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WHY TO INVEST IN YOUR NEIGHBOR? SOCIAL CONTRACT ON EDUCATIONAL INVESTMENT

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Abstract

It may be in the interest of low-ability individuals to subsidize the education of high-ability individuals. Sufficient conditions are surprisingly mild: positive externalities in education and complementarity in production between human capital and labor supllied by the low-ability individuals. However, tax competition and the free mobility of the educated give rise to time-inconsistency and free-riding problems which render such a social contract infeasible and result in a subotimally low investment in education.

Keywords: Externalities in education, complementarity, social contract, tax competition

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1 Introduction

Why is the burden of financing higher education typically shared willingly by non-altruistic low-ability agents who themselves abstain from investment in human capital? Why would anybody be ready to invest in the education of his or her neighbor?[1] Why do low-ability agents typically pay high taxes, thereby participating in financing the education of their fellow citizens? Such a political equilibrium appears surprising in a democratic society where the low-ability agents typically represent a majority.

The current paper suggests an answer to this question based on two key mechanisms: externalities in education and complementarities in production. Large universities, isolated university campuses, and research institutes with a high concentration of trained human brains bear testimony to the existence of positive externalities in the production of human capital. In the light of such evidence, one can expect that the resulting equilibrium tends to be characterized by underinvestment in human capital in systems with decentralized decision-making. It appears therefore to be collectively rational for high-ability agents to coordinate their investment so as to maximize their joint income. A social contract could thus be introduced to internalize the external effects in the education process. Tax policy could be thought of as a mechanism to implement such a contract. However, it can also be argued that such a coordination need not be efficient from a broader perspective because it obviously neglects the impact of the created human capital on the marginal productivity of other productive inputs. Social gains are not limited to the mutual trade between those to be educated. While the external effects justify within-group mutual subsidies, between-group subsidies might offer additional mutual benefits. It is plausible that the investment in human capital made by high-ability agents generates productivity gains for low-ability agents as well. Such gains appear feasible within modern technologies with complementarities in production.[2]

We show that in the presence of externalities and complementarities in production it may actually be in the best interest of low-ability individuals to

[1] More generally, are there efficiency arguments which may explain voluntary cross-subsidization between social classes?

[2] Recent empirical studies point to strong complementarity between workers with low levels of human capital and high levels of human capital, cf. Ciccone, Peri and Almond (1999) using US Census data for 1970, 1980, and 1990. For earlier studies, see Goldin and Katz (1998).

subsidize the educational investment of high-ability individuals so as to enjoy the productivity gains. The distribution of the gains created by such a social contract depends on the relative social power of different groups. We take it as given that the bargaining solution cannot reduce the net income of either group compared to the market solution, where education is financed privately and where there are no cross subsidies. We suggest how an efficient tax structure with respect to earnings by high-ability and low-ability individuals can be derived given their relative social power.

The possibility to arrive at a social contract will radically deteriorate when educated labor becomes mobile and tax policy is not harmonized in a network of jurisdictions. In the absence of binding commitments regarding residence or post-education tax liability independent of residence, educated labor has an incentive ex post to migrate to a jurisdiction with lower tax rates so as to evade its share of the investment cost. Moreover, low-ability agents have an option of free riding on human capital created in other jurisdictions. We show that a national social contract cannot survive for these two reasons in the presence of free mobility without tax coordination.[3] Such a problem can be viewed as a social cost of coordination failure. The resulting regional underinvestment in human capital suggests a need to harmonize educational policy (or tax policy) internationally.We note that Rehme (1999) has recently introduced a complementary analysis where low-skilled individuals participate in financing education. In his model, education is financed by a uniform tax on capital. He analyzes the interaction between investment in education and economic growth under alternative public policy objectives. Individuals are *ex ante* identical, the number of those to be educated being a decision variable of the government.

Our paper is organized as follows. Section 2 introduces a model of a "class" society. People are assumed to be heterogeneous *ex ante*. Both classes may be subject to training or education. However, we assume that the low-ability types are subject to a standard and given education which will not be modeled explicitly. The "talented", high-ability people qualify for further education to acquire special skills. When labor inputs supplied by different ability types are complementary, unskilled labor will also benefit

[3]We notice that more recently there has been some tendency to move from fully tax-financed education towards tuition fees in some Western economies. Such a change obviously has to do with the fact that the mobility of the educated has increased between jurisdictions. For example, Eklund (1998) reports that in 1996 15 % of graduates left Sweden, while ten years earlier the corresponding figure was only one third of that.

from educational investment by high-ability individuals. Section 3 analyzes a Pareto-efficient solution, where surplus created by increased investment in education is shared by both high- and low-ability individuals. We derive a Nash-bargaining solution and show that if the relative weights of the two groups correspond to their income shares arising from constant elasticity technology of the Cobb-Douglas type, both groups face positive tax rates in the efficient solution. In section 4 we show that in the absence of policy coordination, such an outcome cannot survive in a federation if migration is costless. Section 5 concludes.

