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EQUALIZING OPPORTUNITIES THROUGH PUBLIC EDUCATION WHEN INNATE ABILITIES ARE UNOBSERVABLE

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Abstract

I consider the problem of equalizing opportunities among agents who differ in both their tastes and innate productive abilities when these characteristics are unobservable. The government specifically wishes to offset the effects of differences in innate talents by affording public education or training to those with lesser skills. I first show that in the benchmark case involving complete information it is possible to fully equalize opportunities as defined axiomatically by Bossert and Fleurbaey. Moreover, in the incomplete information case, it is possible to implement any input progressive education policy by means of a direct implementation/revelation mechanism. However, it is not possible to afford equal opportunities. I conclude with an example demonstrating the alternative, social welfare function approach which I argue is more suitable for second-best analyses.

Keywords: Equal opportunities; Public education; Individual responsibility; Multidimensional characteristics; Asymmetric information.

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1. Introduction

This paper considers the problem of equalizing opportunities among agents who differ in their tastes and innate productive abilities. While it may be argued that both attributes are "circumstances of birth," I begin with the premise that taste differences may provide a suitable basis for distinguishing economic rewards but differences in innate ability do not.[1] In particular, if agents have the same opportunities and choose to exploit them differently, then such heterogeneities need not be of social concern. However, if agents' opportunities differ for reasons beyond their control, then this warrants remediation. Such is the case with innate talents or handicaps. Thus, any influence these have on the allocation of rewards should be minimized. Toward this end, an egalitarian planner provides public education or training to those with lesser abilities in order to effect a more equitable distribution of income generating skills. The problem is complicated by the fact that both preferences and abilities are private information known only to the agents themselves. Thus, in addition to determining the appropriate level of education to provide each individual, the planner must also identify the correct recipient. Formally, therefore, the task is to design an education policy that equalizes opportunities and simultaneously solves the (multidimensional) screening problem.

Roemer [25], Bossert [4], Fleurbaey [11, 12, 13] and others[2] have considered the problem of equalizing opportunities when agents are responsible, in part, for their circumstances.[3] They argue that agents should be held accountable for, and only for, those circumstances under their control, and that society should indemnify agents for the consequences of their handicaps. Bossert describes the problem succinctly as follows. Pre-tax incomes, or outcomes, are determined by a set of *characteristics*, some of which are deemed *relevant* (for the purpose of allocating rewards) and others *irrelevant*. The problem is to find an allocation mechanism[4] which eliminates the effects of irrelevant characteristics (call it a *neutralizing* mechanism), while preserving the

[1] The purpose of this paper is not to define the proper domain of individual responsibility, but rather to consider tools which may be applicable to such a discussion. In principle, these or similar tools can be developed for other domains as well. For discussions of the proper domain, see, for example, Arneson [1], Cohen [9], or Roemer [25].

[2] See Bossert and Fleurbary [5]; Bossert, Fleurbaey and Van de gaer [6]; Fleurbaey and Maniquet [14, 15]; Iturbe-Ormaetxe and Nieto [18]; Sprumont [26]; and Van de gaer [30].

[3] For an alternative approach to the issue of equitable opportunities, see Kranich [19, 20] where I consider the problem of ranking distributions of opportunities on the basis of fairness. The framework employed therein can be interpreted either as abstracting from the problem of individual responsibility or as applying to the residual elements once *endogenous* opportunities (those for which individuals are responsible) have been extracted. In either case, the objective is to construct a complete ranking (and thus to compare unequal distributions) rather than to formulate a notion of fairness.

[4] In his case, a *redistribution mechanism.*

influence of relevant characteristics (call it a *reward* mechanism). Such a mechanism is said to *equalize opportunities.* Here, preferences are deemed relevant and innate productivities irrelevant.

The aforementioned authors considered the complete information case in which individual characteristics are known. Even in this context, however, it is not obvious how to formulate the precise requirements of a neutralizing reward mechanism when agents differ in more than one dimension. One (axiomatic) approach, adopted by Bossert and Fleurbaey, is to specify conditions only for those cases in which agents share a common characteristic (i.e., on the appropriate subspaces of characteristics) where one's intuition is a more reliable guide. Another approach, adopted by Roemer [25]; Van de gaer [30]; and Bossert, Fleurbaey, and Van de gaer [6] entails specifying a social welfare function which then enables comparisons of arbitrary characteristics. (Ideally, the latter should generalize the former in that social optima should respect the conditions when restricted to the appropriate subspaces – I will return to this point below.)

Among the axioms posed by Bossert and Fleurbaey, the following (strongest versions) have the greatest intuitive appeal.[5] The first reflects the fact that innate abilities lie outside the domain of individual responsibility and thus are compensable, and the second that *only* such differences warrant compensation.

First, if agents have the same preferences, then any resulting difference in their welfare levels must result from their differential handicaps. In this case, a neutralizing reward mechanism would ensure that, *ex post,* agents with equal preferences attain equal welfare. I refer to this as *EWEP.*

Next, if agents have the same ability, then while their choices (and welfare) may differ, there is no ethical basis for differential treatment vis-à-vis a remedial program. Consequently, if one agent were to receive compensation for his or her handicap, then all other agents with the same handicap should receive the same compensation. A neutralizing reward mechanism should thus provide equal compensation for those with equal innate abilities. Subsequently, I call this *ECEA.*

Bossert and Fleurbaey established that, in general, it is possible to equalize opportunities (i.e., there exists an allocation mechanism which satisfies EWEP and ECEA) if and only if the utility (or outcome) functions are separable in the relevant and irrelevant characteristics. In the notation of the present paper, utility is a function of external resources (e), talents (w) (for which the individual is *not* responsible), and variables for which the individual is responsible (α). Then in order to equalize opportunities, it must be the case that utility is separable in the form $u(\phi(w,e),\alpha)$; and, in this case, equal opportunity is achieved by equalizing $\phi(w,e)$ across individuals.

Fleurbaey, in particular, argues that the separability requirement is extremely restrictive and "unlikely to be satisfied except in rather special cases" such as when "the external resources are of the same nature as the handicaps" and are thus additive.

[5] Fleurbaey writes that any weakening of these requisites "implies that some desirable features of the equalizing procedure must be abandoned."

Initially, I consider the benchmark case involving complete information. There, I point out that in many models involving education, separability arises quite naturally.[6] Therefore, equal opportunities can be achieved in the manner described above, namely, by equating $\phi(w,e)$ across individuals. Here, w is interpreted as innate productive ability, e denotes educational resources, and ϕ describes the education technology whereby w and e are transformed into final, or *ex post*, ability.[7,8] Thus, equating $\phi(w,e)$ across individuals means equalizing *ex post* abilities. Notice also that since this first-best objective is achievable (in the event of complete information), any social welfare ordering that is consistent with EWEP and ECEA would recommend a similar solution; one need not resort to second-best considerations for which the social welfare function approach is better-suited.[9]

Next, I turn to the case of incomplete information where the agents' innate productive abilities and taste parameters are unobservable. Here, two questions arise: (i) which policies can be *implemented* in light of the informational asymmetry? and (ii) is it possible to achieve equitable opportunities?[10] I will argue that, at least for the special case in which agents have identical preferences, it is possible to implement any *input progressive*[11]education policy – including that of fully equalizing *ex post* abilities – but there is an (informational) cost of doing so. Even in this case (in which preferences are identical and separable), there is no (differentiable) allocation mechanism which equalizes opportunities and is consistent with the incentives of the agents. As a result, the obstacles to achieving equal opportunities in the context of incomplete information are even more formidable.

