Allocating government education expenditures across K-12 and college education

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Abstract

As of the late 1990s, public spending on education in the U.S. comprised approximately 7.1% of GDP; about 60% of that support was directed at K-12 education and the remainder at post-secondary (college) education. This paper investigates the output and welfare implications of this spending. The paper develops a theoretical model in which agents who are heterogeneous with respect to ability choose whether to pursue higher education. It is shown that higher-ability agents support greater expenditures at both the K-12 and college levels. When public education expenditures are low, all agents prefer that the budget is dedicated solely to K-12 education and when expenditures are large enough, all prefer that some portion of the budget is allocated to college education. Spending increments beyond this threshold should be allocated disproportionately to college education. For some agents, utility as a function of college subsidies is two-peaked so that large increases in tuition subsidies may be supported while smaller increases would not.

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1 Introduction

A well-educated labor force is widely recognized as a prerequisite for a high standard of living. The link between education and economic performance has prompted governments around the world to take a leading role in funding formal education. As of the late 1990s, for example, public expenditures in the United States accounted for more than 90% of all primary and secondary (K-12) spending and nearly half of all spending at the post-secondary (college) level. Collectively, public education expenditures accounted for more than 7% of the U.S. gross domestic product; 2.8% devoted to post-secondary education and the remainder to elementary and secondary education.[1] The economic importance and size of this public expenditure has provided impetus for a vast literature devoted to analyzing and improving the effectiveness of these expenditures.

Economic analysis of such expenditures often builds upon seminal work by Becker (1964) and Ben-Porath (1967) by modelling formal schooling as an instrument of human capital creation. This perspective on the economic role of education has been applied frequently and fruitfully in general equilibrium analysis of government education expenditures. Much of this work either treats K-12 and college education symmetrically or explicitly models a single level of education.[2] As such, the interaction of K-12 and college human capital accumulation and their funding sources has been, until recently, largely unexplored.[3]

Considering K-12 and college expenditures jointly would be of modest importance if the types of expenditures affected the economy through essentially duplicate channels. However, two features of the educational system ensure that this is not likely to be the case. K-12 funding is clearly not intended to have a large impact on enrollment, given that mandatory attendance laws assure high enrollment.[4] Any influence of K-12 expenditures must work through a quality effect where expenditures improve educational outcomes for all students. College expenditures, in contrast, are

[1] Data from the National Center for Education Statistics (NCES).

[2] For example, Benabou (1996, 2002), Fernandez and Rogerson (1999), Kaganovich and Zilcha (1999), and Rangazas (2000) state that public education spending in their models is meant to reflect K-12 spending in the U.S.. Johnson (1984), Fernandez and Rogerson (1995), Blankenau (1999), Fender and Wang (2003), Galor and Moav (2000), Hanushek et.al. (2003), Caucutt and Kumar (2003), and Akyol and Athreya (2005) present models of public spending on college education. Papers that are more generic in discussing human capital include Glomm and Ravikumar (1992, 1997, 1998, 2001), Eckstein and Zilcha (1994), Cassou and Lansing (2003, 2004), and Blankenau and Simpson (2004).

[3] Some recent work has begun to explicitly model the two types of expenditures and explore various aspects of this interaction. See Blankenau (2005), Restuccia and Urrutia (2004) and Su (2004).

[4] Schooling is mandatory up to age 16 in 30 states and up to age 18 in the rest. Approximately 94% of all eligible teenagers remain in high school until age eighteen.

at least partially intended to increase enrollment.[5] Furthermore, a substantial body of empirical and theoretical work supports the notion that education at the college level produces human capital which is qualitatively different from that produced through high school education. For example, it is now commonplace to posit production functions where human capital acquired at the college and K-12 levels enter as separate inputs.[6]

In this paper, we explore a stylized model of human capital accumulation that emphasizes these aspects of the educational system. The model features two levels of education with differing government funding structures at each level. The lower level (K-12) is mandatory and funded exclusively by government.[7] Government K-12 spending provides a uniform endowment of general human capital to all agents, building on a class of human capital production functions which emphasize government's role as a potential direct provider of inputs, an idea going back to Loury (1981).[8] The higher level of education (college) is optional and requires some private expenditure that may be supplemented by government funding. Government spending on college education, in contrast to K-12 spending, encourages a larger share of the population to pursue college education. This feature and the dichotomous nature of the college education choice mirror models used recently by Hanuchek, et al. (2003), Caucutt and Kumar (2003), Fender and Wang (2003) and Restuccia and Urrutia (2004).[9] The two levels of education produce two types of human capital (general and specific) which are imperfect substitutes in production, a feature supported by the large capital-skill complementarity literature (Krusell, et al. (2000)). Finally, agents are heterogeneous in their ability to convert time at college into productive capacity. Heterogeneity in ability gives rise to heterogeneity in the returns to college. As such, the share of the population going to college is endogenously determined and influenced by college subsidies.

We use the model to explore the output and welfare effects of changing spending levels on K-12 and college education. We demonstrate that agents who pursue a college education prefer larger

[5] Currently, approximately 60% of high school graduates go on to post-secondary schooling, up from approximately 42% in 1980. In 2000, 38% of the operating revenue of degree-granting post-secondary institutions came from public sources while 28% came from tuition and fees (NCES data).

[6] Prominent examples include Katz and Murphy (1992) and Krusell, et al. (2000).

[7] Although this is a simplification, with roughly 90% of K-12 students relying on government funding (NCES (2003)), there have been numerous studies exploring the private vs. public financing margin. The focus here is to investigate the K-12 vs. college financing margin.

[8] More recent applications include Barro (1990), Glomm and Ravikumar (1992, 1997, 1998, 2001), Eckstein and Zilcha (1994), Benabou (1996), Kaganovich and Zilcha (1999), Soares (2003), Glomm and Kaganovich (2003), Cassou and Lansing (2003) and Blankenau and Simpson (2004).

[9] For other examples see Johnson (1984), Creedy and Fracois (1990), Fernández and Rogerson (1995), Blankenau (1999), Galor and Moav (2000), and Akyol and Athreya (2005).

K-12 expenditures than those who do not. These agents leverage their human capital endowment through college and thus are more willing to pay for quality K-12 education. We then show that college subsidies can increase welfare for all agents. Those who go on to college support subsidies as a means of lowering their private tuition costs. For others, the advantage results from a wage effect. Subsidies motivate an increase in the amount of specific human capital and a relative scarcity of general human capital. Over a range of subsidies, the resulting wage increase compensates for the larger tax burden. While subsidies can have widespread support, the preferred level is agent specific with the more able preferring larger subsidies. For some agents, utility as a function of college subsidies is two-peaked, leading to the interesting situation where small increases in these subsidies are not supported while larger increases are.

We also consider the question of how to allocate a fixed education budget across K-12 education spending and college subsidies. When expenditures are low, government should fund only K-12 education. Since government is the sole revenue source for general human capital, low levels of funding make general human capital scarce and agents are unwilling to sacrifice general human capital to fund college subsidies. With greater expenditures and more abundant general human capital, income for all agents is increased by allocating some share of expenditures to college subsidies. Of particular interest is that even those who do not attend college prefer allocating some spending toward college education. The key to this result is again the general equilibrium wage adjustments. While the preferred allocation is agent specific, there is unanimity that the allocation should shift toward college subsidies when the level of spending increases.

The presentation of these results is organized as follows. In Section 2, a description of the model is provided. The formal implications of the model are then presented in Section 3. In Section 4 we conclude and discuss the merits of several extensions of this work.

2 A model of education expenditure

We consider a stylized economy which yields closed form solutions and highlights the key trade-offs inherent in considering K-12 and college education jointly. Our model economy is populated by two-period lived agents. Output is generated by a representative competitive firm combining specific and general human capital provided by the agents. In addition, a fiscal authority levies taxes to fund general human capital and subsidize specific human capital. We begin by discussing agent choices and their educational opportunities. Next, we specify the firm's problem and finally the constraints on the fiscal authority.

Agents are heterogeneous with respect to ability; we index both agents and ability by $i \in [0, 1]$. An agent born in period t spends the first period of life in compulsory education and acquires general human capital in the amount g_{t+1}, where the subscript indicates the period in which the general human capital becomes productive. The amount of general human capital acquired depends on the quality of government provided education, q_t, and is uniform across agents:

$$g_{t+1} = \mu_1 q_t^{\mu_2}, \qquad \mu_1 > 0,\ \mu_2 \geq 0. \tag{1}$$

In positing equation (1), we make the assumption that the amount of human capital acquired in K-12 is positively related to the value of resources devoted to education. These resources are measured in terms of the consumption good and determined by the government. This aspect of the model finds support in studies that show a positive relationship between school resources and earnings (Card and Krueger (1992)). This function is similar to that used in Restuccia and Urrutia (2004), who, however, allow for public and private funding of K-12 education and define q as the sum of these two sources of funding. This is a natural feature of their model since they are interested in the intergenerational transmission of income which is influenced by parental investment in education. Here, we wish to focus on the distinction outlined in the introduction between K-12 and college education: K-12 is mostly mandatory and mostly publicly funded, while college is optional and partially financed with private funds. Our specification is most similar to Su (2004), who, however, includes the previous period's level of general human capital in the accumulation equation and assumes the initial endowment of human capital varies across individuals.[10]

In the second period, agent i can take advantage of an additional educational opportunity. If undertaken, the agent acquires specific human capital in the amount[11]

$$s_{t+1}^{i} = 2 g_{t+1} i. \tag{2}$$

Hence, specific skill is derived from two sources: ability and general skill. An agent's ability can be interpreted as innate to the individual or as a product of nurture in a household which is not explicitly modeled here. However acquired, ability is positively related to the amount of specific human capital acquired.

[10]Since the focus here is on steady states, adding a link to the general human capital stock would be equivalent to (1) with a different value for μ_1. Also, making general human capital linked to ability is similar to the model here with a suitably redefined specific human capital formulation (2).

