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Inequality, Politics and Economic Growth*

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Abstract

The paper studies the relationship between inequality and economic growth. This is done in a two sector model of endogenous growth with agents characterized by heterogeneity of factor endowments. The private sector consists of a large number of competitive firms who produce the only final good in the economy. This good is both consumable as well as accumulable. The government is seen to produce a productive factor interpreted as infrastructure. Infrastructure is both nonrival and accumulable. Infrastructural services flow into the production of infrastructural stocks as well as the final good. Capital used for infrastructural production is financed by the government by taxing capital income. The choice of the growth rate is determined by the tax rate on capital income. We study the choice of the economy's growth rate under a median voter democracy. The results show that inequality of the distribution of capital does not hamper growth.

Keywords: Endogenous growth, Infrastructure, Nonrival input, Welfare, Political equilibrium.

JEL classification: O41, H54, H41, D61

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1 Introduction

Differences in the rates of growth among economies is a phenomenon that growth theorists have explained in different ways. They have attributed these to the differences in the rate of accumulation of human capital (Lucas 1988), to human fertility (Becker, Murphy & Tamura), to learning by doing (Arrow 1962), to levels of government expenditure (Barro 1990), international trade (Grossman & Helpman 1991) and research and development (Romer 1990), etc.

The lack of adequate infrastructure has been a major impediment to the growth process in the developing economies. It has been noted by a large number of economists, that lack of such a critical sector has not only prevented many economies from attaining high growth, but also in many cases prevented the growth being sustained over a period of time. Lack of infrastructure also results in lower the productivity of factors of production and lowers the income and welfare of their owners. This sentiment was echoed in the World Bank Development Report(1994) with reference to China. It was estimated that the annual economic cost of inadequate transport in China is at least 1% of its GNP. The India Infrastructure Report (1996) reiterated a similar concern and recommended the government of India to take steps to raise the level of investment in infrastructure. It was projected that the amount of investment in infrastructure needs to be at least 7% of the GDP to ensure that the economy does not stagnate. Sanchez-Robles(1998) finds infrastructure to be positive and significant factor behind growth.

Barro(1990), in his seminal paper, first tried to capture the role of infrastructure on growth. In his paper, publicly provided infrastructural services enter as inputs in the production process. The provision of infrastructure allowed the economy to experience perpetual growth. Alesina and Rodrik (1994) used a variant of Barro's model to study the effect of heterogeneous agents on the provision of infrastructure and growth.

We extend Barro's model to allow infrastructure to be accumulated over time. Hence the economy we study has two growth inducing instruments: physical capital and infrastructure. This feature makes our model a "two-sector" model as opposed to the one-sector model of Barro and Alesina and Rodrik. The government is treated as the sole owner of all infrastructural stocks. This conforms largely to the reality of developing economies such as India. Alternatively, one can also regard infrastructure to be a nonexcludable public good. The scarcity of this stock is seen as a major constraining factor in the process of growth. A major difference between our work and that of Barro(1990) is that we introduce an explicit technology for augmenting the infrastructural stock. This technology is controlled entirely by the government. As in Alesina & Rodrik and Barro, however, the infrastructural service is provided freely to firms in the private sector which combine it with other factor inputs to produce a single private good. A final major departure of our approach from theirs is in the treatment of infrastructure as a nonrival input entering simultaneously into the production of the private good as well as the process controlling changes in the infrastructural stock. Some of these features of infrastructure may also be found in Truong (1993-a, 1993-b).

Alesina and Rodrik (1994) pointed out that while the government of an economy might have noble interests, the political pressures in an economy might force the government to choose policies which are dictated by the majority of the population. Hence a representative agent economy might not be an ideal setting to study the choice of infrastructural provision by a government. Following their approach we allow the economy to be comprised of heterogeneous agents. The agents in the economy differ in terms of their endowments of factors. The preferences of agents over the provision of infrastructure differs because of the heterogeneity of factor ownership.

Subject to the above characterization of infrastructure, the analytical exercise carried out in this paper is the same as in Alesina & Rodrik. Application of the Median Voter Theorem[1] is used in this set up to study the choice of growth rate in the economy.

The paper is organized as follows. The next section spells out the model. The effect of factor endowments on preferred policies is discussed in Section 3 and this is followed by the outcome under majority voting in Section 4. Section 5 studies the implications for growth if unskilled labor is required in the production process of both the final good and infrastructure. Section 6 gives the concluding comments.