Given that the first-best objective is unachievable in this context, it is necessary to consider alternative recourses. One route, pursued by Bossert, Fleurbaey, and

[6]See Arrow [2], Bruno [8], Hare and Ulph [17], Ulph [29], and Tuomala [27, 28].

[7]This specification of the education technology abstracts from the fact that effort expended at school may affect the productivity of education. The references cited above employ the present specification. In contrast, Roemer [25] and Bossert, Fleurbaey and Van de gaer [6] incorporate the effort effect. The former specification may suffice in the event returns to education accrue to the *level* achieved rather than the performance within each level (for example, earnings surveys generally distinguish between high school versus college graduates rather than on the basis of grade point averages in college), in the event students within each level expend roughly equal amounts of effort, or if effort is measured by time. In any case, the alternative specification would affect the results presented here.

[8]It should be noted that in Bossert [4]; Fleurbaey [11, 12, 13] and Bossert, Fleurbaey and Van de gaer [6], the authors explicitly assume that the individual characteristics are not influenced by the allocation rule or policy. In contrast, the purpose of education is precisely to alter abilities.

[9]A social welfare ordering is consistent with EWEP if, when restricted to a subspace of agents with identical preferences, the (restricted) social optimum entails equalizing utilities. Analogously, a social welfare ordering is consistent with ECEA if it recommends equal compensation for those with equal abilities.

[10]"Implementability" is defined precisely below. Intuitively, it means that each agent receives its intended reward despite the fact that agents with private information may behave strategically.

[11]Following Arrow [2], I refer to an educational policy as *input progressive* if agents with lesser abilities receive more educational resources.

Van de gaer in the complete information case, is to relax the requirements and to consider weak forms of the axioms. However, as Fleurbaey points out, "weakening the requisites of equal opportunities to remove this problem [of incompatibility between the strongest forms of the axioms] ... implies that some desirable features of the equalizing procedure must be abandoned." A second course, and that adopted here, is the social welfare function approach of Roemer [25] and Van de gaer [30]. This has the advantage that when first-best outcomes are unattainable (as is the case here), the social welfare function obviates second-best considerations. Since the objective of the present normative analysis is to achieve full equality, I consider the lexicographic extension of the egalitarian or Rawlsian social welfare function, or the leximin objective function.[12] To illustrate the approach, I consider an example in Roemer [25], and I extend it to the incomplete information context. Specifically, I identify the second-best education policy and thus quantify the limits to equalization.

The fact that the first-best optimum under the leximin objective function is not achievable due to incentive considerations should be contrasted with the findings of Dasgupta and Hammond [10]. These authors consider lump-sum redistributive taxation based on unobservable skills, and they establish that the first-best taxation scheme under the maximin social welfare ordering is indeed incentive compatible. This apparent contradiction arises due to the fact that misrepresentation in their model entails working at different (lesser) skill levels and earning the corresponding wage. As discussed in the following paragraph, here one strategically announces a skill level for the purpose of affecting the allocation of educational resources, but one continues to work at one's true level. Thus, for example, if educational resources are allocated on the basis of performance on a standardized test, then one need only misrepresent one's ability on the exam rather than in the workforce.

Before proceeding to the model, some comments on the technical analysis are in order. First, in the incomplete information case, the planner's objective, again, is to design a policy that equalizes opportunities and simultaneously identifies the correct recipients. Given such a mechanism design problem, it is typical to invoke the *revelation principle* (for games with incomplete information).[13] According to the principle, in place of whatever screening devise the planner might employ, it is sufficient to consider a *direct revelation mechanism* in which agents announce their characteristics and the mechanism assigns an outcome and, moreover, to focus on equilibria in which agents announce their true characteristics. That is, for any equilibrium of any mechanism, there is a truthful equilibrium of a direct mechanism which yields the same equilibrium outcome. Consequently, I consider only direct mechanisms and I establish (sufficient) conditions under which such a mechanism provides each agent the incentive to reveal its true type. In doing so, I restrict my attention to differentiable mechanisms, and I adopt the first-order approach to incentive compatibility of

[12]Note that this is consistent with EWEP and ECEA at the first-best optimum in the manner described earlier.

[13]See Fudenberg and Tirole [16], pp.253-257; or Mas-Colell, Whinston and Green [23], pp.883-884.

Laffont and Maskin [21]. I then show that there is a fundamental conflict between the first-order conditions for incentive compatibility and the goal of EWEP. Intuitively, in order to induce agents to reveal their true productivities, it is necessary that those with higher productivity receive greater income. Since the first-order conditions are necessary here, this establishes the incompatibility.

The result that it is possible to implement any input progressive education policy (Theorem 4.1, below) is obtained by modifying the argument of Berliant and Gouveia [3]. There, the authors considered the problem of implementing *individual revenue requirements* (i.e., agent-specific taxes) as a function of unobservable skill. In their framework, skill is invariant, and the objective is to design an income tax scheme which has the effect of insuring that each type pays a predetermined amount, depending on their skill level. In contrast, in my model skill is variable (through education), and the objective is to design a scheme to insure that agents receive the appropriate level of educational support, depending on their initial talents. Thus, in spite of the formal similarities, the economic interpretations of the results are quite different.

The paper is organized as follows. In the next section, I describe the basic structure of the model. In Section 3, I consider the axiomatic approach for the benchmark case of complete information. First, I abstract from the issue of raising revenue, and then I consider the issue of taxation. In Section 4, I turn to the case of incomplete information where, first, I demonstrate the difficulty of adopting the axiomatic approach in the context of fixed educational resources, and then I demonstrate the alternative, social welfare function approach by means of an example. Finally, Section 6 contains a brief conclusion.

2. The Basic Model

There is a continuum of agents who differ in their tastes and innate productive abilities. Each agent is endowed with one unit of time and has preferences defined over consumption, c, and labor, l. I assume the taste differences can be described by a single parameter $\alpha \in A \equiv [\alpha_m, \alpha^m] \subset \mathbb{R}_{++}$, and thus preferences are represented by the (single) utility function $u(c, l; \alpha)$ defined on $\mathbb{X} \equiv \mathbb{R}_+ \times [0, 1]$. Only ordinal properties of u are used in the sequel. I impose the following standard restrictions on u.

Assumptions on u: for all $\alpha \in A$,
*Au.*1 *Differentiability:* u is C^2 on $\mathring{\mathbb{X}}$.[14]
*Au.*2 *Monotonicity:* $u_1 > 0$, $u_2 < 0$.
*Au.*3 *Strict quasiconcavity:* $u_{11} < 0$, $u_{22} < 0$, $u_{11}u_2^2 - 2u_{12}u_1u_2 + u_{22}u_1^2 < 0$.
*Au.*4 *Normality:* $u_{12}u_2 - u_{22}u_1 > 0$.
*Au.*5 *Interiority:*

$$\lim_{c \to 0} u_1(c, l; \alpha) = \infty$$

[14] Subscripts denote partial derivatives all of which are evaluated on the interior of $\mathbb{X}$, denoted $\mathring{\mathbb{X}}$.

$$\lim_{l \to 1} u_2(c, l; \alpha) = -\infty$$
$$\lim_{l \to 0} u_2(c, l; \alpha) = 0$$

Each agent is endowed with an innate productive ability, w (for wage rate). I assume it is known that innate abilities lie in the range $\Omega \equiv [w_m, w^m] \subset \mathbb{R}_{++}$. An agent is thus fully described by its characteristics in $A \times \Omega$. Hence, I associate the set of agents, N, with the space of characteristics, $A \times \Omega$, and I denote specific agents by $i = (\alpha^i, w^i)$, $j = (\alpha^j, w^j)$, etc. I describe the joint distribution of α and w by the density $f : N \longrightarrow [0, 1]$.[15]