[11]More generally, $s_{t+1}^{i} = \eta g_{t+1} i_t$. Setting $\eta = 2$ simplifies many expressions without loss of generality.

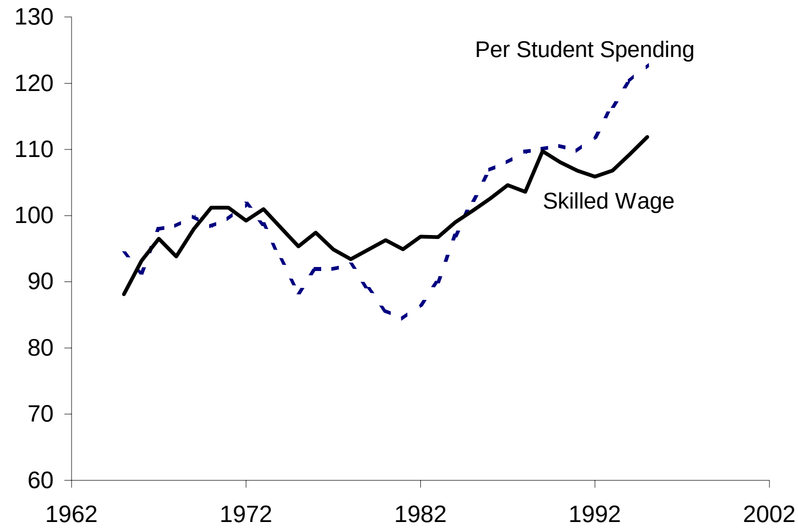

Figure 1: Skilled wage, indexed by average wage (1964 – 1995) from Current Population Survey and per student spending of all degree-granting institutions (NCES Table 341).

The resource cost to provide one agent with specific human capital is given by T_{t+1}. We assume that this fee is a scalar of the cost of hiring units of specific human capital, ω^s_{t+1}: that is,

$$T_{t+1} = \theta g_{t+1} \omega^s_{t+1} \tag{3}$$

where $0 < \theta < 2$ and ω^s_{t+1} is the wage paid to a unit of specific human capital. This function accords with data on per student expenditures of institutions of higher education. For public institutions, per student spending rose 47% in real terms between 1970 and 2000, while the skilled wage rose 28%. Furthermore, the patterns of these increases roughly correspond to each other over this period: both the wage premium and the per student cost of college education were flat or slightly declining during the 1970s, but rose sharply over the 1990s (see Figure 1). Following Galor and Moav (2000) and others, we have modeled this fee as a direct resource cost and not a time cost. Realistically, however, a large part of the private cost of college education is the opportunity cost of time. This will certainly be important when taxes are distortionary (Milesi-Ferretti and Roubini (1998)) since time spent in schooling would not be taxed. Our focus, however, is not on a comparison of financing schemes, so we abstract from distortionary taxation. With lump-sum taxation, incorporation of a time cost would simply scale the amount of specific and general human capital supplied by college educated workers.

After the education choice, agents immediately supply general and specific human capital inelastically in a competitive labor market. Each agent who does not acquire specific human capital supplies g_{t+1} units of general human capital; otherwise, agent i supplies both g_{t+1} units of general human and s^i_{t+1} units of specific human capital.[12]

Agents derive utility from consuming a unique good in the second period of their lives; this allows us to focus on the effect of human capital accumulation on wages and consumption after schooling is completed. Since agents consume in only one period, there is no savings decision to be made and consumption is equal to income net of taxes and education expenditures. Because of this simple structure, we lose no generality in assuming that utility is linear in consumption:

$$U^i = C^i_{t+1}.$$

Agent i maximizes second-period consumption subject to

$$C^i_{t+1} \leq \omega^g_{t+1} g_{t+1} - \tau_{t+1}$$

if he does not acquire specific human capital and

$$C^i_{t+1} \leq \omega^g_{t+1} g_{t+1} + \omega^s_{t+1} s^i_{t+1} - T_{t+1}(1-\psi) - \tau_{t+1}$$

if he does. Here ω^g_{t+1} is the wage paid to a unit of general human capital, ψ is the proportion of college expenses paid by the government and τ_{t+1} is a lump-sum tax paid by all working agents. The term $T_{t+1}(1-\psi)$ reflects the part of a college education paid for by the agent, and includes room, board, tuition and fees.

Since maximizing consumption is equivalent to maximizing income, agent i will acquire specific human capital only if

$$s^i_{t+1} \omega^s_{t+1} \geq T_{t+1}(1-\psi). \tag{4}$$

An agent acquires specific human capital only if specific human capital generates an increment to lifetime income which exceeds its net cost. We denote the lowest-indexed agent who becomes skilled by $\hat{\imath}_{t+1}$. When $\hat{\imath}_{t+1} > 0$, this is the agent who is just indifferent to acquiring specific human capital. For brevity, we sometimes refer to agents with specific human capital as specifically skilled and other agents as generally skilled. In addition, we refer to specific human capital accumulation as college education and general human capital accumulation as K-12 education. Thus all agents

[12] This feature allows tractability. Numerical exercises demonstrate, not surprisingly, that having these agents provide only specific human capital has no meaningful effect in our subsequent experiments.

of generation t with an index higher than or equal to $\hat{\imath}_{t+1}$ will be college educated and specifically skilled; the remainder will have a K-12 education and be generally skilled.

A representative firm hires general human capital, G_{t+1}, and specific human capital, S_{t+1}, to produce the final output good, Y_{t+1}, according to

$$Y_{t+1} = S_{t+1}^{\alpha} G_{t+1}^{1-\alpha}, \qquad \alpha \in [0,1].$$

Given Cobb-Douglas production, the elasticity of substitution between the two inputs is constrained to be one. Using a CES production function that includes two types of physical capital, Krusell, et al. (2000) estimate an elasticity of substitution between skilled and unskilled labor of approximately 1.6, which is higher than the elasticity assumed here. However, since specifically-skilled workers also supply a unit of general skill, these workers supply general labor that is a perfect substitute for the labor of generally-skilled workers. The additional specific skill supplied by these workers is complementary to the general skill supplied by all workers. Hence, the elasticity of substitution between the labor supplied by a college-educated worker and a K-12 worker is more than one. This specification also distinguishes our model from that in Su (2004) and Restuccia and Urrutia (2004); in both papers, production is linear in labor, and general and specific human capital are perfect substitutes. Hence, there is no wage effect from changes in the quantity of specific or general capital; wage effects, however, play an important role in the analysis here.

Labor market clearing requires that the specific and general human capital supplied by workers is equal to that employed by the firms:[13]

$$S_{t+1} = \int_{\hat{\imath}_t}^{1} s_{t+1}^{i} di = \mu_1 q_t^{\mu_2} \left(1 - \hat{\imath}_{t+1}^2\right), \tag{5}$$

$$G_{t+1} = \int_0^{\hat{\imath}_t} g_{t+1} di + \int_{\hat{\imath}_t}^{1} g_{t+1} di = \mu_1 q_t^{\mu_2}. \tag{6}$$

Using (5) and (6), equilibrium output simplifies to

$$Y_{t+1} = \mu_1 q_t^{\mu_2} \left(1 - \hat{\imath}_{t+1}^2\right)^{\alpha}.$$

Wages per unit of general and specific human capital are given by:

$$\omega_{t+1}^{g} = (1-\alpha)\left(1 - \hat{\imath}_{t+1}^2\right)^{\alpha},$$

$$\omega_{t+1}^{s} = \alpha\left(1 - \hat{\imath}_{t+1}^2\right)^{\alpha-1}.$$

[13] Our assumption that $\eta = 2$ simplifies (5). Without this assumption, the expression would be $S_{t+1} = \frac{\eta}{2}\mu_1 q_t^{\mu_2}\left(1 - \hat{\imath}_t^2\right)$. This would only introduce a factor into many of the following expressions that has no qualitative effect on our findings.

A fiscal authority collects revenue via a lump-sum tax and uses this revenue to finance quality in K-12 education and to subsidize the cost of college education. The fiscal authority spends a total of q_{t+1} on general human capital for all agents and $T_{t+1}\psi$ per agent on specific capital for agents attending college. Since government college expenditures only pay a portion of the costs of attending college, we will often refer to these expenditures simply as subsidies. Given that the share of agents attending college is $(1 - \hat{\imath}_{t+1})$, total subsidies are equal to $(1 - \hat{\imath}_{t+1})\, T_{t+1}\psi$ and the fiscal authority's budget constraint is

$$(1 - \hat{\imath}_{t+1})\, T_{t+1}\psi + q_{t+1} = \tau_{t+1}.$$

For analytical tractability, we assume that total government education spending is a constant share, ζ_τ, of output so that $\tau_{t+1} = \zeta_\tau Y_{t+1}$ in equilibrium. For our purposes, it is convenient to rewrite this constraint. Let ζ_g be the share of output devoted to general education and ζ_s be the share devoted to specific education by the government. Then the government's budget constraint each period can be written

$$\left(\zeta_s + \zeta_g\right) Y_{t+1} = \zeta_\tau Y_{t+1},$$

where

$$\zeta_s Y_{t+1} = (1 - \hat{\imath}_{t+1})\, T_{t+1}\psi. \tag{7}$$

Our objective is to evaluate the influence of changes in ζ_s, ζ_g and ζ_τ on the economy.

For the remainder of the paper, we consider the steady state of the model, allowing us to drop all time subscripts and to provide analytical results.[14] The proofs to all lemmas and propositions are given in the appendix.

3 Steady state analysis of policy choices

In this section, we explore the effects of policy changes on the economic equilibrium. Our principle concern is with the heterogeneous welfare effects of such changes.[15] However, we begin with a discussion of college enrollment and aggregate output in section 3.1. There are two reasons for this preliminary exploration. First, understanding each is interesting on its own. Enrollment

[14] With this simple structure, dynamics are easy to track. However, few additional insights arise from this analysis.