2 Decentralized Investment in Knowhow

Assume that a population of size $1 + n$ is heterogeneous and consists of "low-ability" agents whose size is normalized to be one, and of $n > 0$ "high-ability"agents. Before the value-added is produced, the knowhow embodied in skilled labor is created by investment in the education of the high-ability agents. Investment is subject to decreasing returns; however, there will be positive externalities between those to be educated. We denote the resource cost of educational investment by e and the resulting human capital by h. Its production is subject to externalities in the sense that students learn from each other. Then each educated agent is assumed to be equipped with human capital

$$h = e^{\beta}\overline{e}^{\gamma} \tag{1}$$

where $\overline{e}$ is the average educational investment by high-ability agents and h stands for the resulting human capital of each agent. We assume $0 < \beta, \gamma, \beta + \gamma < 1$. Total total human capital of the economy is then given by $H = nh$. This knowhow is used as a complementary input to unskilled labor to produce the value-added, say Y. A production technology of the Cobb-Douglas variety satisfies such a requirement. We thus work out our results by introducing

$$Y = H^{\alpha}1^{1-\alpha}, \tag{2}$$

where 1 stands for the complementary input of unskilled labor and α represents the income share of skilled labor of the total value-added.

Our model can be interpreted as a two-period model, in which education takes place in the first and labor supply in the second period. There is no uncertainty and no discounting.[4] We assume therefore that there are no constraints to lending or borrowing at a constant interest rate assumed to be zero. Furthermore, we assume that labor supply is inelastic, and that there are no leisure costs of education in addition to the resource cost e. It follows from our assumptions that we do not need to introduce any explicit utility function. Individuals do optimize their consumption decisions, but all we have to analyze is how they maximize their total lifetime income, net of investment costs.

We first consider equilibrium in the absence of factor mobility and under fully decentralized investment decisions. The maximization problem of the high-ability agents can be stated as

$$\max_e y = -e + e^{\beta}\overline{e}^{\gamma}\alpha H^{\alpha-1}. \tag{3}$$

The second-term on the right-hand side of (3) is the private return on educational investment e. It is the marginal private return on human capital $\alpha H^{\alpha-1}$ obtained from (2), multiplied by human capital per agent $e^{\beta}\overline{e}^{\gamma}$. Agents behave atomistically, neglecting the impact of their investment on aggregate knowhow, i.e. they consider $H = nh$ as constant in the maximization of (3). The individual's first-order condition determining the optimal e is given by

$$\beta e^{\beta-1}\overline{e}^{\gamma}\alpha H^{\alpha-1} = 1, \tag{4}$$

[4] Allowing for risks in educational investment and risk aversion would lead to the issue of an optimal social insurance contract. It is apparent that an insurance contract among the educated would turn out to be welfare-improving; whether the non-educated would find it rational to raise, compared to the solution without uncertainty, the share of their income they are ready to contribute to the educational investment of the high-ability types will not be addressed here.

where the left-hand side represents the marginal return to educational investment. It is now convenient to introduce

Definition 1. We define

$$\lambda = \frac{1}{\beta} - 1 \tag{5}$$

as the equilibrium intramarginal return on education for high-ability agents, net of the investment cost.

The validity of this definition can be seen as follows. Solving $e^{\beta-1}$ from (4) and inserting its expression into the rate of return on investment, $(e^{\beta}\overline{e}^{\gamma}\alpha H^{\alpha-1} - e)/e$, i.e. the net return to education relative to the investment cost, one arrives at (5).

Inserting the symmetry condition $e = \overline{e}$ and introducing h from (1) into (4), one arrives at the privately optimal investment

$$\widehat{e} = (\alpha\beta n^{\alpha-1})^{\mu}, \tag{6}$$

where $\mu = \frac{1}{1-\alpha(\beta+\gamma)}$. Clearly, $1 - \alpha(\beta + \gamma) > 0$. Thus, private incentives to acquire education are adversely affected by the share of high-ability agents in the population (n). Such a mechanism is natural; high n means that high-ability agents do not represent a scarce resource.