[1]The Median Voter Theorem is used here to capture the notion that, in a democratic society the government is influenced by the preferences of the majority of its population.

2 The Model

In our model, there are three inputs required for the production of the only final good in the economy. Unskilled labor(L) and capital(K)[2] are two inputs for which proper markets exist. The other input is infrastructure(G), for which no market exists. The government is the sole producer of this input. It generates the funds for this purpose by taxing capital income. The final good is consumable as well as accumulable as capital.

There are a large number of competitive firms, having the same constant returns to scale production function for producing the final good Y. The aggregate production function of the economy in every period can described by

$$Y(t) = A[G(t)L(t)]^{1-a}[K_Y(t)]^a$$

where $Y(t)$ is the instantaneous output flow, $L(t)$ and $K_Y(t)$ are the aggregate employments of labor and capital for the production of Y. A is a technological shift parameter and $G(t)$ is the flow of infrastructure, assumed to be provided free of user cost to all firms (as in Barro).

We assume that labor is supplied inelastically and normalize its aggregate value to 1. Therefore, we can write the aggregate production function as

$$Y(t) = AG(t)^{1-a}[K_Y(t)]^a \tag{1}$$

The government produces infrastructure, which we view as another accumulable factor. The flow of infrastructure is assumed to be a non-rival input into all production. In order to add to the stock of infrastructure, the government uses the existing stock of infrastructure and capital. It buys capital services from the market by taxing capital income. All capital income earners are taxed at the same rate. The technology governing the change in the stock of infrastructure is given by

$$\frac{dG(t)}{dt} = BG(t)^{1-b}[K_G(t)]^b,^{3} \qquad 0 < b < 1 \tag{2}$$

[2]Capital here is viewed to be the sum total of Human and Physical capital.

[3]We assume that unskilled labor is not used in the production of infrastructure. It is typically seen that infrastructure is very capital intensive and does not rely heavily on unskilled labor. However, the

where B is a technological shift parameter and $K_G(t)$ is the amount of capital employed in the production of infrastructure. At any moment in time the stock of infrastructure is $G(t)$ and the flow of the service emanating from it is assumed to be $G(t)$ also. Assuming a balanced budget for the government at all points in time, we have

$$K_G(t) = \tau(t)K(t).^4$$

where $\tau(t)$ is the tax rate on capital income and $K(t)$ is the aggregate capital stock of the economy at t. It follows that

$$K_Y(t) = (1 - \tau(t))K(t)$$

The economy consists of a finite number of agents indexed by i. As in Alesina & Rodrik, household agents, or simply agents, in the economy are identified by their endowments. The ith agent is endowed with K_0^i units of capital and l^i units of labor. The endowment of labor is constant over time however agents can decide to accumulate capital over time. We assume that the agents behave competetively in all markets and are able to forecast the sequence of wages $(w(t))$ and rentals $(r(t))$ perfectly.[5] Define,

$$\sigma^i = \frac{l^i}{K_0^i/K_0} \tag{3}$$

where $\sigma^i \in [0, \infty)$. This individual specific parameter represents the endowment ratio of labor and capital of the ith agent relative to the endowment ratio for the economy as a whole(since the aggregate value of labor has been normalized to 1). A person with high σ is capital poor and vice versa. It may be noted that differences in the endowment of capital is the only cause of income disparity among the agents. The variable σ^i is used to index the agents and characterize the equilibrium later on. It will turn out that σ^i is a constant over time for each i. Having specified the model, we can now study the problem faced by the individual agents.

results qualitatively remain the same if we allow for labor to be used in the production process of both the sectors.

[4]The tax revenue of the government at any instant is $\tau(t)r(t)K(t)$. With the tax revenue the government can buy $\tau(t)K(t)$ units of capital. Notice, the way tax is utilized, amounts to physical expropriation of capital by the government. This method of financing capital input gives the government access to a certain proportion of the capital stock of the economy, at all points in time.

[5]It should be noted that the sequence of wages and rentals depend on the path of tax rate, since infrastructure affects the productivity of both the factors.

3 Factor ownership and Policy preferences

We will begin by studying the problem faced by a generic agent in the economy. The agent carries out his utility maximization excercise subject to a budget constraint which depends on his factor endowments and the sequence of wage rates and rental rates. We restrict our attention to the class of balanced growth paths only, i.e., paths along which all variables grow at constant rates.