[15] Because agents are heterogenous, we do not explore optimal fiscal policy since this would require an ad hoc weighting function. However, we do show that there are many circumstances in which agents unanimously agree on the direction of policy. See Fernandez and Rogerson (2003), Hanushek et al. (2003) and Benabou (2002) for recent examples of work which evaluates education policy with heterogeneous agents using various weighting functions.

rates are central to any discussion of college subsidies and output is often taken as a crude indicator of welfare. Second, when we address welfare issues in Section 3.2, we demonstrate that welfare is conveniently expressed as a function of Y and $\hat{\imath}$. As such, understanding the influence of policy on these items is a step toward understanding welfare.

3.1 General results

The following lemma shows how the policy parameters affect the number of agents pursuing college degrees and the level of output.

Lemma 1. *The share of the population that remains generally skilled is*

$$\hat{\imath} = \frac{\theta\alpha - \zeta_s}{2\alpha + \zeta_s} \tag{8}$$

and equilibrium steady state aggregate output is

$$Y = \left[\left(1 - \hat{\imath}^2\right)^{\alpha} \mu_1 \zeta_g^{\mu_2} \right]^{\frac{1}{1-\mu_2}} . \tag{9}$$

An implication of equation (8) is that an increase in the proportion of output used to subsidize specific skill, ζ_s, increases the share of agents who acquire specific human capital. This is to be expected since subsidies reduce the private cost of becoming specifically skilled.[16] In contrast, neither the general tax rate, ζ_τ, nor the provision of K-12 education funds, ζ_g, has an effect on the number of specifically skilled agents. Lump sum taxes are neutral because they have no influence on either the benefit or cost of acquiring specific human capital.[17] The neutrality of K-12 spending, in contrast, arises because of offsetting effects. An increase in ζ_g increases the lifetime income of any skilled worker but through equation (3) this results in a proportional increase in the cost of college. The education choice reflected in equation (4) is thus independent of ζ_g. Another important parameter influencing $\hat{\imath}$ is θ. In this case an increase in tuition via an increase in θ makes specific human capital more costly and reduces its supply.

Lemma 1 also shows that an increase in K-12 education spending will always increase output and an increase in college subsidies will increase output whenever $\hat{\imath} > 0$.[18] Furthermore, each type of expenditure is more productive when the other is larger. To show this, substitute equation (8)

[16] In equilibrium a higher ζ_s implies a higher ψ. See equation (10) below.

[17] The addition of proportional taxation would add a factor to equation (4) and scale the proportional subsidy, (1-ψ). Hence, we can take into account a proportional tax by appropriately calibrating (1-ψ).

[18] However, throughout we consider only cases in which $\zeta_\tau < 1 - \alpha$ to ensure that consumption is positive. See equation (11) below.

into equation (9). It is straightforward to show that $\frac{\partial Y}{\partial \zeta_g}$ is positive and increasing in ζ_s.With college subsidies high, more students choose to acquire specific human capital through college enrollment. Recall that agents who go to college acquire specific human capital in proportion to their endowment of general human capital. In essence, then, the societal investment in general human capital in leveraged when agents decide to continue their education. The more who go to college, the greater is this effect. Thus K-12 investment is made more effective through government college expenditure. Similarly, we can show that $\frac{\partial Y}{\partial \zeta_s}$ is positive (unless $\hat{\imath} = 0$) and increasing in ζ_g. College subsidies are more productive with higher K-12 expenditures. The reason is that K-12 spending leaves agents more prepared to acquire specific human capital, boosting the output response of encouraging college enrollment.

Next, consider the case in which ζ_τ is fixed, while ζ_g and ζ_s are varied. In this case, an increase in ζ_s, for example, increases the number of specifically-skilled agents (a positive effect on output), but requires a decrease in funding for general human capital (a negative effect on output). This trade-off implies an optimization problem for output which can be summarized by the following proposition:

Proposition 1 *Suppose ζ_τ is fixed. If $\zeta_\tau < \frac{(2-\theta)\mu_2}{\theta}$, output is maximized when college education is not subsidized. Otherwise, output is maximized when college education is subsidized; the output maximizing level of ζ_s rises with both ζ_τ and θ and decreases with μ_2.*

The results are tied to the way the two types of human capital are produced and the mechanism by which government policy influences their quality and quantity. When the overall tax rate, ζ_τ, is small the government is the sole source of funds for K-12 education, so low funding translates into a low level, but high marginal product, of general human capital. In this instance, another dollar allocated to K-12 has a high payoff in terms of output. In addition, general skill is a prerequisite to the acquisition of specific skill so low levels of general human capital make it less advantageous to acquire specific human capital.[19]

Funding of college subsidies also influences output, but its effect is different because college can be funded privately. In particular, even when $\zeta_s = 0$, some agents find it optimal to fund their own college education, the supply of specific human capital will be positive and its marginal product

[19] In a more general set up where private expenditures may help finance K-12, an analogous argument could be made. All that is important is that when total expenditures are small, the marginal product of K-12 expenditures must exceed that of college subsidies.

will be finite. An implication is that when total government education spending is small there is a relative scarcity of general human capital and its marginal product is relatively high. In this circumstance, the government should devote its entire budget to general human capital production.

As spending on K-12 education increases, the marginal product of general human capital declines, making spending on college subsidies more attractive. At a threshold of $\zeta_\tau = \frac{(2-\theta)\mu_2}{\theta}$, the most efficient method of increasing output is to allocate new spending increments to both K-12 and college education. The second item in the proposition focuses on the situation in which expenditures exceed this threshold. In this case, the output maximizing value of ζ_s rises with ζ_τ.

College expenditures should also be higher when θ, the parameter controlling the resource cost of college, is larger and when μ_2, the parameter governing the curvature of the education quality function, is smaller. When θ is large, the resource cost of specific skill is high and the fraction of the population with specific skill is small. The resulting higher marginal product of specific skill implies that greater amounts of spending should be allocated to its production. Similarly, when μ_2 is small, the payoff to increased K-12 funding is relatively low and output rises more quickly through specific human capital subsidies.

Two implications of the proposition are worth emphasizing. First, note that if μ_2 is large enough there should be no subsidies to college education (i.e. for large enough μ_2 the threshold total expenditure, $\frac{(2-\theta)\mu_2}{\theta}$, exceeds $1-\alpha$). We conclude that college should be subsidized at the expense of K-12 expenditures only if the elasticity of general human capital production with respect to government inputs is sufficiently small. Second, as the fraction of output devoted to subsidies increases beyond the threshold, an increasing share should be allocated to college education. Thus, in the neighborhood of the threshold, increments to total spending should be allocated disproportionately to college subsidies. Equivalently, ζ_s should rise more rapidly than ζ_τ so that the output maximizing value of $\frac{\zeta_s}{\zeta_\tau}$ rises with ζ_τ.

To see if the second implication holds more generally (away from the threshold), we turn to a calibrated version of the model. We calibrate the model to fit facts about skilled workers and human capital production. Much of our education data is obtained from the National Center for Education Statistics; several of the series end in the year 2000, so we use the 2000 out-going rotation of the CPS to calculate labor market statistics. We calibrate α to be equal to the share of income going to specifically-skilled workers to compensate for supplying specifically-skilled labor. To find this share, we use the CPS, deleting all individuals who were paid less than \$1000 in 1999. We compute

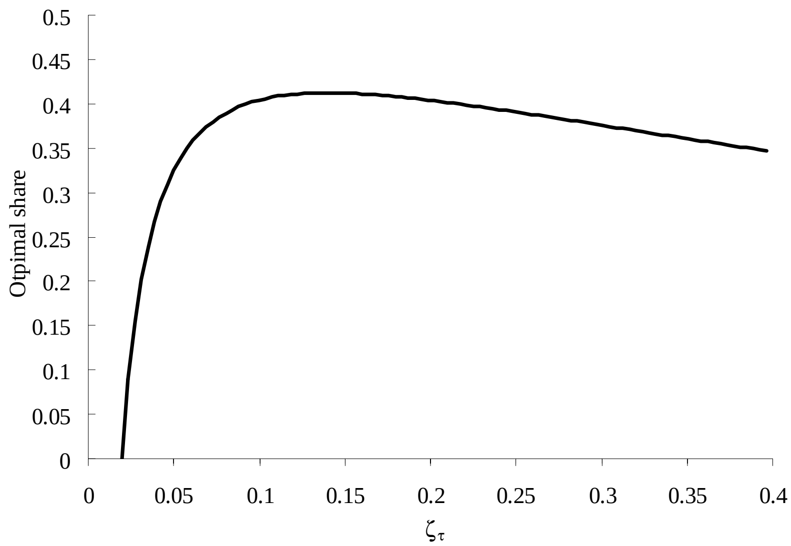

Figure 2: Output maximizing share of government education spending devoted to college subsides (i.e. optimal $\frac{\zeta_s}{\zeta_\tau}$) as a function of ζ_τ.

total income as the sum of income earned by all individuals. Income earned for specific skill is calculated as the difference in the mean wage paid to specifically skilled (college-educated) and to generally skilled (less than college-educated) workers multiplied by the number of skilled workers, producing a value of $\alpha = 0.2$. In the 2000 CPS, approximately 30% of the sample is skilled, so $\hat{\imath}$ is set to 0.70. As noted in the introduction, government support for higher education equaled 2.8% of real GDP by the end of the 1990s, implying $\zeta_s = 0.028$. Given these values, it is straightforward to use equation (8) to solve for θ, yielding a value of $\theta = 1.72$. Finally, note that μ_2 is the elasticity of human capital production with respect to quality in K-12 education. We set $\mu_2 = 0.12$ in line with the estimate by Card and Krueger (1992).

