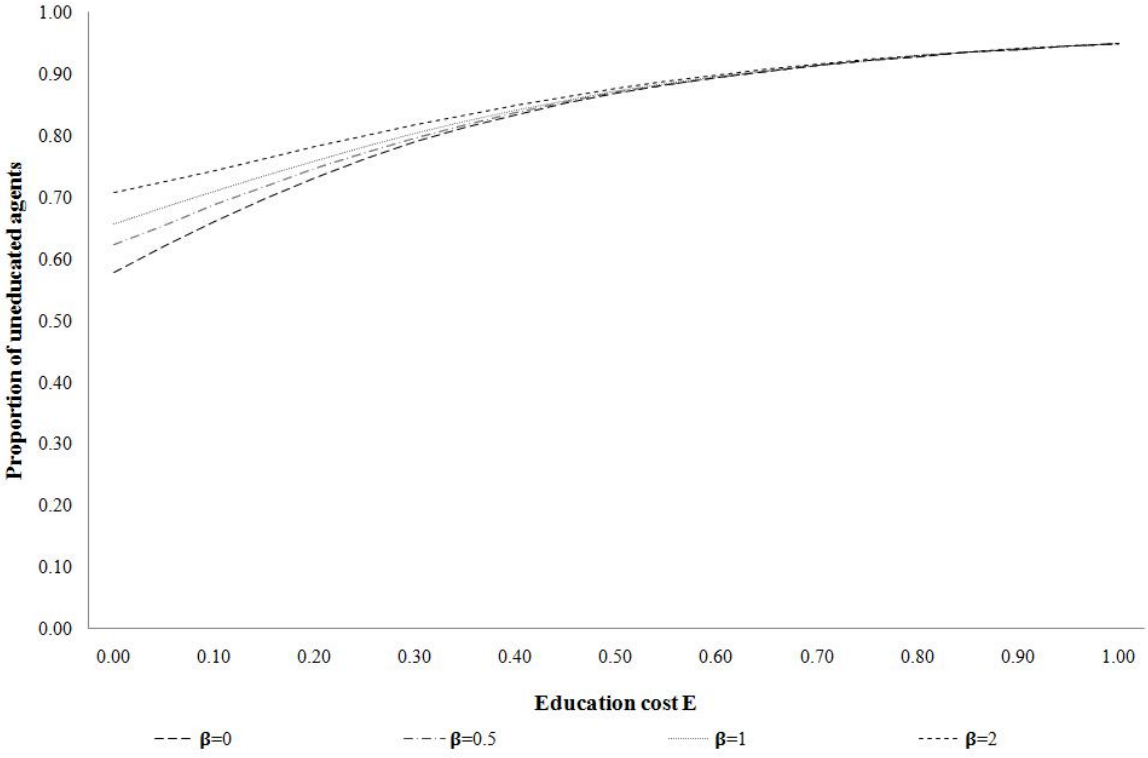


Figure 14: Unskilled Wage

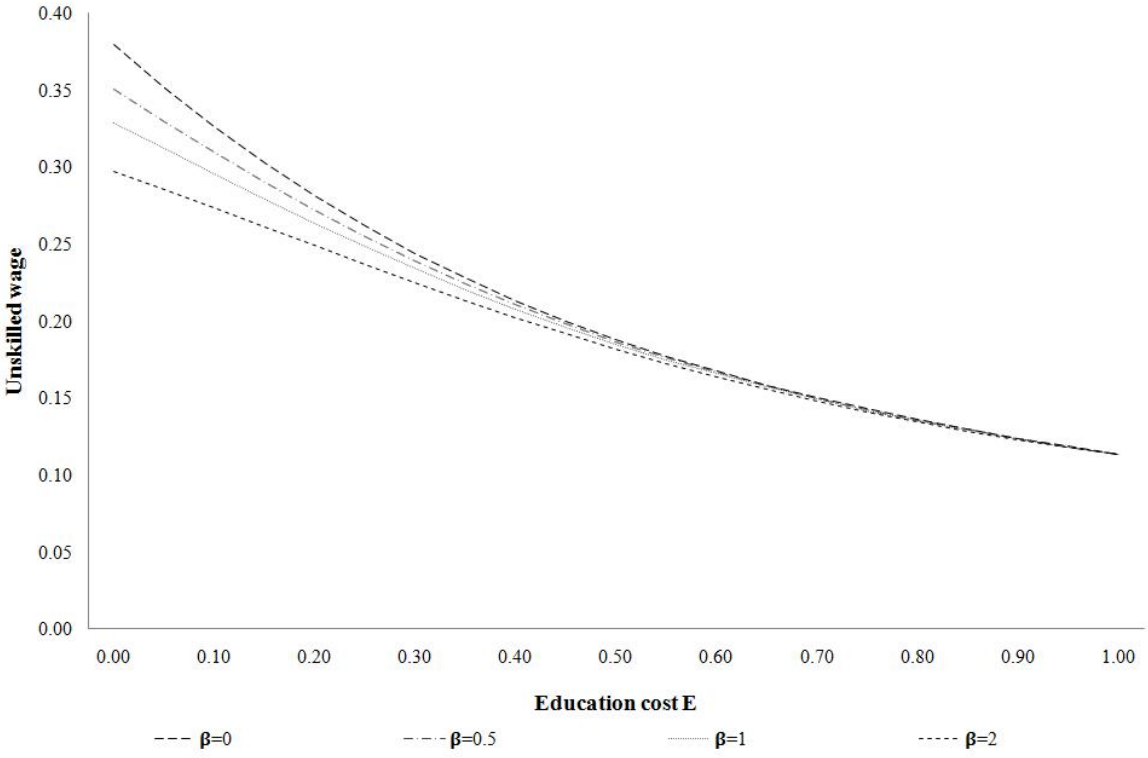


Figure 15: Average Skilled Wage

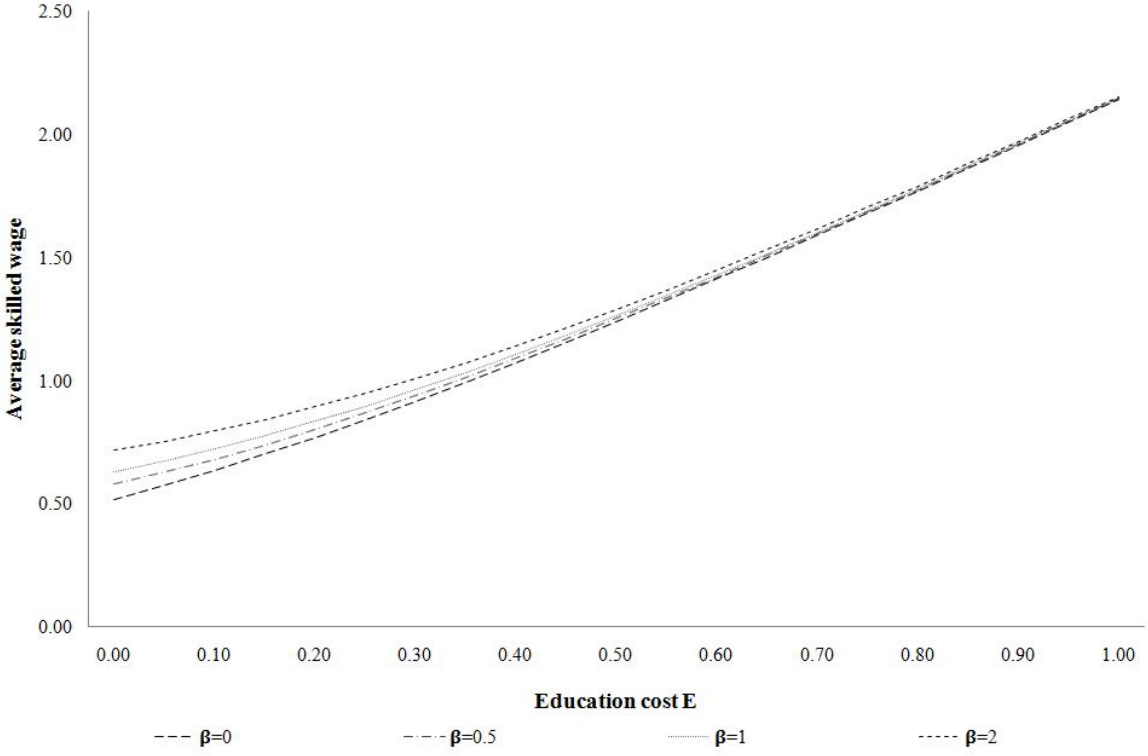


Figure 16: Interest Rate