Proposition 1 *Along the steady state equilibrium growth path, an agent's capital stock(K^i), the aggregate capital stock of the economy(K), the stock of infrastructure(G) and the output of the final good(Y) grow at the same rate as the agent's rate of growth of consumption(C^i), i.e.,*

$$\alpha_{C^i} = \alpha_{K^i} = \alpha_K = \alpha_G = \alpha_Y$$

where α's denote the rates of growth of these variables.

Proof: See the appendix. ■

All agents choose to save and accumulate capital in order to be able to have a steady growth in their consumption. Since all agents recieve the same rate of return on their savings they all accumulate capital at the same rate. The tax rate on capital determines the level of investment in infrastructure. The agents behave competitively in all markets therefore they don't internalize the impact of tax rate on their future wage rates and rental rates. If a political party or government was to decide the tax rate they would take into account the beneficial effect of capital tax on infrastructure. We now proceed to study the problem faced by a social planner if he was trying to maximize the welfare of the ith agent.

Every agent might have a different preference concerning the provision of infrastructure since it is financed through taxation of capital. Each agent's preference of the tax rate can be calculated by a political party by solving the following problem[6]:

$$\max U^i = \int_0^\infty \log C^i(t) e^{-\rho t} dt, \tag{4}$$

subject to:

$$\frac{dK^i(t)}{dt} = Y(t)[a + (1-a)/\sigma^i]l^i - C^i(t), \tag{5}$$

$$\frac{dG(t)}{dt} = BG(t)^{1-b}[\tau^i(\frac{\sigma^i}{l^i})K^i(t)]^b,$$

$$\lim_{t\to\infty} \lambda_1(t)e^{-\rho t} = 0, \tag{6}$$

$$\lim_{t\to\infty} \lambda_2(t)e^{-\rho t} = 0, \tag{7}$$

$G(0) = G_0$, and $K^i(0) = K^i_0$. ρ denotes the rate at which the agent discounts future utility and $\log C^i(t)$ is the instantaneous utility function of the agent[7]. $\lambda_1(t)$ and $\lambda_2(t)$ are the costate variables associated with $K^i(t)$and $G(t)$ respectively.

Proposition 2 *The optimal tax rate for the ith agent will satisfy the following equations:*

$$\frac{\tau^i}{1-\tau^i} = \left(\frac{\alpha^i + \rho}{aA[\sigma^i a + (1-a)]}\right)^{\frac{1}{1-a}} \left(\frac{\alpha^i}{B}\right)^{\frac{1}{b}} \tag{KK}$$

$$\frac{\tau^i}{1-\tau^i} = \left(\frac{(1-a)b}{a}\right)\frac{\alpha^i}{\rho + \alpha^i} \tag{GG}$$

Proof: See the appendix. ■

The (KK) schedule gives the locus of $(\frac{\tau^i}{1-\tau^i}, \alpha^i)$ combinations along which the rate of growth of consumption demanded by the agent i is equal to the rate of growth of

[6]We find it convenient to express the aggregate capital stock of the economy as a function of the ith agent's endowment parameter σ^i. It follows from Proposition 1 that σ^i does not vary over time. Hence the aggregate capital stock of the economy $K(t) = (\frac{\sigma^i}{l^i})K^i(t)$. The income of the ith agent at any instant t after some manipulations can be written as a function of aggregate output, that is, $Y^i(t) = Y(t)[a + (1-a)/\sigma^i]l^i$.

[7]The results we derive will hold for the whole class of utility functions with constant elasticity of marginal utility.

infrastructure. Notice, that the form of this relationship depends on the ith agent's endowment parameter σ^i. The (KK) curve is only a partial characterization of the optimal balanced growth path since along this curve we have only considered the rate at which agents would want their consumption to grow. For overall optimum α_G too must be chosen similarly. This requirement gives rise to another locus of $(\frac{\tau^i}{1-\tau^i}, \alpha^i)$ combinations called the (GG) schedule. The (GG) curve is independant of σ^i. For a graphical illustration of the (KK) and (GG) schedules see Figure 1.