The principal redistributive instrument available to the government is an *education policy*, or *program*. Such a policy is described by a function $e : N \longrightarrow \mathbb{R}_+$, where $e(\alpha, w)$ specifies the quantity of (public) educational resources to be afforded an individual of type (α, w). Generally, I will use e^i to denote the resources allocated to agent i. The *education technology*, that is, the process by which educational resources affect measured productivity, is given by the function $\phi : \Omega \times \mathbb{R}_+ \longrightarrow \mathbb{R}_{++}$; $\phi(w, x)$ measures the *ex post* ability of an agent whose innate ability is w and who receives (external) educational resources x. I assume ϕ satisfies the following:

Assumptions on ϕ:
$A\phi$.1 *Differentiability:* ϕ is C^2 on $\mathring{\Omega} \times \mathbb{R}_{++}$.
$A\phi$.2 *Monotonicity:* $\phi_w > 0$, $\phi_x > 0$.
$A\phi$.3 *Educability:* for all $w \in \Omega$ and for all $w > w'$, there exists $x \in \mathbb{R}_+$ such that $\phi(w, x) = w'$.
$A\phi$.4 *Weak complementarity:* $\phi_w \cdot \frac{w}{\phi} \geq \phi_{xw} \cdot \frac{w}{\phi_x}$.

Assumptions $A\phi$.1 and $A\phi$.2 are standard. $A\phi$.3 means that given sufficient resources anyone is educable to any extent, or each agent is capable of achieving any ability level *ex post*. Finally, consider that ϕ_{xw} can be of either sign. If it is negative (x and w are *substitutes*), then $A\phi$.4 follows from $A\phi$.2. If it is positive (x and w are *complements*), then $A\phi$.4 requires that the degree of complementarity be sufficiently weak. Specifically, it requires that the direct influence of innate ability on final ability dominates the indirect effect through enhancing the productivity of educational resources. Both the direct and the indirect effects are expressed as elasticities. $A\phi$.4 is satisfied by the entire class of CES production functions.

One education policy of particular interest here is that in which *ex post* abilities are fully equalized. Before defining this formally, I introduce the following notation. For $w' > w$, let $\phi^{-1}(w, w')$ denote the amount of educational resources necessary for an agent with innate ability w to achieve *ex post* ability w'. Under $A\phi$.2 and $A\phi$.3, ϕ^{-1} is well-defined.

[15]Implicitly, therefore, I assume the population size is normalized to 1.

Definition 2.1. *The education policy which fully equalizes ex post abilities (at w^m) is defined by* $\overline{e}^i \equiv \phi^{-1}(w^i, w^m)$.

Under $\overline{e}$, all agents would achieve the ability level w^m. Thus, any resulting differences in income would reflect different levels of labor/effort (presumably resulting from different preferences for leisure). Subsequently, when considering the policy of full equalization, I will abbreviate $\phi^{-1}(w^i, w^m)$ by $\overline{\phi}^{-1}(w^i)$.

In the following sections, I consider two cases. In the first, the aggregate quantity of educational resources is fixed; in the second, the government levies taxes in order to finance education.

3. Complete Information: A Benchmark Case

3.1. Lump-sum policies with fixed educational resources

To determine the effect of the informational asymmetry, I begin by considering the benchmark case involving complete information. Thus, I assume the government has at its disposal all of the relevant information in the economy including knowledge of the precise characteristics of each agent. Therefore, it is possible to distinguish between agents on the basis of their characteristics as well as their behavior. Moreover, given such information, I assume it is possible to implement *lump-sum* (first-best) policies specific to each agent type.[16]

Also, in this subsection, I abstract from the issue of raising revenues for the purpose of financing education. Rather, I assume there is a fixed quantity of educational resources, R. In the absence of taxation, a *policy* simply consists of an education program, e. Such a program is *feasible* providing

$$R \geq \int_N e^i df. \tag{3.1}$$

Let $E(R)$ denote the set of feasible education programs with aggregate resources R.

Taking $e \in E(R)$ as given, the problem facing agent i is the following:

$$\max_y u(y, \frac{y}{\phi(w^i, e^i)}; \alpha^i). \tag{3.2}$$

Let $y^i(e)$ denote the solution to (3.2), and let $v^i(e) = u(y^i(e), \frac{y^i(e)}{\phi(w^i,e^i)}; \alpha^i)$.[17]

I now turn to the objective of the government. In this section, rather than specify a particular objective function, I take an appropriate policy to be one which satisfies the following properties:

[16] Since I am interested in determining which policies are achievable from a normative point of view rather than with their actual implementation, I abstract from political constraints which may preclude lump-sum policies.

[17] Under the above assumptions, there will be a unique maximizer of (3.2).

Axiom 1 (EWEP). *Equal-welfare-for-equal-preference: for all $i, j \in N$, if $\alpha^i = \alpha^j$, then $v^i(e) = v^j(e)$.*

Axiom 2 (ECEA). *Equal-compensation-for-equal-ability: for all $i, j \in N$, if $w^i = w^j$, then $e^i = e^j$.*

As described in the Introduction, EWEP means that when agents have identical tastes the only basis for distinguishing economic rewards are differences in innate abilities. Since the latter are assumed to be irrelevant, an appropriate policy should neutralize any welfare differences.[18] Alternatively, ECEA means that agents with the same irrelevant characteristic should be treated equally vis-à-vis the education policy. Otherwise, the policy would depend on attributes which the government expressly does not wish to offset (here, taste differences).

Definition 3.1. *An education policy provides equal opportunities if it satisfies EWEP and ECEA.*

Bossert and Fleurbaey have shown that EWEP and ECEA are compatible only when u is separable in α. Moreover, Fleurbaey argues that the assumption of separability is rarely justified. As the next result shows, however, education provides a natural setting in which the separability condition is satisfied. First, let $\overline{R} = \int_N \overline{\phi}^{-1}(w^i)df$.

Theorem 3.2. *If $R \geq \overline{R}$, then the policy of fully equalizing ex post abilities, $\overline{e}$, provides equal opportunities.*

Proof. Clearly, $\overline{e}$ depends only on w and thus satisfies ECEA. Also, if $\alpha^i = \alpha^j$ and $\phi(w^i, e^i) = \phi(w^j, e^j)$ in (3.2), then $v^i(e) = v^j(e)$. ■

3.2. Lump-sum policies with taxation

Next, suppose the government were to impose lump-sum taxes in order to finance education. Then a policy will include a specification of the tax structure as well. Formally, a (*lump-sum*) *tax function* is a mapping $\tau : N \to \mathbb{R}_+$, where $\tau^i \equiv \tau(\alpha^i, w^i)$ indicates the tax levied on agent i. $R(\tau) \equiv \int_N \tau^i df$ is the tax revenue collected under τ.

A *policy* is now a pair $\rho = (\tau, e)$ consisting of an education policy, e, as well as a tax function, τ. Given ρ, i's optimization problem is now:

$$\max_y u(y - \tau^i, \frac{y}{\phi(w^i, e^i)}; \alpha^i). \tag{3.3}$$

[18] Roemer [22] argues that "if all agents have the *same* preferences, it seems any suitable equality-of-resource mechanism should bring about equality of welfare."

Let $y^i(\rho)$ denote the solution to (3.3), and let $v^i(\rho) = u(y^i(\rho) - \tau^i, \frac{y^i(\rho)}{\phi(w^i,e^i)}; \alpha^i)$. ρ is *feasible* if

$$R(\tau) \geq \int_N e^i df, \tag{3.4}$$

and

$$y^i(\rho) \geq \tau^i \text{ for all } i \in N. \tag{3.5}$$

Again, I wish to consider the existence of a policy which satisfies EWEP and ECEA. Note that EWEP now requires that agents with identical preferences suffer equal utility losses from taxation.