Figure 2 shows the output maximizing share, $\frac{\zeta_s}{\zeta_\tau}$, as a function of ζ_τ. For $\zeta_\tau < \frac{(2-\theta)\mu_2}{\theta} \approx .02$ the optimal share going to college subsidies is zero. As ζ_τ increases beyond the threshold, the optimal share rises rapidly at first and then slows to a maximum at $\zeta_\tau \approx .14$. Since no country has a total education budget near 14% of GDP, Figure 2 suggests that as education expenditures rise through the empirically relevant range, increments to public education spending should be allocated disproportionately to college subsidies.

Finally, the proposition implies that an increase in total expenditures should be allocated in such a way that a larger share of tuition is covered by government. Stated differently, if government acts to maximize output, ψ will rise with ζ_τ. This is not immediately obvious. The proposition states that ζ_s should rise with ζ_τ. However, since more agents go to college when ζ_s is large, this increase in college expenditure needs to be spread across a greater number of students. It is straightforward to show that in equilibrium,

$$\psi = 1 - \frac{2}{\theta}\frac{\theta\alpha - \zeta_s}{2\alpha + \zeta_s}, \tag{10}$$

so ψ rises with ζ_s.[20]

3.2 Utility effects of changes in policy

We now turn attention to welfare considerations. As a first step, we present Lemma 2, which provides an expression for the utility of the different agents.

Lemma 2. *The lifetime utility of agent i is*

$$U = \begin{cases} Y(1-\alpha-\zeta_\tau) & \text{if generally skilled} \\ Y\left(1-\alpha-\zeta_\tau+\frac{2\alpha(i-\hat{\imath})}{(1-\hat{\imath}^2)}\right) & \text{if specifically skilled.} \end{cases} \tag{11}$$

For the generally skilled, lifetime income (and utility) is simply proportional to output. This follows because production is Cobb-Douglas, so competitive markets imply the share of output paid to general human capital is $1-\alpha$. The unit mass of agents uniformly supplies general human capital so the gross per capita income from this input is $(1-\alpha)Y$. For the generally skilled, this is the only source of income. Furthermore, the equilibrium per-capita tax burden is $\zeta_\tau Y$, leaving the generally skilled with net income of $(1-\alpha-\zeta_\tau)Y$. Specifically-skilled agents earn this amount plus an increment that reflects the skill premium per unit of general human capital net of private education costs (hereafter, called the net skill premium). The cost of specific human capital is identical across agents, but the skill premium is increasing in the agent's ability endowment i. Thus the net skill premium increases with i.

3.2.1 Changes in general human capital spending

We first investigate the effects of increasing spending on general human capital with ζ_s held constant. In equilibrium, the share of tuition paid by the government will also be constant (see

[20] This formula can be seen in the steps deriving formula (8) in the proof to Lemma 1.

equation (10)). Since $\hat{\imath}$ does not depend on ζ_g, there is no effect on the net skill premium and there are only two effects to consider. First, output increases with K-12 expenditures, thus increasing utility. Second, taxes increase with K-12 expenditures, decreasing utility. The welfare effect of an increase in ζ_g thus depends upon the relative magnitudes of these opposing effects. As discussed previously, the marginal output effect of K-12 spending is initially large but diminishes. On the other hand, increasing ζ_g increases ζ_τ linearly. Maximum utility occurs when these effects offset. Also note that since i is an argument in equation (11) for the specifically skilled, the welfare maximizing level of expenditures is agent specific. Proposition 2 summarizes the optimal policy from the perspective of all agents.

Proposition 2 *Suppose the fraction of output devoted to college subsidies is fixed (i.e., ζ_s is fixed).*

1. *For generally-skilled agents $(i < \hat{\imath})$, utility is maximized when*

$$\zeta_g = \mu_2 (1 - \alpha - \zeta_s).$$

2. *For specifically-skilled agents $(i \geq \hat{\imath})$, utility is maximized when*

$$\zeta_g = \mu_2 \left(1 - \alpha - \zeta_s + \frac{2\alpha (i - \hat{\imath})}{1 - \hat{\imath}^2}\right).$$

A key implication is that specifically-skilled agents prefer higher spending on general human capital than do the generally-skilled agents. All agents gain general human capital as K-12 expenditures rise. The specifically skilled also receive specific human capital in proportion to general human capital. This second effect is larger for the more able, so the preferred ζ_g rises in i. Furthermore, all agents prefer less K-12 spending when the college subsidy is high (ζ_s, and hence ψ, is large).[21] To some extent, this is surprising. We showed earlier that output is more responsive to changes in ζ_g when ζ_s is large. Since output is an argument in the utility expressions, this suggests agents might be more willing to fund K-12 spending when college expenditure are high. However the requisite increased tax burden lowers the share of this output that agents are able to consume. This second effect dominates. A high ζ_s implies an already high tax burden making agents less willing to fund additional K-12 spending.

[21] For the generally-skilled, this relationship is clear. For the specifically-skilled, it is not obvious since $\hat{\imath}$ decreases with ζ_s. A proof is available from the authors.

3.2.2 Changes in specific human capital subsidies

In this section, we hold the subsidy to general human capital constant and vary the subsidy to specific human capital. Clearly, this will alter output and taxes as in the previous section. However, in the earlier analysis, policy change had no effect on $\hat{\imath}$. In contrast, increasing ζ_s will increase the fraction of agents who choose to acquire specific human capital (i.e. decrease $\hat{\imath}$). Because of this, we must consider those agents who remain generally skilled, those who remain specifically skilled, and those who switch between these groups as a result of policy. The following proposition summarizes the relationship between agent utility and college subsidies, making use of agent specific critical values which are formalized in the proof.

Proposition 3 *Suppose K-12 education spending is fixed (i.e. ζ_g is fixed). If ζ_g is above a threshold value, utility of agent i is maximized when college education is not subsidized. If ζ_g is less than the threshold value, the utility maximizing level of ζ_s is positive, decreasing in ζ_g and increasing in μ_2.*

Proposition 3 tells us that if the proportion of output devoted to K-12 education (and the taxes that support these expenditures) is large, agents prefer no further taxation to support college subsidies. On the other hand, if K-12 support is low enough, all agents will support some level of college subsidy.[22] Additionally, agents prefer larger college subsides when the marginal gain in terms of general human capital for an increment in K-12 funding is high (μ_2 is larger). When the level of general human capital is high, the effect on output of an increase in the subsidy is big and, thus, agents are more willing to finance that subsidy.

While Proposition 3 makes it clear that all agents may prefer some subsidy to college education, it is interesting to note that no agent prefers that college education be free. This result is stated in Corollary 1.

Corollary 1 *For a fixed ζ_g, no agent is best off with college education fully subsidized.*

With the private cost low, many agents become specifically skilled. As a result, not only are taxes high but the skill premium is low. Because of this, all agents prefer that college students participate in funding their education.

To illustrate these ideas, we analyze the model under a particular parameterization. Our base settings for α, ζ_s, θ, and μ_2 were described above in the discussion of Figure 2. Two other parameters, ζ_g and μ_1 are needed for the present exercise. Since, government support for K-12 education

[22] It can be formally shown that the level of ζ_g at which preferences switch from no support to some support varies by the ability of the agent with higher ability agents having higher thresholds.

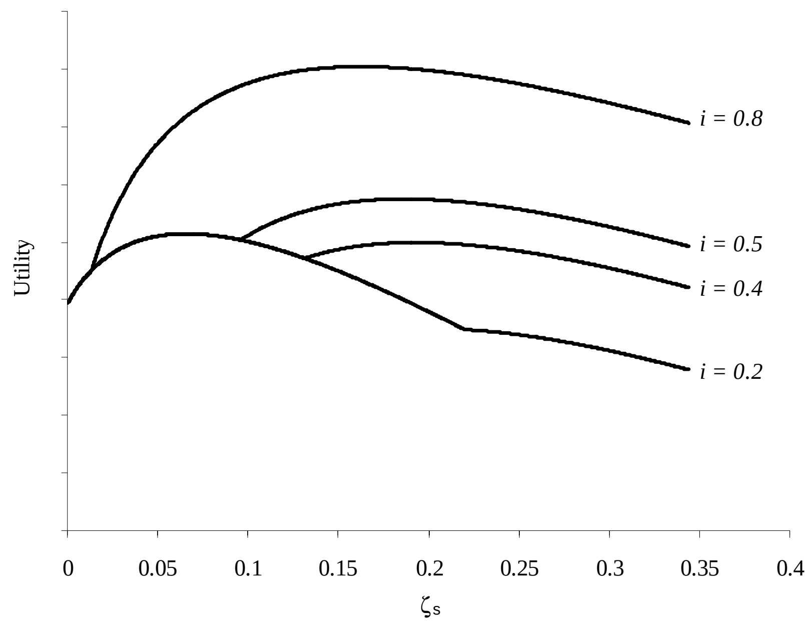

Figure 3: Utility of agents i=.2, .4, .5 and .8 as ζ_s increases and ζ_g is fixed. Points of inflection occur at subsidy levels just large enough to cause the agent to be specifically skilled.

amounted to approximately 4.3% of real GDP by the end of the 1990s, we set $\zeta_g = 0.043$. Since μ_1 merely scales the size of the economy and has little effect on the results, we arbitrarily set μ_1 equal to 10.

Figure 3 illustrates utility at progressively higher levels of tuition subsidies, ζ_s, for agents $i \in \{.2, .4, .5, .8\}$. The vertical axis is utility and the horizontal axis is ζ_s. The top line corresponds to a high-ability agent ($i = 0.8$) for whom the utility maximizing level of the subsidy is $\zeta_s \approx 0.16$. Their utility is not monotonic in subsidies. A larger subsidy provides the agent with greater tuition savings, but, as more agents become specifically skilled the net skill premium falls. When ζ_s is small the first effect dominates. As ζ_s increases, the second effect dominates. Utility is maximized where the effects offset.