Proposition 3 *There exists a strictly positive and unique solution* $(\overline{\alpha}^i, \overline{\tau}^i)$ *to the ith agent's problem.*

Proof: See the appendix. ■

The (KK) curve must rotate towards right with a rise in σ^i. This means that a person with a higher σ^i will choose a higher $\frac{\tau^i}{1-\tau^i}$ and hence a higher α^i and τ^i (refer to Figure 1)[8]. Thus we have the following result.

Proposition 4 *The ideal value of* τ^i *is a monotone increasing function of* σ^i.

Proof: See the appendix. ■

Notice that in our model a higher tax rate on capital income is associated with a higher rate of growth contrary to the case in Alesina and Rodrik. This follows from the fact that in their model the only growth inducing instrument was capital. Consequently, taxation of capital income above the growth maximizing rate was a disincentive for saving given that the rate of return on savings was $r(t) - \tau$. This resulted in a lower rate of growth of capital and output. In our model however, the tax on capital income does not create such a distortionary effect. As we have already seen from the (KK) schedule, the overall rate of return on savings is in fact the rental rate of capital i.e., $r(t)$. Thus, a tax on capital income has no negative effect on growth. A perfect capitalist i.e., an agent with $\sigma^i = 0$ also prefers a strictly positive tax rate.

Proposition 5 *The preferences of agents are single peaked in tax rates*(τ^i).

Proof: See the appendix. ■

Proposition 5 says that each agent has a unique optimal tax rate. Deviation from

[8] A higher value of $\frac{\tau^i}{1-\tau^i}$ implies a higher value for τ^i as $\frac{\tau^i}{1-\tau^i}$ is a monotonic and increasing function of τ^i.

this optimal tax rate in any direction causes a decline in the level of the agent's welfare.

4 Policy Choice

Now let us see what the political equilibrium of the economy is going to be. To this effect we wish to make following comments:

(1) Suppose there are two political parties(P_1 and P_2) fighting an election at any point in time t. Each party has to choose a tax rate as its election stance. So the strategy set of each party is $S_1 = S_2 = [0, 1]$. Assume that both the parties are aware of the distribution of preferred policies of the agents in the economy. If the parties play a simultaneous move game where the objective of each party is to maximize the number of votes, then it is easy to show that $s_p^* = \tau^m$; $p = 1, 2$, is the unique Nash Equilibrium of this game, where τ^m is the preferred tax of the median voter.

(2) Suppose there are more than two (say N) political parties. The strategy set of each party $S_p = [0, 1] \; \forall \; p$. The parties choose tax rates ($s_p \in S_p$) simultaneously as their election stance. Assume that the choice over tax rate is made by a pairwise comparison under a majority voting rule. The Median Voter Theorem can be applied to this case because the preferences of agents are single peaked and there exists a monotonic relationship between agents' endowments and their preferred policies. The outcome of the majority voting will depend upon the preference of the median voter. Notice that this is the kind of voting procedure referred to by Alesina and Rodrik.

Thus under the above two kinds of election procedure, the economy's political choice of the tax rate will be the median voter's preferred tax rate. This will depend on the endowment parameter of the median voter σ^m.

Now if capital is distributed in a highly inegalitarian manner, the median voter's endowment parameter σ^i would be high. Thus, Proposition 4 implies that the median voter's choice of the tax rate would be high. This is shown in Figure 1, where KK^1 corresponds to σ_1^m and KK^2 corresponds to σ_2^m ($\sigma_1^m < \sigma_2^m$). In addition, since the ideal policies are constant over time and the distribution of factors is also time invariant, it does not matter whether voting takes place only once at time zero or is repeated every period.

In Alesina and Rodrik(1994) higher inequality in a society resulted in a more than desirable tax rate on capital dampening incentive for savings. This resulted in a lower rate of accumulation of capital and lower growth. Bertola too had derived a similar result. However, it has been empirically seen that higher tax on capital leads to higher rates of growth. Perotti (1996) has noted this fact in his cross-sectional study on tax rates and growth. A recent study by Uhlig & Yanagawa (1996) also shows the possibility of a higher capital income tax giving rise to a higher growth rate in an overlapping generations economy. In our model we reach a similar conclusion in the context of a dynastic set up.

5 Labor used in the production process of both the goods

In this section, we will study the preference of agents if unskilled labor was required in the production process of both the final good and infrastructure. The allocation of two factors across two sectors makes the analysis a bit more complicated but the results are similar to those derived in the previous sections.