Under decentralized investment, the reward to the educated agents, net of the private cost of education, and the reward to the fixed factor, respectively, are given by

$$\widehat{Y}_1 = -n\widehat{e} + \alpha H^{\alpha} = n\widehat{e}\lambda \tag{7}$$

$$\widehat{Y}_2 = (1 - \alpha)H^{\alpha}. \tag{8}$$

Notice that $\lambda = 0$ when $\beta = 1$, i.e. with constant private returns to educational investments there will be no intramarginal rents; hence, the rent on education will vanish. Note also that we analyze here only the rent from

educational investment. The result should not be interpreted to imply that all the income of the educated would have to be tied to educational investment. To be exact, the income of the educated should equal investment cost plus opportunity cost, that is, the income a high-ability individual would earn if he or she remained uneducated. We abstract from the opportunity cost. We could, of course, include the opportunity cost in education technology, but that would only complicate the analysis.

The earnings by the high-ability and low-ability agents can be presented after substituting $H = nh$, (1) and (6) to (7) and (8) to read as

$$\widehat{Y}_1 = n(\alpha\beta n^{\alpha-1})^{\mu}\lambda \tag{9}$$

$$\widehat{Y}_2 = (1-\alpha)[n(\alpha\beta n^{\alpha-1})^{(\beta+\gamma)\mu}]^{\alpha}. \tag{10}$$

We next report the key result:

Proposition 1 *Unskilled labor will benefit from the educational investment of the high-ability agents and the more so, the more productive such investments are and the bigger the externalities between the educated are. Moreover, the income of unskilled labor is positively dependent upon the size of the population of educated people in the economy.*

Proof. The proof follows directly from the foregoing, i.e. from the role played by β, γ and n in the equations above. ■

This finding is rather striking. It raises the exciting question whether the unskilled agents have incentives to contribute to the education investment of the high-ability types. In other words, are Pareto improvements available through a voluntary social contract? We formulate below such a mechanism in terms of a Nash-bargaining procedure regarding the equilibrium of the current section as the social "status quo". It turns out that the answer is definitively positive - but only if $\gamma > 0$, i.e. the private investments are inefficient.

3 Social Contract between High-Ability and Low-Ability Agents

Consider social bargaining on a social contract where both types of agents agree to contribute to the production of knowhow a fraction of their income, say t_1 and t_2.[5] Such a voluntary contract may arise as a result of a political process, in which case it would be natural to regard them as tax (or subsidy) rates. Assume that the bargaining power of the two groups is given by θ and $1-\theta$, respectively, and consider the outcome of the following Nash bargaining

$$\max_{e,t_1,t_2} U = (Y_1 - \widehat{Y}_1)^{\theta}(Y_2 - \widehat{Y}_2)^{1-\theta}. \tag{11}$$

We have denoted the fall-back values by $\widehat{Y}_1$ and $\widehat{Y}_2$ and net incomes as

$$Y_1 = (1-t_1)\alpha H^{\alpha}$$

$$Y_2 = (1-t_2)(1-\alpha)H^{\alpha},$$

where t_1 and t_2 denote the shares of income contributed to financing education. Because we are working with the case of an inelastic labor supply, it is possible to separate the maximization of the surplus from its division between the factors. Indeed, it is in the interest of both groups that the surplus is maximized regardless of its division.[6] As an externality is involved, the market solution cannot lead to the maximization of surplus. The educational investment which maximizes the surplus

[5] There is no identification problem in the sense of low-ability types trying to acquire publicly financed education. Such an incentive can be eliminated either by the government's ability to screen students or by the sufficiently large non-monetary costs faced by low-ability individuals when mimicking the high-ability types.