The bottom line in Figure 3 illustrates the utility of a low-ability agent ($i = 0.2$). This agent also prefers a positive tuition subsidy. Recall that output is increasing in ζ_s and that utility for the generally-skilled is proportional to output. As long as the increase in output offsets the tax increase, the agent is willing to help finance increased subsidies. However, the marginal effect on Y diminishes as ζ_s rises while the marginal effect of the tax is constant. For this agent, the effects offset at $\zeta_s \approx 0.07$.

Finally, consider the two middle lines in Figure 3. Each of these agents ($i = 0.4$ and $i = 0.5$) remain generally skilled when the tuition subsidy is low. While generally skilled, each has income equal to that of agent $i = 0.2$ and thus has a local utility maximum at $\zeta_s \approx 0.07$. When the subsidy becomes large enough, these agents prefer to become specifically skilled. This is the source of the inflection points at $\zeta_s \approx 0.1$ and $\zeta_s \approx 0.14$. Beyond the agent-specific threshold level of subsidies, the agents' policy preferences are similar to those of agent $i = 0.8$. In particular there is another locally preferred level of subsidy. Since the return to earning specific skill is agent specific, the local maximum occurs at different levels of ζ_s. A key point is that agents in the center of the ability distribution have two locally preferred subsidy levels, one that is relevant if the agent remains generally skilled and one that is relevant if the agent acquires specific skill. Global preference depends on the agent's index. Some agents (say, $i = 0.5$) globally prefer a high subsidy, while others ($i = 0.4$) globally prefer a low subsidy. This provides a useful way to dichotomize the agents: those with lower indices globally prefer to remain generally skilled and others globally prefer to be specifically skilled.

For agents at the ends of the ability distribution, utility is single-peaked in ζ_s. Agents with low indices (e.g., $i = 0.2$ in Figure 3) will become specifically skilled with high enough subsidies.[23] This occurs at the point of inflection on the line at $\zeta_s \approx 0.22$. However, subsidies which encourage them to be specifically-skilled decrease welfare even locally. On the other hand, agents with high indices become specifically skilled even at $\zeta_s = 0$, removing the possibility of two-peaked policy preferences.[24]

Proposition 3 and Corollary 1 show that all agents may benefit when the cost of college education is split between the individual and government. This result has some resemblance to that in Johnson (1984) and helps to explain why college subsidies are widespread though only a minority benefit directly.[25] Not surprisingly, the preferred split differs across agents. In Figure 3, agents who globally prefer to become specifically skilled prefer larger subsidies than other agents. This is a general and unsurprising result since the specifically skilled benefit directly from subsidies.[26]

[23] Equation (8) shows that if $\theta\alpha \leq \zeta_s < 1 - \alpha$, *all* agents will acquire specific skill.

[24] Note that agent $i = 0.8$ actually remains generally skilled for very low subsidies. The marginal agent who becomes specifically skilled even when there are no subsides, $\zeta_s = 0$, can be found from (8). Using $\theta = 1.72$ shows that agents with ability indexes above .86 will become specifically skilled under any circumstance.

[25] Johnson shows that unskilled workers may prefer to subsidize the education of the more skilled if the two types of labor are sufficiently complementary. See Fernandez and Rogerson (1995) and Creedy and Francois (1990) for other explanations.

[26] A proof of the generality of this statement is available from the authors.

Among these more skilled agents, the preferred level of subsidies depends on ability. In Figure 3, the more able prefer lower subsidies. This relationship holds when α and μ_2 are sufficiently small. Otherwise the relationship is reversed.[27] Specifically-skilled agents benefit equally from tuition subsidies and are hurt equally by the requisite tax increase. However, they are affected unequally by general equilibrium adjustments in wages. On one hand, an increase in ζ_s will increase output. This disproportionately favors the more able (see equation (11)). On the other hand, a larger number of specifically skilled agents lowers the net skill premium which disproportionately hurts the more able. The relative size of these effects is governed by α and μ_2.

Propositions 2 and 3 indicate that if K-12 spending is small, all agents are better off with increased K-12 expenditures and that if college expenditures are small, all agents may be better off with increased college subsidies. These results complement the findings in Su (2004). In a significantly different economic environment, Su also finds that when K-12 funding is small, increases can yield Pareto improvements. Furthermore she finds that in more developed countries, increased college expenditures can be Pareto improving. In her model, college expenditures affect the quality of college education rather than the private cost. In addition, human capital acquired at the college and K-12 levels are perfect substitutes in a linear production function. As such, there are no relative wage effects of the funding decisions. Instead, she highlights the importance of funding on the size of the economy and hence the revenue base.

3.2.3 The trade-off between general and specific human capital spending

In each of the previous sections, we analyzed increases in the level of spending for one type of education holding the other level constant. We now analyze changes in which the overall proportion of output devoted to education is constant, so an increase in one type of expenditure must be accompanied by a decline in the other. With no loss of generality, we consider an increase in ζ_s that is funded by a decrease in ζ_g, so that ζ_τ is unchanged.

In Proposition 4, we discuss in greater detail the policy effects from the perspective of all agents making use of agent-specific threshold values which are formalized in the proof.

Proposition 4 *Suppose the tax rate is fixed (i.e. ζ_τ is fixed).*

1. *If ζ_τ is below a threshold value, utility of agent i is maximized where college education is not*

[27] A proof is available from the authors.

subsidized. If ζ_τ exceeds the threshold value, the utility maximizing level of ζ_s is positive and increasing in ζ_τ.

2. *For agents whose utility given ζ_τ is globally maximized where they are generally skilled, the threshold value is $\zeta_\tau = \theta^{-1}(2-\theta)\mu_2$. For other agents, the threshold value is smaller.*

3. *Agents whose utility given ζ_τ is globally maximized where they are generally skilled prefer smaller college subsides than do other agents. Among the other agents, the preferred ζ_s is decreasing in i.*

The first item in the proposition highlights several areas of unanimity in policy choice. First, when government spends little on education, all agents prefer that the entire amount be allocated to K-12 expenditures. Second, when the level of total expenditures is sufficiently high, all agents prefer that some resources be allocated to college subsidies.

It is perhaps surprising that the generally-skilled should ever want to support college education at the expense of K-12 spending. However, with ζ_τ constant, utility of a generally skilled worker is maximized where output is maximized and the results in Section 3.1 apply directly. More intuitively, the generally skilled suffer a direct loss when resources are directed away from their schooling since they enter the labor market with less human capital. However, it is the value of human capital, not its quantity, that determines an agent's welfare. College subsidies make general human capital scarce relative to specific human capital and drive up its per unit wage. Increases in the per unit *value* of general human capital may compensate for the decreased *level*. This can occur only if ζ_τ is large enough; if ζ_τ is small, general human capital is scarce and its wage is high.

For those who globally prefer to be specifically skilled, similar trade-offs exist. When resources are allocated more to college education, the specifically skilled too receive less general human capital. In fact, they suffer a larger negative effect in this regard since their level of specific human capital is in proportion to their general human capital. For these agents, even the price adjustments are not strictly in their favor. As more agents become specifically skilled, the wage for their general human capital rises but the wage for their specific human capital falls. Countering the negative effects, of course, is that when funding shifts toward college education, they are less burdened by the tuition payment.

A third area of unanimity arises when ζ_τ exceeds the threshold level of $\theta^{-1}(2-\theta)\mu_2$. In this case, all agents prefer that any increase in ζ_τ be allocated in part to college subsides; i.e. that

ζ_s increase with ζ_τ. Because an increase in ζ_s implies an equilibrium increase in ψ (see equation 10), any increase in total expenditures beyond this threshold should be allocated in such a way that a larger share of tuition is covered by government. Given our calibration, this threshold value is 0.0195. Since the observed value of ζ_τ is 0.071, this unanimity appears to hold for empirically relevant parameters.

In our discussion of Proposition 1, we emphasized several implications of the *output* maximizing split of resources across K-12 and college expenditures. These implications are again valid in discussing the *welfare* maximizing split of resources. First, if μ_2 is large enough, college education should not be subsidized since the threshold ζ_τ exceeds $1-\alpha$ for all agents. Second, over the empirically relevant range of education expenditures, all agents prefer that increases in ζ_τ beyond the threshold value be allocated disproportionately to fund college subsidies.[28]

While the first item in Proposition 4 highlights areas of agreement in policy, items 2 and 3 point out areas where agents of different ability levels have different policy preferences. Item 2 shows that agents who prefer to be specifically skilled have a lower threshold for when positive college subsidies should be implemented. Item 3 shows that these agents also prefer higher college subsidies than do their generally-skilled counterparts. We conclude that while all agents can agree that positive subsidies to college education are appropriate, tension exists in choosing an appropriate level of subsidies. This tension exists also among the specifically skilled as the final sentence in item 3 attests. The more able among the specifically skilled provide more units of specific human capital. As such, they are hurt more by the decrease in the per unit wage to specific human capital caused by the subsidy. This causes them to prefer lower college subsidies.

Some insights into Proposition 4 can be seen in Figure 4 which presents information analogous to that of Figure 3. The difference is that as ζ_s increases along the horizontal axis, ζ_g (not shown) is decreasing. Clearly many of the results are qualitatively similar to those of the previous section. Most importantly, all agents for this parametrization again prefer some subsidies. In addition, agents in the center of the ability distribution again have two-peaked preferences over policy. Thus again agents may value small and large policy increments in qualitatively different ways. Those with higher indices again globally prefer to be specifically skilled and the remainder globally prefer to remain generally skilled.

[28] This is based on a numerical exercise analogous to that which generated figure 1. The only difference is that we look at the welfare (rather than output) maximizing allocation. For those who globally prefer to be generally skilled, the results are identical. For others, the optimal share increases over an even larger range of ζ_τ.