Suppose that in addition to the tax on capital income the government also sets a tax on unskilled labor[9]. The government sets a proportion of labor hours, which have to be contributed by all agents for the production of infrastructure. The production functions of Y and G now are,

$$Y = AK_Y(t)^a[G(t)(1-\phi(t))]^{1-a} \tag{8}$$

and

$$\frac{dG(t)}{dt} = BK_G(t)^b[G(t)\phi(t)]^{1-b}, \tag{9}$$

where ϕ is the tax rate on labor. From the above equations, we can interpret that infrastructure clubs with labor to increase the efficiency units of labor[10]. In order to

[9]In a perfect foresight competitive equilibrium, the agents would voluntarily want to utilize a part of their labor in the production of infrastructure.

[10]We now have a model very similar to Rebelo (1991). The interpretation of effective units of labor is a bit different though, as all agents get the same benefit from infrastructure in terms of scaling up his efficiency units of labor. The exponents of labor has been set in this manner to simplify the algebra.

calculate the preferred choice of tax policy of the ith agent, a similar exercise (like the one in section 3) is carried out. We maximize (4) subject to

$$\frac{dK^i(t)}{dt} = r(t)[1-\tau^i(t)]K^i(t) + w(t)[1-\phi^i(t)]l^i - C^i(t), \tag{10}$$

(9), $K^i(0) = K_0^i$ and $G(0) = G_0$. Along the balance growth path, C^i, K^i, K and G grow at the same rate and the tax rates ϕ and τ are constant.

Now, an optimal allocation of both labor and capital has to made between the two sectors. In an efficient allocation for agent i, the loss in income due to any tax is equal to the gain in income arising from an increase in infrastructure, at the margin. These conditions are,

$$\lambda_1(t)r(t)K^i(t) = \lambda_2(t)Bb[G(t)\phi^i]^{1-b}[\tau^i K(t)]^b \frac{1}{\tau^i}, \tag{11}$$

and

$$\lambda_1(t)w(t)l^i = \lambda_2(t)B(1-b)[G(t)\phi^i]^{1-b}(\tau^i K(t))^b \frac{1}{\phi^i}. \tag{12}$$

Eliminating λ_1 and λ_2 from (11) and (12) yields

$$\frac{(1-a)}{a}\frac{1-\tau^i}{1-\phi^i} = \frac{1-b}{b}\frac{\tau^i}{\phi^i\sigma^i} \ . \tag{13}$$

The other efficiency condition is dynamic in nature. It is regarding the decision to invest in capital or infrastructure. A new unit of capital is worth its net marginal product in Y sector:

$$r = Aa[\frac{(1-\tau^i)K(t)}{(1-\phi^i)G(t)}]^{a-1} \tag{14}$$

An alternative to investing in one more unit of capital is to accumulate $1/p(t)$ units of infrastructure, where $p(t)$[11] is the relative value of infrastructure with respect to capital.

An additional unit of infrastructure increases the efficiency units of labor and its net return valued in terms of capital is,

[11] $p(t) = \frac{\lambda_2(t)}{\lambda_1(t)}$

$$r^* = B(1-b)[\frac{\tau^i K(t)}{\phi^i G(t)}]^b + \frac{dp(t)/dt}{p(t)} \ . \tag{15}$$

At optimum, the two rates of returns have to be the same. $p(t)$ is constant given (K/g) is a constant. Thus $r = r^*$ implies

$$Aa[\frac{(1-\tau^i)K(t)}{(1-\phi^i)G(t)}]^{a-1} = B(1-b)[\frac{\tau^i K(t)}{\phi^i G(t)}]^b \ . \tag{16}$$

Substituting (13) in (16) we get

$$\frac{(1-\tau^i)K(t)}{(1-\phi^i)G(t)} = [\frac{aA}{(1-b)B}\frac{1}{\eta^b}]^x[\frac{1}{\sigma^i}]^b x, \tag{17}$$

where $\eta = \frac{(1-a)b}{(1-b)a}$ and $x = \frac{1}{b-a+1}$.