[6] We would like to point out that the solution of (11) does not necessarily coincide with that of an optimal tax model. First, even if there is a fixed input in the model pointing to the possibility that the associated optimal tax rate would be high perhaps even approaching unity, there are heterogeneous agents in our model, whereby income effects also become relevant. Second, a standard welfare criterion, say of a utilitarian or Rawlsian variety, would apparently lead to a different solution, unless the benevolent government would adjust its criterion to replicate the process of Nash bargaining.

$$\max_e(Y_1 + Y_2) = -ne + H^\alpha = -ne + n^\alpha e^{\alpha(\beta+\gamma)} \tag{12}$$

is given by

$$e^* = [\alpha(\beta+\gamma)n^{\alpha-1}]^\mu. \tag{13}$$

Comparing (13) and (6), the socially optimal education e^* exceeds the market solution, $e^* > \widehat{e}$. The shares of financing the educational investment are found as follows. It has to hold that the total expenditure on education, ne, is financed by the contributions of the two classes, satisfying the educational budget constraint

$$t_1\alpha H^\alpha + t_2(1-\alpha)H^\alpha = ne,$$

yielding

$$t_2 = \frac{ne - t_1\alpha H^\alpha}{(1-\alpha)H^\alpha}. \tag{14}$$

Inserting this expression into the maximization problem (11), we obtain

$$\max_{t_1} U = [(1-t_1)\alpha H^\alpha - \widehat{Y}_1]^\theta [(1 - \frac{ne - t_1\alpha H^\alpha}{(1-\alpha)H^\alpha})(1-\alpha)H^\alpha - \widehat{Y}_2]^{1-\theta}.$$

Taking logarithms and denoting $u = \ln U$, we obtain

$$\max_{t_1} u = \theta \ln[(1-t_1)\alpha H^\alpha - \widehat{Y}_1] + (1-\theta)\ln[(1-\alpha)H^\alpha - ne + t_1\alpha H^\alpha - \widehat{Y}_2]. \tag{15}$$

In an appendix we show that the tax rates resulting from Nash bargaining are given by

$$t_1 = (1 - \frac{\theta}{\alpha} + \beta\theta)(1 - (\frac{\beta}{\beta+\gamma})^{\alpha(\beta+\gamma)\mu}) + \gamma\theta + \beta(\frac{\beta}{\beta+\gamma})^{\alpha(\beta+\gamma)\mu} \tag{16}$$

$$t_2 = \frac{\alpha}{1-\alpha}(\beta + \gamma - t_1). \tag{17}$$

It is the intrinsic nature of these solutions that they depend upon the fall-back values given by (9) and (10). The key issue we address is under what conditions low-ability types willingly end up subsidizing high-ability types. Such an outcome is equivalent to having $t_2 > 0$, which then is equivalent to $t_1 < \beta + \gamma$, from (17). When $\gamma = 0$, we can see that $t_1 = \beta$ and $t_2 = 0$. This is expected, because the market solution is an efficient solution in the absence of the externality, and the high-ability types finance their education themselves. Moreover, assuming extreme values of the parameters, one cannot exclude the case that the contribution of any of the two groups may be negative.[7] However, they are definitely both positive in more interesting cases. Assume, for example, that bargaining power is linked to economic power. More specifically, let us work out the case where $\theta = \alpha$, that is, the relative weight of the high-ability individuals is determined by their income share arising from their role in production. Then one can show that the contribution of the high-ability agents resulting from Nash bargaining is given by

$$t_1 = \beta\alpha(1 - (\frac{\beta}{\beta+\gamma})^{\alpha(\beta+\gamma)\mu}) + \gamma\alpha + \beta(\frac{\beta}{\beta+\gamma})^{\alpha(\beta+\gamma)\mu}. \tag{18}$$

The corresponding contribution of the low-ability agents who remain uneducated, in turn, is given by

$$t_2 = \alpha(\beta + \gamma)[1 - (\frac{\beta}{\beta+\gamma})^{\mu}]. \tag{19}$$

[7] For example, if $\alpha = 0.1$, $\beta = 0.2$, $\gamma = 0.5$, and $\theta = 0.9$, meaning that human capital depends more on the average investment in education than on the own investment of an individual, we obtain $t_1 = -0.07$. On the other hand, if $\alpha = 0.9$, $\beta = 0.5$, $\gamma = 0.2$ and $\theta = 0.1$, we obtain $t_2 = -0.1$.

Proposition 2 *When the relative power of the high-ability agents is determined by their income share arising from their role in production, the social contract on financing education, obtained through Nash-bargaining, results in voluntary positive contributions of both the high-ability and the low-ability agents.*

Proof. The claim follows from the fact that (18) and (19) are positive.