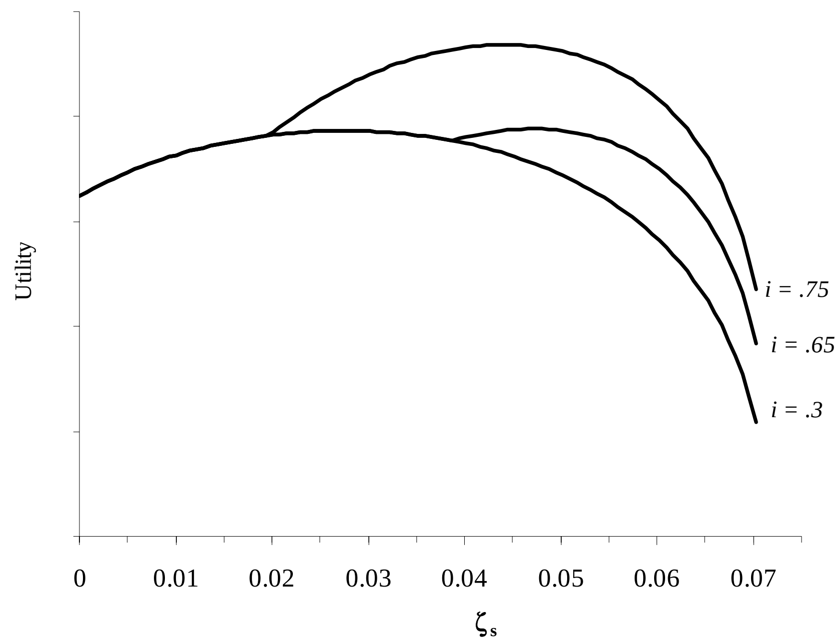

Figure 4: Utility of agents i=.3, .65 and .75 as ζ_s increases and ζ_g falls so that ζ_τ is fixed. Points of inflection occur at subsidy levels just large enough to cause the agent to be specifically skilled.

Despite the inherent tensions as to the appropriate level of college subsidies, there is another possibility for unanimity. In particular, there may be cases where all agents prefer that college education be fully subsidized. With a zero private cost, all agents will earn a college degree. For this to be unanimously preferred, all agents must globally prefer to be specifically skilled for the given level of ζ_τ. This clearly cannot occur when ζ_τ is small. Furthermore, it is not assured even when ζ_τ is large. Corollary 2 shows that a low value of μ_2 is also required.

Corollary 2 *For μ_2 sufficiently small and ζ_τ sufficiently large, all agents are best off with college education fully subsidized.*

This stands in contrast to Corollary 1 which argues that *no* agent prefers free college education. To reconcile these results, recall that in the previous section, increased college subsidies required increased taxes. No agents were best off paying the requisite high tax rate. In this section, the tax burden is fixed. If total spending is large *and* K-12 expenditures are relatively unimportant in generating human capital, the marginal resources to K-12 education are unproductive. Under these circumstances, *all* agents may prefer free college education.

4 Concluding Remarks

In this paper, we consider the interaction of and trade-off between public funding of K-12 and college education, focussing on the output and welfare implications of this spending. Our analysis demonstrates that when public education expenditures are low, all agents prefer that the entire government education budget be allocated to K-12 education. When expenditures are large enough, all prefer that some portion of the budget be allocated to college education. Furthermore, all agents prefer that spending increments beyond this threshold should be allocated disproportionately to college education. There is disagreement across agents regarding the proper level of funding for both K-12 and college education with the college bound agents generally supporting greater expenditures at both levels. For some agents, utility as a function of college subsidies is two-peaked. In this case, some agents benefit from large subsidies to college education but are harmed by smaller subsidies. Other agents will be harmed even more by large subsidies than by smaller subsidies.

Several simplifying features were introduced into the model in order to allow analytical results. This has the attraction of yielding clarity and formality to the analysis, but leaves questions about how the results may differ if the stylized assumptions are relaxed. The essential features of the model are that the inputs are not perfectly substitutable; the financing system for general and specific human capital are different; if all agents fully participate in college education, the distribution for agent utilities will be monotonically ordered so that low ability agents have lower utilities and higher ability agents have higher utilities.

The first feature only requires that unskilled (K-12) labor and skilled (college) labor are modeled as different inputs in the production process. Changing the production function from Cobb-Douglas to one in which the inputs are more substitutable changes our results quantitatively but not qualitatively.

The second feature introduces an avenue for differential government policy toward the two inputs. This allows, for instance, outcomes in which the government focuses its resources entirely on general education when resources are tight, but then shifts to supporting specific education when resources become more plentiful. Although this mechanism can support small generalizations, it is the least malleable of the three. However, our specification fits several important features of the prevailing funding system for education. Namely, K-12 education is mandatory and heavily funded by public funds, college education is optional and funded partly through private sources and the quality of K-12 education is a determinant of the return on a college education.

The third feature allows for an ordering of agents thus creating an agent who is indifferent between getting specific education and not. This agent is then used as a reference to make statements about the entire population. Modelling changes that do not ultimately impact the ordering of utilities will not have qualitative effects on the results in the paper. Some examples include allowing heterogeneity of general human capital endowments or modelling general human capital as a function of parental inputs and ability. Similarly, allowing parental participation in funding specific education, letting ability to acquire specific skill be a function of parental ability, and adding a multiperiod decision environment can be done without affecting the ordering of utilities. Such modifications will not change the results qualitatively.

Appendix

Proof of Lemma 1. Substituting (2) into (4) gives

$$2gi\omega^s > T\left(1-\psi\right).$$

This holds with equality for agent $\hat{\imath}$ and thus implies

$$\hat{\imath} = \frac{T\left(1-\psi\right)}{2g\omega^s}.$$

Using $T = \theta g\omega^s$ gives

$$\hat{\imath} = \frac{\theta}{2}\left(1-\psi\right) \tag{12}$$

Using $T = \theta g\omega^s$ and $g = \mu_1 q^{\mu_2}$ in equation (7) gives

$$\zeta_s Y = \psi\left(1-\hat{\imath}\right)\theta\mu_1 q^{\mu_2}\omega^s. \tag{13}$$

Then putting $\omega^s = \alpha\frac{Y}{S}$ and (5) into (13) gives

$$\zeta_s = \psi\left(1-\hat{\imath}\right)\theta\mu_1 q^{\mu_2}\frac{\alpha}{\mu_1 q^{\mu_2}\left(1-\hat{\imath}^2\right)}.$$

Since $\left(1-\hat{\imath}^2\right) = \left(1-\hat{\imath}\right)\left(1+\hat{\imath}\right)$, this implies

$$\zeta_s = \frac{\psi\theta\alpha}{\left(1+\hat{\imath}\right)}.$$

Next note that (12) implies $\psi = 1-\hat{\imath}\frac{2}{\theta}$ which substituted into the proceeding expression for ψ and solved for $\hat{\imath}$ gives

$$\hat{\imath} = \frac{\theta\alpha - \zeta_s}{2\alpha + \zeta_s}.$$

This completes the proof for formula (8).

Next note that (5) and (6) imply

$$Y = \left(\frac{S}{G}\right)^{\alpha} G = \left(1 - \hat{\imath}^2\right)^{\alpha} \mu_1 q^{\mu_2}.$$

By definition $q = \zeta_g Y$, so

$$Y = \left(1 - \hat{\imath}^2\right)^{\alpha} \mu_1 \left(\zeta_g Y\right)^{\mu_2},$$

which can be rearranged to get (9).

Proof of Proposition 1. Substituting (8) and $\zeta_g = \zeta_\tau - \zeta_s$ into (9) gives

$$Y = \left[\left(1 - \left(\frac{\theta\alpha - \zeta_s}{2\alpha + \zeta_s}\right)^2\right)^{\alpha} \left(\zeta_\tau - \zeta_s\right)^{\mu_2}\right]^{\frac{1}{1-\mu_2}}.$$

Standard Kuhn-Tucker conditions imply

$$\frac{\partial Y}{\partial \zeta_s} < 0 \quad \text{for} \quad \zeta_s = 0 \quad \text{and} \quad \frac{\partial Y}{\partial \zeta_s} = 0 \quad \text{for} \quad \zeta_s > 0.$$

The first claim in the proposition corresponds to the first Kuhn-Tucker case while the second claim corresponds to the second. Taking the derivative of Y with respect to ζ_s and cancelling terms that have no bearing on the sign of the derivative shows $sign\left(\frac{\partial Y}{\partial \zeta_s}\right) = sign\left(Z_1\right)$ where

$$Z_1 \equiv \alpha^2 2\left(\frac{\alpha\theta - \zeta_s}{2\alpha + \zeta_s}\right)(2+\theta)\left(\zeta_\tau - \zeta_s\right) - \left(4\alpha^2 + 4\alpha\zeta_s - \alpha^2\theta^2 + 2\alpha\theta\zeta_s\right)\mu_2.$$

When an interior output maximizing level of ζ_s exists (the second Kuhn-Tucker case), it is defined implicitly by the function $Z_1 = 0$. Second order conditions for a maximum require that Z_1 is decreasing in ζ_s when evaluated at $Z_1 = 0$. This verification is relegated to an unpublished appendix available from the authors.

It is straightforward to show that the threshold between the two cases (i.e. when $Z_1 = 0$ and $\zeta_s = 0$) occurs when $\zeta_\tau = \frac{(2-\theta)\mu_2}{\theta}$. Focussing on the first Kuhn-Tucker case, note that Z_1 is decreasing in ζ_s (from the second order condition) and increasing in ζ_τ (from inspection). This implies that an incremental decrease in ζ_τ from $\zeta_\tau = \frac{(2-\theta)\mu_2}{\theta}$ requires an offsetting incremental decrease in ζ_s from 0 to preserve $Z_1 = 0$. Since ζ_s is constrained to be nonnegative, Z_1 is negative for $\zeta_\tau < \frac{(2-\theta)\mu_2}{\theta}$. Thus we see that for $\zeta_\tau < \frac{(2-\theta)\mu_2}{\theta}$, output is maximized where college education is not subsidized ($\zeta_s = 0$).