Given that the population size is normalized to 1, $R(\tau)$ is the average tax as well. Therefore, $\overline{\tau}^i \equiv \overline{R}$ for all i defines a *poll*, or *head*, tax which generates the minimum revenue necessary to fully equalize abilities at w^m.

Note that the maximal achievable wealth (that is, if an agent with ability w^m were to devote full time to work) is w^m.

Theorem 3.3. *If $w^m \geq \overline{R}$, then $\overline{\rho} = (\overline{\tau}, \overline{e})$ is feasible and, furthermore, it equalizes opportunities.*

Proof. First, given the boundary conditions, $Au.5$, the solution $y^i(\overline{\rho})$ will be such that $y^i(\overline{\rho}) > \overline{R}$. Thus, (3.5) holds. Also, under $\overline{\tau}$, the tax burden is fully allocated, i.e., $\overline{R} = \int_N \overline{\tau}^i df$. Hence, (3.4) is satisfied, and $\overline{\rho}$ is feasible.

Clearly, $\overline{\rho}$ satisfies ECEA. In this case, the problem facing i is to $\max_y u(y - \overline{R}, \frac{y}{w^m}; \alpha^i)$. If $\alpha^i = \alpha^j$, then $y^i(\overline{\rho}) = y^j(\overline{\rho})$ and $v^i(\overline{\rho}) = v^j(\overline{\rho})$. ■

The results of this section demonstrate that in the benchmark case involving complete information it is indeed possible to achieve equal opportunities through public education.

4. Incomplete Information

4.1. A problem with the axiomatic approach

I now assume both characteristics, α and w, are private information. Thus, while the government again wishes to eliminate the influence of w (and permit differences based on α), it cannot observe agents' abilities; rather, I assume it can only observe gross income or output $y = wl$. Consequently, the lump-sum, or agent-specific, education policies considered in the previous section are no longer feasible. Now the government must offer an entire schedule or menu of education levels to all agents and let the agents themselves choose the level they prefer. Since the government cannot verify the identity of the recipient, it must design a policy which provides each agent the incentive to choose the level appropriate for its type, i.e., it must design an *incentive compatible* policy.

The purpose of this section is to demonstrate that there is no policy which provides equal opportunities and is incentive compatible. For this, it is sufficient to concentrate on the case in which agents have identical preferences. In this case, the informational asymmetry exacts a cost: in order to ensure that agents have the incentive to claim the educational resources intended for them, it is necessary that those with higher innate productivities receive greater income. But this would necessarily violate EWEP.

I again consider the case in which aggregate educational resources are fixed. Thus, a government policy will consist solely of an education program. Facing such a policy, each agent chooses y. As discussed in the Introduction, however, since the informational asymmetry concerns w, according to the revelation principle (for games with incomplete information), it is sufficient to consider the direct revelation mechanism in which each agent announces its type (w) and, based on these announcements, the mechanism assigns an *outcome*; that is, it specifies the consumption/production of each agent as well as the educational resources it is to be afforded. Thus, the direct revelation mechanism consists of a pair $(y(w), e(w))$, for all $w \in \Omega$. (Clearly, any such pair will satisfy ECEA.)[19] Following the first-order approach of Laffont and Maskin [21], I will restrict my attention to *differentiable* mechanisms, or mechanisms in which $y(w)$ and $e(w)$[20] are differentiable.

Given an arbitrary education policy, e, I will say e is *implementable* if there exists y such that the direct revelation mechanism (y, e) induces each agent to announce its true ability. Such a mechanism thus awards the (correct) educational resources $e(w)$ to an agent with innate ability w. According to the revelation principle, therefore, this spans the set of *all* equilibria of *all* mechanisms.

In the terminology of Arrow [2], I will say an education policy is *input progressive* if for all $i, j \in N$, $w^i > w^j$ implies $e^i < e^j$. The following theorem establishes that any input progressive education policy is implementable.

Theorem 4.1. *For all $e \in E(R)$, if $e' < 0$, then e is implementable.*

To establish the theorem, I adapt the argument of Berliant and Gouveia [3] for implementing *individual revenue (tax) requirements* for the case involving lump-sum education policies. I include the details in an appendix.

Corollary 4.2. *$\bar{e}$ is implementable. That is, it is possible to fully equalize ex post abilities.*

The previous theorem and its corollary afford the prospect of improving the distribution of opportunities through the use of input progressive education policies and, moreover, in a manner consistent with the incentives of the agents. However, the following theorem establishes that the extent of such remedial efforts is limited; it establishes the logical inconsistency between incentive compatibility and EWEP.

[19] For the general case in which agents differ in both α and w, the direct mechanism would consist of their announcing both characteristics, and the outcome would specify $(y(\alpha, w), e(\alpha, w))$. Since, at present, I am considering the case in which agents have identical preferences, I suppress notation of α.

[20] And, when necessary, the tax function as well.

Theorem 4.3. *There is no (differentiable) mechanism which provides equal opportunities and is incentive compatible.*

Proof. Suppose to the contrary, that the policy (y, e) is incentive compatible and satisfies EWEP. The problem facing agent i is

$$\max_{\tilde{w}} u(y(\tilde{w}), \frac{y(\tilde{w})}{\phi(w^i, e(\tilde{w}))}). \tag{4.1}$$

Since (y, e) is incentive compatible, the following (necessary) first order condition is satisfied at $\tilde{w} = w^i$.

$$\begin{aligned} & u_1(y(\tilde{w}), \frac{y(\tilde{w})}{\phi(w^i, e(\tilde{w}))}) \cdot y'(\tilde{w}) + \\ & u_2(y(\tilde{w}), \frac{y(\tilde{w})}{\phi(w^i, e(\tilde{w}))}) \cdot \left(\frac{y'(\tilde{w}) \cdot \phi(w^i, e(\tilde{w})) - \phi_x(w^i, e(\tilde{w})) \cdot e'(\tilde{w}) \cdot y(\tilde{w})}{\phi(w^i, e(\tilde{w}))^2} \right) \\ = \; & 0. \end{aligned} \tag{4.2}$$

That is,

$$\begin{aligned} & u_1(y(w^i), \frac{y(w^i)}{\Phi(w^i)}) \cdot y'(w^i) + \\ & u_2(y(w^i), \frac{y(w^i)}{\Phi(w^i)}) \cdot \left(\frac{y'(w^i) \cdot \Phi(w^i) - \phi_x(w^i, e(w^i)) \cdot e'(w^i) \cdot y(w^i)}{\Phi(w^i)^2} \right) \\ = \; & 0, \end{aligned} \tag{4.3}$$

where $\Phi(w^i) \equiv \phi(w^i, e(w^i))$.