■

This result shows that it is in the interest of the low-ability agents to participate in the financing of education of the high-ability types if that is the only way to encourage the educational investments of the high-ability agents.[8]

4 The Time-Inconsistency and Free-Riding Problems in an Open Economy

In an open economy with global markets, factor mobility can be detrimental to the feasibility of the social contract discovered above, especially if the cost of migration is low for the educated but prohibitive for the uneducated. The optimal behavior of the educated will be *time inconsistent*. The uneducated, in turn, have an incentive to become *free riders*; their commitment to educational subsidy vanishes as they rationally anticipate the inflow of educated individuals when domestic *net* return to human capital exceeds that abroad. The resulting international tax optimum will be inefficient.[9] Even worse, as shown below, the uneducated have a preference for zero contribution not only from themselves but also from the educated, resulting in the risk of collapse of the education system.

To develop the argument, we note that from the point of view of the educated, their optimal choice as to the labor market will be determined by their after-tax income. Once educated, they have both an option and an incentive to re-optimize their location. *Ex ante*, they have an incentive to accumulate human capital in the form of publicly financed education. *Ex*

[8]The bargaining outcome with demographic weights $\theta = n/(1+n), 1-\theta = 1/(1+n)$ would depend on the relative sizes of the classes.

[9]One can interpret the tax system as an institution which can be used to implement a social contract.

post, however, they have an incentive to engage in tax avoidance. Those who are uneducated will rationally anticipate such an incentive and in equilibrium, we claim, there will be underinvestment in education, in that there cannot be any social contract which would generate publicly financed education.

Let us denote the after-tax return to human capital in the world economy by r. It is regarded as exogenous by every jurisdiction, and it dictates that under free mobility, the domestic required rate of return on the human capital in jurisdiction, say i, has to satisfy the following condition:

$$r = (1 - t_1)\alpha H_i^{\alpha - 1}.$$

Imposing such a condition, the domestic human capital in migration equilibrium can be solved as

$$H_i = \left[\frac{\alpha(1 - t_1)}{r}\right]^{\frac{1}{1-\alpha}}. \tag{20}$$

Clearly, H_i depends negatively on the magnitude of the tax rate on educated labor, $\partial H_i / \partial t_1 < 0$. High domestic tax thus leads to flight of the skilled input.

That the uneducated will oppose any contract which levies a tax on the incomes of the educated can be shown as follows. From their perspective and given that the net return to human capital is exogenous, the optimal contract has to maximize the sum of their gross income and the tax revenue from the educated, given by

$$\Pi = (1 - \alpha + \alpha t_1)\left[\frac{\alpha(1 - t_1)}{r}\right]^{\frac{\alpha}{1-\alpha}}.$$

To study the determination of the optimal tax rate, evaluate first the derivative

$$\begin{aligned}
\frac{\partial \Pi}{\partial t_1} &= \alpha\left[\frac{\alpha(1 - t_1)}{r}\right]^{\frac{\alpha}{1-\alpha}} - (1 - \alpha + \alpha t_1)\frac{\alpha}{1 - \alpha}\frac{1}{1 - t_1}\left[\frac{\alpha(1 - t_1)}{r}\right]^{\frac{\alpha}{1-\alpha}} \\
&= -\frac{\alpha}{1 - \alpha}\frac{t_1}{1 - t_1}\left[\frac{\alpha(1 - t_1)}{r}\right]^{\frac{\alpha}{1-\alpha}}.
\end{aligned}$$

Now, it is clear that $\partial\Pi/\partial t_1 > 0$ when $t_1 < 0$, and $\partial\Pi/\partial t_1 < 0$ when $t_1 > 0$. Therefore, the optimal contribution of the educated must satisfy $t_1 = 0$. This implies that in a global economy, the burden of public financing of education of the skilled is borne entirely, if by anyone, by the unskilled. The latter, however, cannot benefit from such investments, either. We present this result as follows:

Proposition 3 *Social contract of financing education between high- and low-ability individuals breaks down when the educated become mobile and social contracts are restricted to be national.*

Our result is analogous to that in Sinn (1997). He derives a result that tax competition does not lead to inefficiently low provision of an intermediate public good used in production, but may cause adverse distributional consequences. However, in the current case, the unskilled cannot benefit from subsidizing education. The reason behind this difference is the following. In Sinn (1997), the public good is infrastructure and is independent of the mobile factor. In our model, public expenditures are used to finance an intermediate good which is embodied in the mobile factor and is thus also itself mobile.