Next focusing on the second Kuhn-Tucker case we see that an incremental increase in ζ_τ from $\zeta_\tau = \frac{(2-\theta)\mu_2}{\theta}$ requires an offsetting incremental increase in ζ_s from 0 to preserve $Z_1 = 0$. Thus for $\zeta_\tau > \frac{(2-\theta)\mu_2}{\theta}$, output is maximized where college education is subsidized ($\zeta_s > 0$). Finally, applying the implicit function theorem to $Z_1 = 0$ shows that the output maximizing level of ζ_s decreases with μ_2 and rises with ζ_τ and θ. Details are in the unpublished appendix.

Proof of Lemma 2. In equilibrium the budget constraint holds with equality. For the generally skilled, then, utility is given by

$$U = \omega^g \mu_1 q^{\mu_2} - \tau.$$

Using $\omega^g = (1-\alpha)\frac{Y}{G}$, (6) and $\tau = \zeta_\tau Y$ gives

$$U = (1-\alpha)\frac{Y}{\mu_1 q^{\mu_2}}\mu_1 q^{\mu_2} - \tau = Y(1-\alpha-\zeta_\tau),$$

which is the generally-skilled agent part of (11). For the specifically skilled income, and hence utility, is given by

$$U = (\omega^g + 2i\omega^s)\mu_1 q^{\mu_2} - (1-\psi)\theta\omega^s \mu_1 q^{\mu_2} - \tau.$$

Next use $\omega^g = \frac{(1-\alpha)Y}{G} = \frac{(1-\alpha)Y}{\mu_1 q^{\mu_2}}$, $\omega^s = \frac{\alpha Y}{S} = \frac{\alpha Y}{(1-\hat{\imath}^2)\mu_1 q^{\mu_2}}$ and $\tau = \zeta_\tau Y$ to get

$$\begin{aligned} U &= \left(\frac{(1-\alpha)Y}{\mu_1 q^{\mu_2}} + 2i\frac{\alpha Y}{(1-\hat{\imath}^2)\mu_1 q^{\mu_2}}\right)\mu_1 q^{\mu_2} - (1-\psi)\theta\frac{\alpha Y}{(1-\hat{\imath}^2)\mu_1 q^{\mu_2}}\mu_1 q^{\mu_2} - \zeta_\tau Y \\ &= Y\left(1-\alpha-\zeta_\tau + \frac{2i\alpha - (1-\psi)\alpha\theta}{(1-\hat{\imath}^2)}\right). \end{aligned}$$

Using (12), we have $(1-\psi) = \frac{\hat{\imath}2}{\theta}$ which upon substitution into the above gives

$$U = Y\left(1-\alpha-\zeta_\tau + \frac{2\alpha(i-\hat{\imath})}{(1-\hat{\imath}^2)}\right).$$

Proof of Proposition 2. First focus on the workers that prefer to remain generally skilled. Substituting (8) into (9) and then into the generally-skilled utility in (11) and using $\zeta_\tau = \zeta_g - \zeta_s$ gives

$$U = \left[\left(1-\left(\frac{\theta\alpha-\zeta_s}{2\alpha+\zeta_s}\right)^2\right)^\alpha \mu_1 \zeta_g^{\mu_2}\right]^{\frac{1}{1-\mu_2}} (1-\alpha-\zeta_g-\zeta_s). \tag{14}$$

Setting the first order condition equal to 0 and solving for ζ_g gives the expression in item 1 of the proposition.

Next note that similar substitutions into the specifically-skilled utility function gives

$$U = \left[\left(1-\left(\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}\right)^2\right)^\alpha \mu_1 \zeta_g^{\mu_2}\right]^{\frac{1}{1-\mu_2}} \left(1-\alpha-\zeta_g-\zeta_s+\frac{2\alpha\left(i-\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}\right)}{\left(1-\left(\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}\right)^2\right)}\right). \tag{15}$$

Taking the first order condition and setting it to zero produces the formula in part 2 of the proposition.

Second order conditions for a maximum at these values are satisfied as shown in the unpublished appendix available from the authors.

Proof of Proposition 3. As in the proof of Proposition 2 we begin with (14). Standard Kuhn-Tucker conditions for the utility maximizing level of ζ_s imply

$$\frac{\partial U}{\partial \zeta_s} < 0 \quad \text{for} \quad \zeta_s = 0 \quad \text{and} \quad \frac{\partial U}{\partial \zeta_s} = 0 \quad \text{for} \quad \zeta_s \geq 0.$$

The first sentence corresponds to the first Kuhn-Tucker case while the second sentence corresponds to the second case. For a generally-skilled agent, taking the derivative of U with respect to ζ_s and cancelling terms that have no bearing on sign of the derivative gives $sign\left(\frac{\partial U}{\partial \zeta_s}\right) = sign\left(Z_2\right)$ where

$$Z_2 \equiv \frac{2\alpha^2 \left(2+\theta\right)}{1-\mu_2} \left(\frac{\alpha\theta - \zeta_s}{2\alpha + \zeta_s}\right) \left(1 - \alpha - \zeta_g - \zeta_s\right) - \left(4\alpha^2 + 4\alpha\zeta_s - \alpha^2\theta^2 + 2\alpha\theta\zeta_s\right). \tag{16}$$

When an interior utility maximizing level of ζ_s exists (the second Kuhn-Tucker case), it is implicitly defined by the function $Z_2 = 0$. Second order conditions for a maximum require that Z_2 is decreasing in ζ_s when evaluated at $Z_2 = 0$. This verification is available in the unpublished appendix.

It is straightforward to show that the threshold between the two cases (i.e. when $Z_2 = 0$ and $\zeta_s = 0$) occurs when

$$\zeta_g = \tilde{\zeta}_{g,g} \equiv 1 - \alpha - \left(1 - \mu_2\right) \frac{2-\theta}{\theta}.$$

Focussing on the first Kuhn-Tucker case, note that Z_2 is decreasing in ζ_s (from the second order condition) and decreasing in ζ_g (from inspection). This implies that an incremental increase in ζ_g from $\tilde{\zeta}_{g,g}$ requires an offsetting incremental decrease in ζ_s from 0 to preserve $Z_2 = 0$. Since ζ_s is constrained to be nonnegative, Z_2 is negative for $\zeta_g > \tilde{\zeta}_{g,g}$. Thus we see that for $\zeta_g > \tilde{\zeta}_{g,g}$, utility for these agents is maximized where college education is not subsidized ($\zeta_s = 0$).

Next focusing on the second Kuhn-Tucker case we see that an incremental decrease in ζ_g from $\tilde{\zeta}_{g,g}$ requires an offsetting incremental increase in ζ_s from 0 to preserve $Z_2 = 0$. Thus for $\zeta_g < \tilde{\zeta}_{g,g}$, utility for these agents is maximized where college education is subsidized ($\zeta_s > 0$). Applying the implicit function theorem to $Z_2 = 0$ shows that the utility maximizing level of ζ_s falls with ζ_g and rises with μ_2. Details are in the unpublished appendix. This proves the final sentence.

Next consider a specifically skilled agent. Again we follow Proposition 2 by beginning with (15). Taking the derivative of (15) with respect to ζ_s and cancelling terms that have no bearing on sign of the derivative gives $sign\left(\frac{\partial U}{\partial \zeta_s}\right) = sign\left(Z_3\right)$ where

$$\begin{aligned} Z_3 \quad \equiv \quad & \frac{2\alpha^2\left(2+\theta\right)}{1-\mu_2}\left(\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}\right)\left(1-\alpha-\zeta_g-\zeta_s\right)-\left(4\alpha^2+4\alpha\zeta_s-\alpha^2\theta^2+2\alpha\theta\zeta_s\right) \\ & +\frac{2\alpha^2\left(2+\theta\right)}{1-\mu_2}\left(\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}\right)\frac{2\alpha\left(i-\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}\right)}{1-\left(\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}\right)^2} \\ & +\left[\frac{2\alpha^2\left(2+\theta\right)\left(1-\left(\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}\right)^2\right)-4\alpha^2\left(2+\theta\right)\left(i-\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}\right)\left(\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}\right)}{1-\left(\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}\right)^2}\right]. \end{aligned}$$

When an interior utility maximizing level of ζ_s exists (the second Kuhn-Tucker case), it is implicitly defined by the function $Z_3 = 0$. Second order conditions for a maximum require that Z_3 is decreasing in ζ_s when evaluated at $Z_3 = 0$. This verification is available in the unpublished appendix.

It is straightforward to show that the threshold between the two cases (i.e. when $Z_3 = 0$ and $\zeta_s = 0$) occurs when

$$\zeta_g = \tilde{\zeta}^i_{s,g} \equiv \tilde{\zeta}_{g,g} + \frac{2\left(1-\mu_2\right)}{\theta} + \frac{4(\alpha+\mu_2-1)\left(2i-\theta\right)}{4-\theta^2}.$$

Focussing on the first Kuhn-Tucker case, note that Z_3 is decreasing in ζ_s (from the second order condition) and decreasing in ζ_g (from inspection). This implies that an incremental increase in ζ_g from $\tilde{\zeta}_{g,g}$ requires an offsetting incremental decrease in ζ_s from 0 to preserve $Z_3 = 0$. Since ζ_s is constrained to be nonnegative, Z_3 is negative for $\zeta_g > \tilde{\zeta}^i_{s,g}$. Thus we see that for $\zeta_g > \tilde{\zeta}^i_{s,g}$, utility for these agents is maximized where college education is not subsidized ($\zeta_s = 0$).