Next, since agents have identical preferences, EWEP requires that (y, e) be such that all agents achieve the same utility level, or

$$u(y(w^i), \frac{y(w^i)}{\phi(w^i, e(w^i))}) = \bar{u} \text{ for all } i \in N. \tag{4.4}$$

Consequently, (4.4) must be preserved as w varies over Ω. Hence,

$$\begin{aligned} & u_1(y(w^i), \frac{y(w^i)}{\Phi(w^i)}) \cdot y'(w^i) + \\ & u_2(y(w^i), \frac{y(w^i)}{\Phi(w^i)}) \cdot \\ & \left(\frac{y'(w^i) \cdot \Phi(w^i) - (\phi_w(w^i, e(w^i)) + \phi_x(w^i, e(w^i)) \cdot e'(w^i)) \cdot y(w^i)}{\Phi(w^i)^2} \right) \\ = \; & 0. \end{aligned} \tag{4.5}$$

Clearly, (4.3) and (4.5) are consistent only if $\phi_w \equiv 0$. However, this contradicts the fact that ϕ is strictly increasing. ■

4.2. The leximin social welfare function

4.2.1. An example with fixed educational resources

The results of the previous section are rather disheartening. For the more realistic case in which agents' innate abilities are private information, one cannot design an education program that equalizes opportunities and that benefits precisely the target populations.[21] In this section, I demonstrate the alternative approach of specifying a social welfare function. In particular, I consider a variation of an example presented in Roemer [25].[22] However, given the informational asymmetry, the analysis is quite different.[23] Specifically, I again pose the problem as one of finding an optimal direct revelation mechanism. I begin in the present subsection by abstracting from the issue of taxation. I then extend the example in the following subsection.

In Roemer's example, agents have identical preferences represented by the utility function $u(c, l) = c - \frac{1}{2}l^2$. The budget constraint is $y = wl$. For simplicity, I assume there are two types of agents, those with low productivity, $\underline{w}$, and those with high productivity, $\overline{w}$. (Thus, $\Omega = \{\underline{w}, \overline{w}\}$.) In particular, I take $\underline{w} = \frac{1}{2}$ and $\overline{w} = 1$. Generally, I distinguish values pertaining to the former by "_" and to the latter by "—". The government is assumed to know the form of the utility function and the distribution of w, but it does not know the type of a particular agent. The education technology is of the multiplicative form $\phi(w, e) = w\sqrt{e+1}$.[24]

In this case, a direct revelation mechanism specifies an income/educational resource pair for each of the two types. Thus, the mechanism requires that each agent announces a type, $\underline{w}$ or $\overline{w}$, and receives either $(\underline{y}, \underline{e})$ or $(\overline{y}, \overline{e})$, accordingly. I will write $v(y, e; w)$ to denote agent w's utility if it were to receive (y, e), i.e., $v(y, e; w) = y - \frac{1}{2}\frac{y^2}{\phi^2(w,e)}$.

The problem facing the government is to design an optimal policy subject to the incentive compatibility constraints that each agent prefers its own pair and to the budgetary constraint that total educational resources per capita do not exceed R, which, for simplicity, I take to be 3 — the minimum amount necessary to fully equalize

[21] Note that the lump-sum policies considered here offer the greatest likelihood of achieving first-best outcomes. Thus, if such targeted programs are prohibited, the prospects are even more limited.

[22] Roemer includes various illustrative examples of his theory of equal opportunities with responsibility. One involves production with redistribution without education and another involves education. In the latter, effort influences the productivity of education. In this respect, my model of education lies in between. However, both of Roemer's examples involve complete information and, in this respect, mine is quite different. Analytically, however, the incentive compatibility constraints associated with information revelation are closer to the autonomous choice constraints in the example involving production.

[23] Also, for this reason, the results are not directly comparable.

[24] In the model involving taxation in the following subsection, this specification avoids the "money pump" problem, that is, the anomaly that the instantaneous return to education could exceed the investment. Were this the case, one could generate infinite income by taxing all earnings and (instantaneously) returning the tax revenue to provide more education. The problem would arise due to the static framework.

abilities. Here, I formalize the government's objective as follows:[25]

$$\text{lexi} \max_{((\underline{y},\underline{e}),(\overline{y},\overline{e}))} \min\{v(\underline{y},\underline{e};\underline{w}), v(\overline{y},\overline{e};\overline{w})\}, \tag{4.6}$$

Thus, the problem is to solve (4.6) subject to the resource, or fiscal, constraint and the incentive constraints

$$\begin{aligned} v(\underline{y},\underline{e};\underline{w}) &\geq v(\overline{y},\overline{e};\underline{w}) \\ v(\overline{y},\overline{e};\overline{w}) &\geq v(\underline{y},\underline{e};\overline{w}), \end{aligned} \tag{4.7}$$

or

$$\begin{aligned} \underline{y} - \frac{1}{2}\frac{\underline{y}^2}{\underline{w}^2(1+\underline{e})} &\geq \overline{y} - \frac{1}{2}\frac{\overline{y}^2}{\underline{w}^2(1+\overline{e})} \\ \overline{y} - \frac{1}{2}\frac{\overline{y}^2}{\overline{w}^2(1+\overline{e})} &\geq \underline{y} - \frac{1}{2}\frac{\underline{y}^2}{\overline{w}^2(1+\underline{e})}. \end{aligned} \tag{4.8}$$

In this model, there is no taxation. Therefore, the only issue concerns the allocation of R. An egalitarian planner would choose to allocate as much of R as possible to $\underline{w}$. (Note that were the entire education budget allocated to $\underline{w}$, this would *not* reverse the ranking of productivities, i.e., it would still be the case that $\phi(\underline{w},\underline{e}) \leq \phi(\overline{w},\overline{e})$.) But for *any* values of $\underline{e}$ and $\overline{e}$, the lexicographic maximization in (4.6) requires that $\underline{y}$ and $\overline{y}$ be chosen so as to maximize $v(\underline{y},\underline{e};\underline{w})$ and $v(\overline{y},\overline{e};\overline{w})$, respectively.[26] This entails setting $\underline{y} = \phi^2(\underline{w},\underline{e})$ and $\overline{y} = \phi^2(\overline{w},\overline{e})$. Then (4.6) becomes

$$\text{lexi} \max_{(\underline{e},\overline{e})} \min\{\frac{1}{2}\phi^2(\underline{w},\underline{e}), \frac{1}{2}\phi^2(\overline{w},\overline{e})\},$$

or, upon substituting,

$$\text{lexi} \max_{(\underline{e},\overline{e})} \min\{\frac{1}{8}(1+\underline{e}), (1+\overline{e})\}. \tag{4.9}$$

Thus, the government's problem is to solve (4.9) subject to the (per capita) resource constraint $\underline{e} + \overline{e} \leq R$ and the incentive constraints

[25]The lexicographic order on $\mathbb{R}^2$ is defined by $(x_1, x_2) >_L (x_1', x_2')$ if $x_1 > x_1'$ or if $x_1 = x_1'$ and $x_2 > x_2'$. The maximization is then with respect to $>_L$. Whereas the maximin social welfare function is weakly Pareto efficient (in the first-best context), the leximin is strongly Pareto efficient.

[26]The direct mechanism involves offering each agent the optimal income level for its type. Consequently, it may appear that the same outcome could be achieved simply by offering agents their choice of $\underline{e}$ or $\overline{e}$. However, by offering the choice of $(\underline{y},\underline{e})$ or $(\overline{y},\overline{e})$, the planner precludes, for example, agent $\overline{w}$ claiming the resources $\underline{e}$ and earning $\overline{y}$. Moreover, since y is observable, compliance with the appropriate reward is verifiable.

$$\frac{1}{8}(1+\underline{e}) \geq -(1+\overline{e}) \tag{4.10}$$
$$\frac{1}{2}(1+\overline{e}) \geq \frac{7}{32}(1+\underline{e}). \tag{4.11}$$

Clearly, (4.10) is nonbinding.