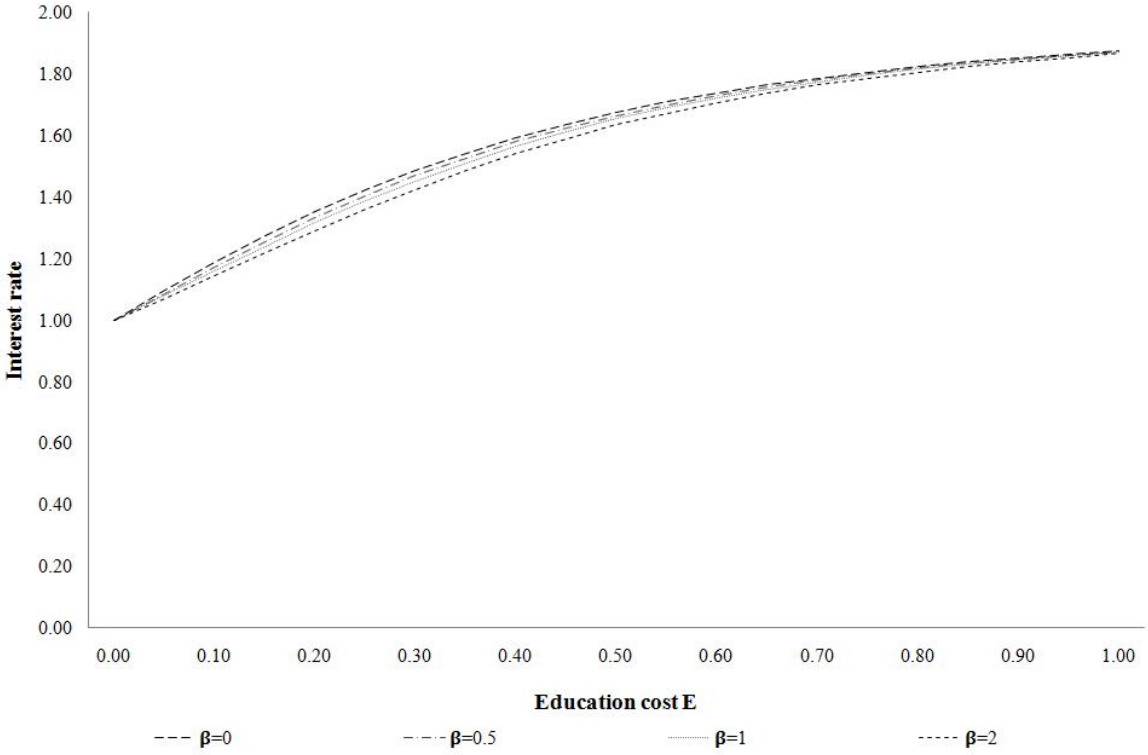


Figure 17: Ratio of Education Costs to Average Skilled Wage

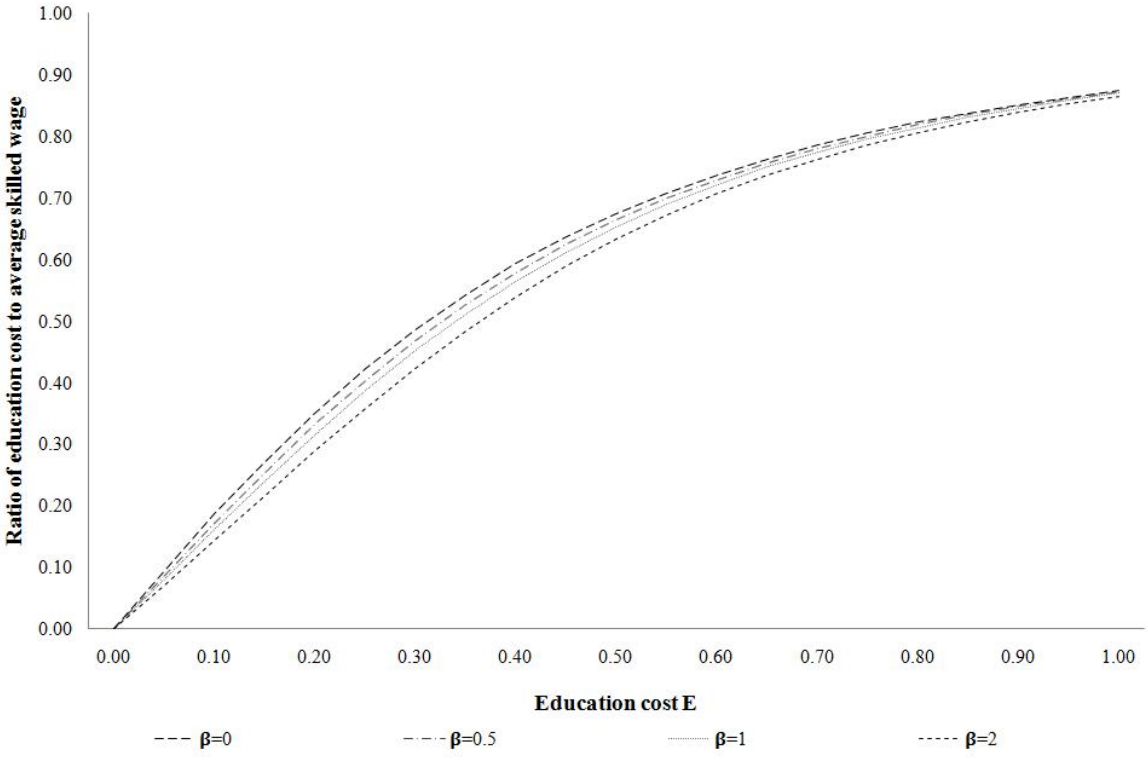


Figure 18: Gini Coefficient for Wage Income

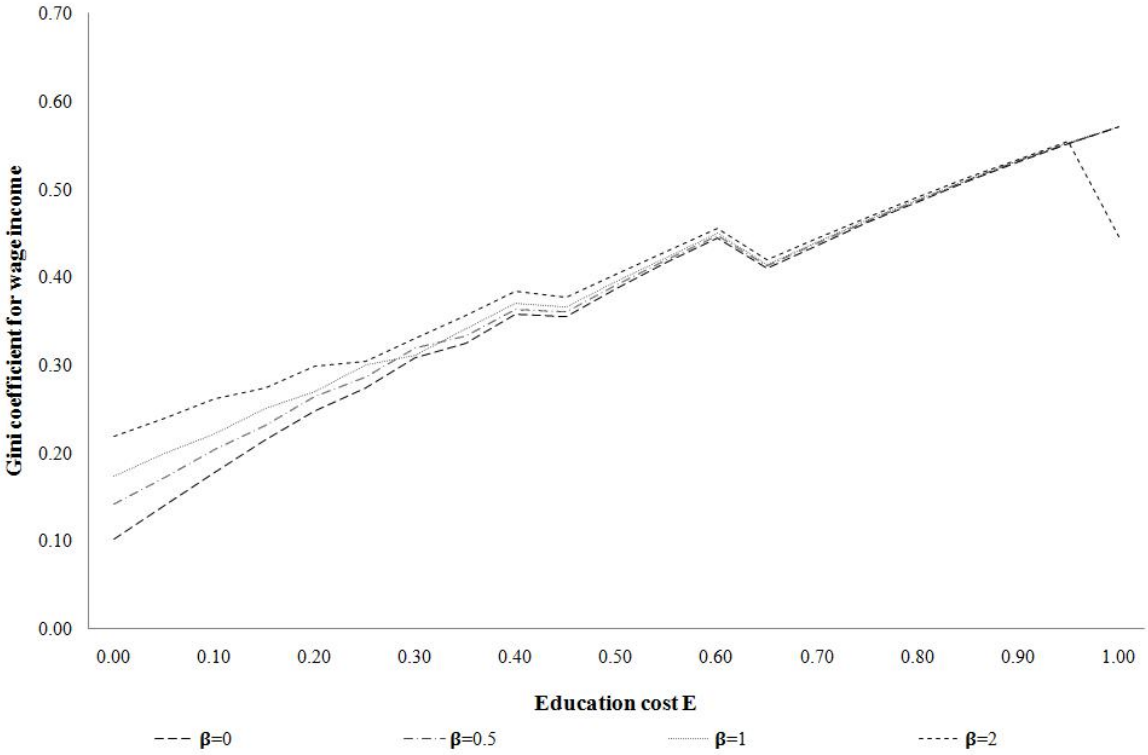