Next focusing on the second Kuhn-Tucker case we see that an incremental decrease in ζ_g from $\tilde{\zeta}^i_{s,g}$ requires an offsetting incremental increase in ζ_s from 0 to preserve $Z_3 = 0$. Thus for $\zeta_g < \tilde{\zeta}^i_{s,g}$, utility for these agents is maximized where college education is subsidized ($\zeta_s > 0$). Applying the implicit function theorem to $Z_3 = 0$ shows that the utility maximizing level of ζ_s falls with ζ_g and rises with μ_2. Details are in the unpublished appendix.

Proof of Corollary 1. Consider a situation in which there are full subsidies. This requires $\zeta_s = \alpha\theta$. In this case $\hat{\imath} = 0$ (see equation 8) and thus all individuals become specifically skilled. This means we need to focus on the specifically-skilled individual's decision problem. It can be shown that when $\zeta_s = \alpha\theta$

$$Z_3 = -\left(4\alpha^2 + 4\alpha^2\theta + \alpha^2\theta^2\right) + 2\alpha^2\left(2+\theta\right) = -2\alpha^2\left(2+\theta\right)\theta$$

which is less than zero. Since $sign\left(\frac{\partial U}{\partial \zeta_s}\right) = sign\left(Z_3\right)$ this means that all individuals prefer ζ_s to be smaller than full subsidization.

Proof of Proposition 4. Consider the first item in the proposition for a generally-skilled agent. Substitute $\zeta_g - \zeta_s = \zeta_\tau$ into (14). Since total expenditure (ζ_τ) is held constant, maximizing this objective is equivalent to maximizing,

$$U = \left[\left(1 - \left(\frac{\theta\alpha - \zeta_s}{2\alpha + \zeta_s}\right)^2\right)^\alpha \left(\zeta_\tau - \zeta_s\right)^{\mu_2}\right]^{\frac{1}{1-\mu_2}}.$$

Since this is equal to Y from Proposition 1, the proof of the first item for a generally-skilled agent follows from Proposition 1.

Next consider the first item again but for a specifically-skilled agent. Substitute $\zeta_g - \zeta_s = \zeta_\tau$ into (15). Standard Kuhn-Tucker conditions for the utility maximizing level of ζ_s imply

$$\frac{\partial U}{\partial \zeta_s} < 0 \quad \text{for} \quad \zeta_s = 0 \quad \text{and} \quad \frac{\partial U}{\partial \zeta_s} = 0 \quad \text{for} \quad \zeta_s \geq 0.$$

The first sentence in item one corresponds to the first Kuhn-Tucker case while the second sentence corresponds to the second case. Taking the derivative of U and cancelling terms that have no bearing on sign of the derivative gives $sign\left(\frac{\partial U}{\partial \zeta_s}\right) = sign\left(Z_4\right)$ where

$$\begin{aligned} Z_4 \quad \equiv \quad & \left[\frac{2\alpha^2\left(2+\theta\right)}{1-\mu_2}\left(\frac{\alpha\theta - \zeta_s}{2\alpha + \zeta_s}\right) - \frac{\mu_2}{1-\mu_2}\left(4\alpha^2 + 4\alpha\zeta_s - \alpha^2\theta^2 + 2\alpha\theta\zeta_s\right)\left(\zeta_\tau - \zeta_s\right)^{-1}\right] \\ & \left(1 - \alpha - \zeta_\tau + \frac{2\alpha\left(i - \frac{\alpha\theta - \zeta_s}{2\alpha + \zeta_s}\right)}{\left(1 - \left(\frac{\alpha\theta - \zeta_s}{2\alpha + \zeta_s}\right)^2\right)}\right) \\ & + \left[\frac{2\alpha^2\left(2+\theta\right)\left(1 - \left(\frac{\alpha\theta - \zeta_s}{2\alpha + \zeta_s}\right)^2\right) - 4\alpha^2\left(2+\theta\right)\left(i - \frac{\alpha\theta - \zeta_s}{2\alpha + \zeta_s}\right)\left(\frac{\alpha\theta - \zeta_s}{2\alpha + \zeta_s}\right)}{1 - \left(\frac{\alpha\theta - \zeta_s}{2\alpha + \zeta_s}\right)^2}\right]. \end{aligned} \tag{17}$$

When an interior utility maximizing level of ζ_s exists (the second Kuhn-Tucker case), it is implicitly defined by the function $Z_4 = 0$. Second order conditions for a maximum require that Z_4 is decreasing in ζ_s when evaluated at $Z_4 = 0$. This verification is available in the unpublished appendix.

It is straightforward to show that the threshold between the two cases (i.e. when $Z_4 = 0$ and

$\zeta_s = 0$) occurs when

$$\frac{1}{1-\mu_2}\left[\frac{\theta(2+\theta)}{4}\zeta_\tau - \mu_2\left(1-\left(\frac{\theta}{2}\right)^2\right)\right]\left((1-\alpha-\zeta_\tau)\left(1-\left(\frac{\theta}{2}\right)^2\right)+2\alpha\left(i-\frac{\theta}{2}\right)\right)$$
$$+\frac{\zeta_\tau(2+\theta)}{2}\left[\left(1-\left(\frac{\theta}{2}\right)^2\right)-2\left(i-\frac{\theta}{2}\right)\left(\frac{\theta}{2}\right)\right]=0$$

which implicitly defines $\tilde{\zeta}^i_\tau$.

Focussing on the first Kuhn-Tucker case, note that Z_4 is decreasing in ζ_s (from the second order condition) and increasing in ζ_τ (shown in the unpublished appendix). This implies that an incremental decrease in ζ_τ from $\tilde{\zeta}^i_\tau$ requires an offsetting incremental decrease in ζ_s from 0 to preserve $Z_4 = 0$. Since ζ_s is constrained to be nonnegative, Z_4 is negative for $\zeta_\tau < \tilde{\zeta}^i_\tau$. Thus we see that for $\zeta_\tau < \tilde{\zeta}^i_\tau$, utility for these agents is maximized where college education is not subsidized ($\zeta_s = 0$).

Next focusing on the second Kuhn-Tucker case we see that an incremental increase in ζ_τ from $\tilde{\zeta}^i_\tau$ requires an offsetting incremental increase in ζ_s from 0 to preserve $Z_4 = 0$. Thus for $\zeta_\tau > \tilde{\zeta}^i_\tau$, utility for these agents is maximized where college education is subsidized ($\zeta_s > 0$). Applying the implicit function theorem to $Z_4 = 0$ shows that the utility maximizing level of ζ_s rises with ζ_τ and decreases with μ_2. Details are in the unpublished appendix. This proves the final sentence of the first item for a specifically-skilled agent.

Now consider the second item in the proposition. We show that when ζ_τ is at the threshold for generally-skilled agents, the specifically skilled strictly prefer positive subsidies and thus have a lower threshold. From Proposition 1, the threshold for the preferred generally skilled is $\zeta_\tau = \frac{(2-\theta)\mu_2}{\theta}$. Put this into (17). To make the point, we need to show that with this level of expenditure $\frac{\partial U}{\partial \zeta_s} > 0$ at $\zeta_s = 0$ so that the specifically skilled would prefer positive subsidies over the zero subsidy. Since $sign\left(\frac{\partial U}{\partial \zeta_s}\right) = sign\left(Z_4\right)$, then, we need to show that Z_4 is positive in this case. It is straightforward to show that this holds if

$$\left(1-\left(\frac{\theta}{2}\right)^2\right) > 2\left(i-\frac{\theta}{2}\right)\left(\frac{\theta}{2}\right).$$

Since $i < 1$ it is sufficient that $\left(1+\frac{\theta}{2}\right) > \theta$ which holds for $\theta < 2$.

Finally, consider the third item in the proposition. To establish the first sentence, we show that when ζ_s is chosen to maximize the utility of a preferred generally-skilled worker, $\frac{\partial U}{\partial \zeta_s} > 0$ for a specifically skilled agent. First note from (16) that when ζ_s is chosen to maximize the utility of a preferred generally-skilled worker, the first two lines of (17) are equal to 0. Thus $\frac{\partial U}{\partial \zeta_s} > 0$ for specifically skilled agent at this point if

$$1-\left(\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}\right)^2>2\left(i-\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}\right)\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}.$$

Notice that the left hand side of this is

$$\left(1-\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}\right)\left(1+\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}\right).$$

Since $\left(1-\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}\right)>\left(i-\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}\right)$, a sufficient condition for the inequality to hold is that

$$1+\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}>2\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}.$$

Since $\frac{\alpha\theta-\zeta_s}{2\alpha+\zeta_s}=\hat{\imath}<1$, the inequality always holds.

To show the second sentence of the third item, an application of the implicit function theorem shows that agents with a higher i prefer lower subsidies than those with a lower i.

Proof of Corollary 2. Consider a situation in which there are full subsidies. This requires $\zeta_s=\alpha\theta$. In this case $\hat{\imath}=0$ (see equation 8) and thus all individuals become specifically skilled. This means we need to focus on the specifically-skilled individual's decision problem. It can be shown that when $\zeta_s=\alpha\theta$

$$Z_4=2\alpha^2(2+\theta)-\frac{1}{(\zeta_\tau-\alpha\theta)}\frac{\mu_2}{1-\mu_2}(2\alpha+\alpha\theta)^2\left[2\alpha i+(1-\alpha-\zeta_\tau)\right].$$

Note that if $\zeta_s=\alpha\theta$, ζ_τ must exceed $\alpha\theta$. Furthermore, we implicitly make the assumption $(1-\alpha-\zeta_\tau)>0$ as this is required for positive consumption (see equation 14). Given this, the second term in the above expression is positive. Still, the difference clearly exceeds 0 for any i as μ_2 approaches 0. Since $sign\left(\frac{\partial U}{\partial\zeta_s}\right)=sign\left(Z_4\right)$ this means that if μ_2 is small enough and $\zeta_\tau>\alpha\theta$ all individuals may prefer ζ_s to be as large as $\alpha\theta$; they may prefer full subsidies.

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