Suppose, for the moment, that the government were to equalize abilities by issuing $\underline{e} = 3$ and $\overline{e} = 0$. This would yield $\underline{y} = \overline{y} = 1$. And, indeed, this would entail equal-welfare-for-equal-preferences ($v(\underline{y}, \underline{e}; \underline{w}) = v(\overline{y}, \overline{e}; \overline{w})$). However, this solution is not incentive compatible, for (4.11) would fail to hold. Thus, the optimal policy will entail allocating as much of R as possible to $\underline{w}$ until the incentive constraint (4.11) just binds. The optimal values of $\underline{e}$ and $\overline{e}$ are $\frac{57}{23}$ and $\frac{12}{23}$, respectively. The associated values of $\underline{y}$ and $\overline{y}$ are $\frac{20}{23}$ and $\frac{35}{23}$. At these levels, $v(\underline{y}, \underline{e}; \underline{w}) = \frac{10}{23}$ and $v(\overline{y}, \overline{e}; \overline{w}) = \frac{35}{46}$. In particular, this solution does *not* afford the agents equal welfare.

4.2.2. The example continued with taxation

Next, I extend the example to include taxation. In this case, an *outcome* will include a specification of the tax each agent must pay. Thus, the associated direct mechanism will specify $((\underline{y}, \underline{e}, \underline{\tau}), (\overline{y}, \overline{e}, \overline{\tau}))$. Now, I denote by $v(y, e, \tau; w)$ the utility of agent w in the event it were to receive (y, e) and pay τ. Analogous to (4.6), the government's objective is to:

$$\text{lexi} \max_{((\underline{y},\underline{e},\underline{\tau}),(\overline{y},\overline{e},\overline{\tau}))} \min\{v(\underline{y}, \underline{e}, \underline{\tau}; \underline{w}), v(\overline{y}, \overline{e}, \overline{\tau}; \overline{w})\} \tag{4.12}$$

subject to the incentive and fiscal constraints. However, now the latter take the form $\underline{e} + \overline{e} \leq \underline{\tau} + \overline{\tau}$, $\underline{\tau} \leq \underline{y}$, and $\overline{\tau} \leq \overline{y}$.

As before, for any values of $\underline{e}$, $\overline{e}$, $\underline{\tau}$, and $\overline{\tau}$, (4.12) requires that $\underline{y}$ and $\overline{y}$ be chosen so as to maximize $v(\underline{y}, \underline{e}, \underline{\tau}; \underline{w})$ and $v(\overline{y}, \overline{e}, \overline{\tau}; \overline{w})$, respectively. This again entails setting $\underline{y} = \phi^2(\underline{w}, \underline{e})$ and $\overline{y} = \phi^2(\overline{w}, \overline{e})$. Substituting into (4.12), the problem becomes

$$\text{lexi} \max_{((\underline{e},\underline{\tau}),(\overline{e},\overline{\tau}))} \min\{\underline{w}^2(1+\underline{e}) - \underline{\tau}, \overline{w}^2(1+\overline{e}) - \overline{\tau}\}$$

or

$$\text{lexi} \max_{((\underline{e},\underline{\tau}),(\overline{e},\overline{\tau}))} \min\{\frac{1}{8}(1+\underline{e}) - \underline{\tau}, \frac{1}{2}(1+\overline{e}) - \overline{\tau}\} \tag{4.13}$$

subject to the constraints.

Next, the incentive constraint for agent $\overline{w}$ will preclude $v(\underline{y}, \underline{e}, \underline{\tau}; \underline{w}) > v(\overline{y}, \overline{e}, \overline{\tau}; \overline{w})$ at the solution to (4.13). Specifically, the constraint requires that $v(\overline{y}, \overline{e}, \overline{\tau}; \overline{w}) \geq v(\underline{y}, \underline{e}, \underline{\tau}; \overline{w})$, or substituting for $\underline{y}$, $\overline{y}$, and $\overline{w}$,

$$\frac{1}{2}(1+\bar{e})-\bar{\tau} \geq \frac{7}{32}(1+\underline{e})-\underline{\tau}. \tag{4.14}$$

In the absence of such rank reversals, the optimal policy will never entail taxing $\underline{w}$ for the purpose of providing educational resources either for itself or for $\overline{w}$. Thus, $\underline{\tau}=0$. Nor will such a policy entail taxing $\overline{w}$ for $\bar{e}$. Thus, the sole remaining issue concerns the optimal level of $\bar{\tau}$ to provide $\underline{e}$.

Substituting $\underline{\tau}=\bar{e}=0$ and $\bar{\tau}=\underline{e}$, (4.13) reduces to

$$\text{lexi}\max_{\underline{e}} \min\{\frac{1}{8}(1+\underline{e}), \frac{1}{2}-\underline{e}\} \tag{4.15}$$

subject to the constraint $\frac{1}{2}-\underline{e} \geq \frac{7}{32}(1+\underline{e})$. Clearly, the unconstrained solution to (4.15) would entail setting $\frac{1}{8}(1+\underline{e})=\frac{1}{2}-\underline{e}$, or $\underline{e}=\frac{1}{3}$. However, this would violate (4.14). Instead, the constrained solution is $\underline{e}=\frac{3}{13}$, at which $\frac{1}{2}-\underline{e}=\frac{7}{32}(1+\underline{e})$.

Thus, at the solution to (4.12), $\underline{e}$ and $\bar{e}$ are $\frac{3}{13}$ and 0, respectively. The associated values of $\underline{y}$ and $\bar{y}$ are $\frac{4}{13}$ and 1. And at these levels, $v(\underline{y},\underline{e},\underline{\tau};\underline{w})=\frac{2}{13}$ and $v(\bar{y},\bar{e},\bar{\tau};\overline{w})=\frac{7}{26}$. Here, too, the solution does not afford the agents equal welfare.

5. Conclusion

In this paper, I have shown that in the benchmark case involving complete information, public education can be an effective means to equalize opportunities. Specifically, in this case, the necessary and sufficient condition that utility be separable in the preference parameter α follows quite naturally. However, when abilities are unobservable, the power of the government to effect equitable opportunties via public education is restricted, even if utility is separable. While this limits the attractiveness of the axiomatic approach, the social welfare function approach, by incorporating second-best considerations, affords an attractive alternative.

6. Appendix

Proof of Theorem 4.1. The proof proceeds as in Berliant and Gouveia [3], Proposition 1, appropriately modified for the case in which the government wishes to implement an education policy rather than individual revenue requirements, that is, in which the policy is to affect productivity rather than to collect agent-specific revenue.

First, let $e(\cdot)$ be given. The (first-best) optimal income for an agent with innate ability w who receives educational resources $e(w)$ is defined implicitly by the first order condition[27]

$$u_1(\psi(w), \frac{\psi(w)}{\Phi(w)}) + u_2(\psi(w), \frac{\psi(w)}{\Phi(w)}) \cdot \frac{1}{\Phi(w)} = 0. \tag{6.1}$$

[27] Recall $\Phi(w^i) \equiv \phi(w^i, e(w^i))$.

$\psi(\cdot)$ is well-defined under the assumptions on u and ϕ. Moreover, $\psi(w) > 0$ for all $w > 0$. Let $I(w) \equiv (0, \psi(w))$. Then $I(w)$ is nonempty for all w.