5 Conclusions

In this paper we have shown that a national social contract to finance education between mobile high-ability agents and immobile low-ability agents can arise in a closed economy but does not survive harsh tax competition. The possibility of migration combined with tax competition represents a destructive force leading to a Pareto-inferior outcome. We did not include efficiency gains of migration. If the return to education is subject to region-specific uncertainty, the possibility of migration may insure the educated against region-specific risks. In the presence of migration costs, taxation may prevent migration and thus lead to a loss of at least part of efficiency gains attainable through migration. These ideas have been developed, for example, by Wildasin (1995). On the other hand, migration costs may create a possibility to sustain a social contract even when the educated can migrate. We suppose that the presence of migration would in any case lead to a lower investment in education even if some kind of social contract could be maintained. Lower investment in education means lost opportunities in

production, but it also alleviates the time-inconsistency problem by lowering gains from emigration to a country with lower taxation.

The tax system presented here was a result of Nash bargaining. This idea of government is very optimistic. Brennan and Buchanan (1980) argue that if governments are selfish Leviathans, tax competition may be a remedy offered by a federal structure and should be favored rather than controlled. We have focused on the idea of a government resting on the consent of the governed and using tax revenues to the benefit of the citizens. If the low-ability voters are in the majority, the fact that they participate in financing higher education lends plausibility to our model. It should also be noted that in addition to the low-ability individuals, the complementary factor may include other fixed factors, for example immobile capital and natural resources.

Our model suggests that in Europe, for example, the social contract of financing higher education should perhaps be established at the Union level.[10] Although this still leaves to the educated the possibility to avoid their tax share through migration, say, to the United States, it would make the European Union approximate a closed economy. On the other hand, a centralized solution might impose inefficient harmonization. Restrictions to migration would both be opposite to the principles of free mobility and eliminate any potential efficiency gains from migration that are not present in current model. The challenge is to create a system that would combine the possibility of free migration and tax-financed education without the problems of tax competition. Poutvaara (1998) analyzes the case where the governments maximize the expected utility of those to be educated, and only those to be educated pay taxes. Under these conditions, a tax constitution where the educated pay their taxes to the region which has financed their education encourages the formation of human capital, thus benefiting the complementary uneducated labor. In our model, also the low-skilled participate in financing education. Even if the educated would pay their taxes to the region where they have obtained education, the uneducated would not receive compensation for their subsidy. An additional mechanism is needed to solve the free-riding problem: the unskilled of the region receiving skilled immigrants should compensate the subsidies for education to the unskilled of the region with emigration of human capital.

[10]This idea has earlier been discussed by Sinn (1997). See also Bhagwati and Hamada (1982) for a related discussion in a different context.

Appendix. Deriving tax rates resulting from Nash bargaining

The contribution by the high-ability types in the Nash bargaining is

$$t_1 = -\frac{\theta}{\alpha} + 1 + \frac{1}{\alpha} H^{-\alpha} \theta n e + \frac{1}{\alpha} H^{-\alpha} \theta \widehat{Y}_2 + \frac{\theta - 1}{\alpha} H^{-\alpha} \widehat{Y}_1. \tag{A1}$$

Using

$$H^{-\alpha} = n^{-\alpha} h^{-\alpha} = n^{-\alpha} e^{-\alpha(\beta+\gamma)} \tag{A2}$$

and (13), the third term in (A1) can be written as $\theta(\beta + \gamma)$. Using (10), (13) and (A2), the fourth term in (A1) can be written as $\theta \frac{1-\alpha}{\alpha} (\frac{\beta}{\beta+\gamma})^{\alpha(\beta+\gamma)\mu}$. Using (9), (13) and (A2), the fifth term in (A1) can be written as $-(1 - \theta)(\frac{\beta}{\beta+\gamma})^{\alpha(\beta+\gamma)\mu}(1 - \beta)$. Substituting these into (A1), one obtains

$$t_1 = 1 - \frac{\theta}{\alpha} + (\beta + \gamma)\theta + (\frac{\beta}{\beta + \gamma})^{\alpha(\beta+\gamma)\mu} [\frac{\theta}{\alpha} - 1 + \beta - \theta\beta].$$

After rearrangement, one obtains (16) in the main text.

From (14), we obtain

$$t_2 = \frac{ne - t_1 \alpha H^{\alpha}}{(1 - \alpha) H^{\alpha}} = \frac{n}{1 - \alpha} e H^{-\alpha} - t_1 \frac{\alpha}{1 - \alpha}.$$

Using first (A2) and then (13), one obtains (17) in the main text.

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