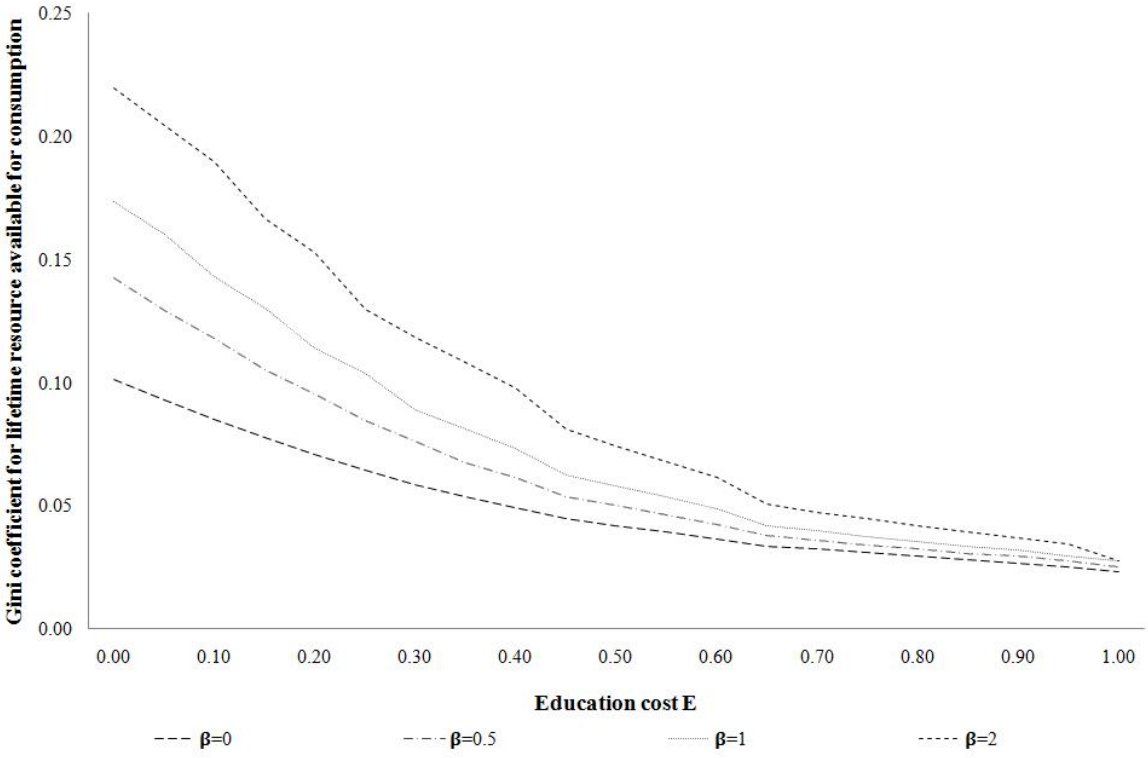


Figure 19: Gini Coefficient for Lifetime Resources Available for Consumption



Appendix D

The Gini coefficient is a measure of the inequality of the distribution of income or resources. It is often calculated as the ratio of the area between the line of absolute equality and the Lorenz curve to the area below the line of absolute equality from a Lorenz curve graph. The Office for Research, Development, and Education (2009) describe the Gini coefficient as

$$G = \left(\frac{2}{n^2\overline{x}}\right)\sum_{i=1}^{n}\left(\left(i - \frac{n+1}{2}\right)x_i\right), \tag{16}$$

where $0 \leq G \leq 1$ and

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i. \tag{17}$$