Define

$$\psi^+ \equiv \{(w,c) | u_1(c, \frac{c}{\Phi(w)}) + u_2(c, \frac{c}{\Phi(w)}) \cdot \frac{1}{\Phi(w)} > 0\},$$

and

$$\psi^- \equiv \{(w,c) | u_1(c, \frac{c}{\Phi(w)}) + u_2(c, \frac{c}{\Phi(w)}) \cdot \frac{1}{\Phi(w)} < 0\}.$$

Next, in the direct mechanism described previously, when facing the policy (y, e), agent i would solve the maximization problem

$$\max_{\tilde{w}} u(y(\tilde{w}), \frac{y(\tilde{w})}{\phi(w^i, e(\tilde{w}))}). \tag{6.2}$$

The first order condition for (6.2) is

$$\begin{aligned} & u_1(y(\tilde{w}), \frac{y(\tilde{w})}{\phi(w^i, e(\tilde{w}))}) \cdot y'(\tilde{w}) + \\ & u_2(y(\tilde{w}), \frac{y(\tilde{w})}{\phi(w^i, e(\tilde{w}))}) \cdot \left(\frac{y'(\tilde{w}) \cdot \phi(w^i, e(\tilde{w})) - \phi_x(w^i, e(\tilde{w})) \cdot e'(\tilde{w}) \cdot y(\tilde{w})}{\phi(w^i, e(\tilde{w}))^2} \right) \\ = \; & 0. \end{aligned} \tag{6.3}$$

Truthful revelation requires that (6.3) hold at $\tilde{w} = w^i$ and, moreover, that it hold for all i. Thus, treating (6.3) as an identity yields

$$\begin{aligned} & u_1(y(w^i), \frac{y(w^i)}{\Phi(w^i)}) \cdot y'(w^i) + \\ & u_2(y(w^i), \frac{y(w^i)}{\Phi(w^i)}) \cdot \left(\frac{y'(w^i) \cdot \Phi(w^i) - \phi_x(w^i, e(w^i)) \cdot e'(w^i) \cdot y(w^i)}{\Phi(w^i)^2} \right) \\ \equiv \; & 0. \end{aligned} \tag{6.4}$$

Solving (6.4) for y',

$$y'(w^i) = \frac{u_2(y(w^i), \frac{y(w^i)}{\Phi(w^i)}) \cdot \phi_x(w^i, e(w^i)) \cdot e'(w^i) \cdot \frac{y(w^i)}{\Phi(w^i)^2}}{u_1(y(w^i), \frac{y(w^i)}{\Phi(w^i)}) + u_2(y(w^i), \frac{y(w^i)}{\Phi(w^i)}) \cdot \frac{1}{\Phi(w^i)}}. \tag{6.5}$$

Under assumptions $A.u$ and $A.\phi$, there is a unique solution to (6.5) through each point $(w, c) \in \psi^+$ and, moreover, the solution is continuous.[28] In particular, choose

[28] See Brock and Malliaris [7], Chapter 1, Theorem 5.1, p.14.

$y(w^m) \in I(w^m)$ (recall $I(w) \neq \emptyset$ for all $w > 0$), and let $y(\cdot)$ be the solution to (6.5) through $(w^m, y(w^m))$.[29]

Since the right-hand side (RHS) of (6.5) is $\mathcal{C}^1$, $y(\cdot)$ is $\mathcal{C}^2$.

Next, the second order condition for a solution to (6.2) is

$$
\begin{aligned}
& u_{11}(y(\widetilde{w}), \frac{y(\widetilde{w})}{\phi(w^i, e(\widetilde{w}))}) \cdot y'(\widetilde{w})^2 + \\
& 2u_{12}(y(\widetilde{w}), \frac{y(\widetilde{w})}{\phi(w^i, e(\widetilde{w}))}) \cdot \left(\frac{y'(\widetilde{w}) \cdot \phi(w^i, e(\widetilde{w})) - \phi_x(w^i, e(\widetilde{w})) \cdot e'(\widetilde{w}) \cdot y(\widetilde{w})}{\phi(w^i, e(\widetilde{w}))^2} \right) \cdot y'(\widetilde{w}) + \\
& u_{22}(y(\widetilde{w}), \frac{y(\widetilde{w})}{\phi(w^i, e(\widetilde{w}))}) \cdot \left(\frac{y'(\widetilde{w}) \cdot \phi(w^i, e(\widetilde{w})) - \phi_x(w^i, e(\widetilde{w})) \cdot e'(\widetilde{w}) \cdot y(\widetilde{w})}{\phi(w^i, e(\widetilde{w}))^2} \right)^2 + \\
& u_1(y(\widetilde{w}), \frac{y(\widetilde{w})}{\phi(w^i, e(\widetilde{w}))}) \cdot y''(\widetilde{w}) + \\
& u_2(y(\widetilde{w}), \frac{y(\widetilde{w})}{\phi(w^i, e(\widetilde{w}))}) \cdot \left(\begin{array}{c} \frac{y''(\widetilde{w})}{\phi(w^i, e(\widetilde{w}))} - \\ \frac{\phi_{xx}(w^i, e(\widetilde{w})) \cdot e'(\widetilde{w}) \cdot y(\widetilde{w}) + \phi_x(w^i, e(\widetilde{w})) \cdot e''(\widetilde{w}) \cdot y(\widetilde{w}) + 2\phi_x(w^i, e(\widetilde{w})) \cdot e'(\widetilde{w}) \cdot y'(\widetilde{w})}{\phi(w^i, e(\widetilde{w}))^2} \\ + \frac{2(\phi_x(w^i, e(\widetilde{w})))^2 \cdot (e'(\widetilde{w}))^2 \cdot y(\widetilde{w})}{\phi(w^i, e(\widetilde{w}))^3} \end{array} \right) \\
< \; & 0.
\end{aligned}
\tag{6.6}
$$

At $\widetilde{w} = w^i$, (6.6) can be written

$$
\begin{aligned}
D^2 \equiv \; & u_{11} \cdot y'^2 + 2u_{12} \cdot \left(\frac{y' \cdot \Phi - \phi_x \cdot e' \cdot y}{\Phi^2} \right) \cdot y' + \\
& u_{22} \cdot \left(\frac{y' \cdot \Phi - \phi_x \cdot e' \cdot y}{\Phi^2} \right)^2 + u_1 \cdot y'' + \\
& u_2 \cdot \left(\frac{y''}{\Phi} - \frac{\phi_{xx} \cdot e' \cdot y + \phi_x \cdot e'' \cdot y + 2\phi_x \cdot e' \cdot y'}{\Phi^2} + \frac{2\phi_x^2 \cdot e'^2 \cdot y}{\Phi^3} \right) \\
< \; & 0,
\end{aligned}
\tag{6.7}
$$

where all functions are evaluated at w^i.

Next, differentiating the identity (6.4) and simplifying,

$$
\begin{aligned}
& u_{11} \cdot y'^2 + 2u_{12} \cdot y' \cdot \left(\frac{y' \cdot \Phi - \phi_x \cdot e' \cdot y}{\Phi^2} \right) + \\
& u_{22} \cdot \left(\frac{y' \cdot \Phi - \phi_x \cdot e' \cdot y}{\Phi^2} \right)^2 + u_1 \cdot y'' +
\end{aligned}
$$

[29] Here $y(w)$ is to be interpreted as the income of an agent with innate ability w *after* receiving the educational resources $e(w)$ and achieving the *ex post* ability $\Phi(w)$. Thus, the labor expended in earning $y(w)$ is $\frac{y(w)}{\Phi(w)}$.

$$
\begin{aligned}
& u_2 \cdot \left(\frac{y''}{\Phi} - \frac{\phi_{xx} \cdot e' \cdot y + \phi_x \cdot e'' \cdot y + 2\phi_x \cdot e' \cdot y'}{\Phi^2} + \frac{2\phi_x^2 \cdot e'^2 \cdot y}{\Phi^3} \right) - \\
& u_{12} \cdot \frac{y \cdot y'}{\Phi^2} \cdot \phi_w - u_{22} \cdot \frac{y}{\Phi^2} \cdot \phi_w \cdot \left(\frac{y' \cdot \Phi - \phi_x \cdot e' \cdot y}{\Phi^2} \right) - \\
& u_2 \cdot \left(\frac{y' \cdot \phi_w}{\Phi^2} + \frac{\phi_{xw} \cdot e' \cdot y}{\Phi^2} - \frac{2\phi_w \cdot \phi_x \cdot e' \cdot y}{\Phi^3} \right) \\
\equiv\ & 0. \qquad (6.8)
\end{aligned}
$$

From (6.8), (6.7) can be rewritten as

$$
\begin{aligned}
& u_{12} \cdot \frac{y \cdot y'}{\Phi^2} \cdot \phi_w + u_{22} \cdot \frac{y}{\Phi^2} \cdot \phi_w \cdot \left(\frac{y' \cdot \Phi - \phi_x \cdot e' \cdot y}{\Phi^2} \right) + \\
& u_2 \cdot \left(\frac{y' \cdot \phi_w}{\Phi^2} + \frac{\phi_{ew} \cdot e' \cdot y}{\Phi^2} - \frac{2\phi_e \cdot \phi_w \cdot e' \cdot y}{\Phi^3} \right) < 0. \qquad (6.9)
\end{aligned}
$$

From (6.4), $\frac{y' \cdot \phi - \phi_x \cdot e' \cdot y}{\Phi^2} = -\frac{u_1 \cdot y'}{u_2}$. Substituting into (6.9) yields

$$
\begin{aligned}
& u_{12} \cdot \frac{y \cdot y'}{\Phi^2} \cdot \phi_w - u_{22} \cdot \frac{u_1}{u_2} \cdot \frac{y \cdot y'}{\Phi^2} \cdot \phi_w + u_2 \cdot \frac{\phi_{xw} \cdot e' \cdot y}{\Phi^2} \\
& -u_1 \cdot \frac{y' \cdot \phi_w}{\Phi} - u_2 \cdot \frac{\phi_w \cdot \phi_x \cdot e' \cdot y}{\Phi^3} \\
<\ & 0. \qquad (6.10)
\end{aligned}
$$

Simplifying this expression, the appropriate second order condition when agents truthfully report their types is

$$
\frac{y \cdot y'}{\Phi^2} \cdot \phi_w \cdot \left(\frac{u_{12} \cdot u_2 - u_{22} \cdot u_1}{u_2} \right) - \phi_w \cdot \left(\frac{u_1 \cdot y' \cdot \Phi^2 + u_2 \cdot \phi_x \cdot e' \cdot y}{\Phi^3} \right) + u_2 \cdot \frac{\phi_{xw} \cdot e' \cdot y}{\Phi^2} < 0,
$$

or

$$
\phi_w \cdot \left(\frac{y \cdot y'}{\Phi^2} \right) \cdot \left(\frac{u_{12} \cdot u_2 - u_{22} \cdot u_1}{u_2} \right) < \phi_w \cdot \frac{u_1 \cdot y'}{\Phi} + \frac{u_2 \cdot e' \cdot y}{\Phi^2} \cdot \left(\frac{\phi_x \cdot \phi_w}{\Phi} - \phi_{xw} \right). \qquad (6.11)
$$

Providing $y > 0$ and $y' > 0$, the LHS of (6.11) is negative. Also, since $e' < 0$, it is sufficient that $y > 0$, $y' > 0$ and $\frac{\phi_x \cdot \phi_w}{\Phi} \geq \phi_{xw}$ to ensure that the RHS is positive. The latter follows immediately from $A\phi.4$. I conclude by establishing $y(w) > 0$ and $y'(w) > 0$ for all $w \in \mathring{\Omega}$.

Returning to (6.5), since $e' < 0$, it is sufficient to show that $y(w) > 0$ and

$$
u_1(y(w), \frac{y(w)}{\Phi(w)}) + u_2(y(w), \frac{y(w)}{\Phi(w)}) \cdot \frac{1}{\Phi(w)} > 0, \qquad (6.12)
$$

for all $w \in\underset{\circ}{\Omega}\equiv (w_m, w^m]$. However, (6.12) is equivalent to $(w, y(w)) \in \psi^+$.

Thus, it is sufficient to show that $\psi(w) > y(w) > 0$ for all $w \in\underset{\circ}{\Omega}$.

Clearly, $\psi(w^m) > y(w^m) > 0$ given the selection of y. To establish that $\psi(w) > y(w)$ for all $w \in\underset{\circ}{\Omega}$, first, suppose to the contrary that there exists $w \in\underset{\circ}{\Omega}$ such that $y(w) \geq \psi(w)$. Then since both ψ and y are continuous, there is a largest w' for which $y(w') \geq \psi(w')$; indeed, it must be the case that $y(w') = \psi(w')$. Since $\underset{\circ}{\Omega}$ is bounded above, consider a sequence $\{w_n\}_{n=1}^{\infty}$ such that $w_n \to w'$ from above. By (6.1) and (6.5), $\lim_{n\to\infty} y'(w_n) = \infty$.

Next, from (6.1),

$$u_1(\psi(w), \frac{\psi(w)}{\Phi(w)}) + u_2(\psi(w), \frac{\psi(w)}{\Phi(w)}) \cdot \frac{1}{\Phi(w)} = 0.$$

Differentiating,

$$\psi' = \frac{(u_{12} \cdot \psi + u_{22} \cdot \frac{\psi}{\Phi} + u_2) \cdot \Phi'}{u_{11} \cdot \Phi^2 + 2u_{12} \cdot \Phi + u_{22}}. \tag{6.13}$$

From $Au.3$, $u_{11} \cdot u_2^2 - 2u_{12} \cdot u_1 \cdot u_2 + u_{22} \cdot u_1^2 < 0$. Dividing by u_1^2 and substituting $\Phi = -\frac{u_2}{u_1}$ from (6.1) yields $u_{11} \cdot \Phi^2 + 2u_{12} \cdot \Phi + u_{22} < 0$. Hence, the denominator of (6.13) is negative. Also, by $Au.3$ and $Au.4$, $\frac{u_1}{u_2} < \frac{u_{12}}{u_{22}}$. Again substituting $\Phi = -\frac{u_2}{u_1}$ yields $-\frac{1}{\Phi} < \frac{u_{12}}{u_{22}}$, or $u_{12}+u_{22}\cdot\frac{1}{\Phi} < 0$. Since $\psi(w) > 0$ for all $w \in \Omega$, $u_{12}\cdot\psi+u_{22}\cdot\frac{\psi}{\Phi} < 0$. Also $u_2 < 0$ by $Au.3$ and $\Phi' > 0$ by $A\phi.2$. Hence, the numerator of (6.13) is negative as well. Therefore, $\psi' > 0$ and finite, in particular at w'. Consequently, there exists $\widetilde{w} > w'$ for which $y(\widetilde{w}) > \psi(\widetilde{w})$, which contradicts the definition of w'. Hence, $\psi(w) > y(w)$ for all $w \in\underset{\circ}{\Omega}$.

Clearly under $Au.2$ and $Au.5$, $y(w) \geq 0$ for all $w \in\underset{\circ}{\Omega}$. Suppose, however, that for some $w^\circ \in\underset{\circ}{\Omega}$, $y(w^\circ) = 0$. Then by (6.5), $y(w) = 0$ for all $w \in (w_m, w^\circ]$. Since $y(w^m) > 0$, consider an alternative solution to (6.5), say $\widehat{y}(\cdot)$, such that at w^m, $0 < \widehat{y}(w^m) < y(w^m)$. Since $\widehat{y}$ and y are distinct and each is continuous, and since there is a unique solution to (6.5) through each point $(w, c) \in \psi^+$, it must be the case that $y(w) > \widehat{y}(w) \geq 0$ for all $w \in\underset{\circ}{\Omega}$. But since $y(w) = 0$ for all $w \in (w_m, w^\circ]$, this is a contradiction. ■

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