A person with lower endowment of capital would therefore prefer lower $\frac{(1-\tau^i)K(t)}{(1-\phi^i)g(t)}$ ratio in Y sector which would imply a higher rate of return on capital. The rate of growth preferred by the ith agent is

$$\alpha^i = \frac{aA^{1-x}}{(1-b)B^x}\eta^{b(1-a)x}\sigma^{ib(1-a)x} - \rho \ . \tag{18}$$

Agents with lower endowment of capital prefer higher growth rates. The intuition for this is fairly simple. Consider an agent with negligible amount of capital. He would prefer higher capital tax viz a viz tax on labor to attain growth. This would imply a higher "efficiency units of labor" to capital ratio in the Y-sector and higher rate of return on capital, thus higher growth.

If voting takes place only regarding the choice of growth rates then, it is clear that economies with higher inequality in distribution of capital (i.e., higher σ^m) would choose a higher rate of growth. However, growth can be achieved by choice of a combination of taxes (τ, ϕ). If voting takes place over this (τ, ϕ) plane, the outcome is not easy to predict[12]. The standard Median Voter Theorem does not hold for voting on two variables.

In cases where voting takes place over the (τ, ϕ) plane, there may be cases where the economy ends up choosing tax and growth rates which are not in keeping with the median voter's preferences. Such an outcome however would be a result of certain flaws in the political choice process.

[12]Restrictions on preferences would be needed for the Median Voter Theorem to hold in multidimensional voting problems.

6 Conclusion

This paper has attempted to demonstrate that the inequality in the distribution of factor endowments does not constrain growth as long as the tax revenues are invested in a growth inducing instrument. In fact, we find that higher inequality in the distribution of capital leads to a higher rate of growth. Even when labor is required for the production of infrastructure, we have seen that agents with lower endowment of capital prefer higher growth rates.

However, we observe that in reality democratic societies with high inequality can grow at low rates. Casual empiricism suggests at least two explanations for it. First, in a country like India, a large fraction of the population living below poverty has a high demand for government provided free lunches. This forces the government to opt for the Alesina and Rodrik, Barro variety of flow infrastructure only. In this situation, the Alesina and Rodrik result could apply as government services only has level effects and no growth effect.

We have noted that in case voting decisions take place over two dimensions, the outcome of the voting cannot be predicted using the Median Voter Theorem. The outcome of the political process in such a scenario may lead to lower rates of growth than preferred by the majority of the population. There may also be other institutional factors responsible for retarding growth. It has been seen that in societies with high inequality of income distribution, the institutions tend to be underdeveloped in terms of both their efficiency as well as accountability. The Politics of such countries also come under severe pressure from the rich capitalist lobbies, to adopt policies to suit their vested interests. Also, the poorer section of the population typically tend to be unorganized and uninformed, compared to their capital rich counterparts. This would imply in turn that the model of democracy in countries such as India does not fall within the purview of the Median Voter Theorem. Barro(1999), in his empirical study finds that higher inequality tends to harm growth in poorer economies while in richer economies higher inequality leads to higher rate of growth[13]. This suggests that in an underdeveloped economy with high inequality, the richer section of the society is able to circumvent the democratic process quite easily.

[13]In Barro(1999) economies with per capita income above 2070(1985 dollars) show a positive relationship between inequality and growth.

However, it would be erroneous to conclude that these economies show sluggish growth because the median voter prefers policies to which lead to lower rate of growth.

Appendix

Proof of Proposition 1:

Given the sequence of wages $w(t)$, taxes $\tau(t)$ and rentals $r(t)$ the ith agent solves the following problem:

$$\max U^i = \int_0^\infty \log C^i(t) e^{-\rho t} dt$$

subject to:

$$\frac{dK^i(t)}{dt} = r(t)[1-\tau(t)]K^i(t) + w(t)l^i - C^i(t) \tag{19}$$

$$r(t) = aA\left(\frac{G(t)}{(1-\tau(t))K(t)}\right)^{1-a} \tag{20}$$

$$w(t) = (1-a)AG(t)^{1-a}[(1-\tau(t))K(t)]^a \tag{21}$$

$$\lim_{t\to\infty} \widetilde{\lambda}_1(t)e^{-\rho t} = 0 \tag{TC}$$

$$K^i(0) = K_0^i$$

where ρ denotes the rate at which the agent discounts future utility and $\log C^i(t)$ is the instantaneous utility function of the agent. The control variables for the agent is $C^i(t)$ the state variable is $K^i(t)$. $\widetilde{\lambda}_1(t)$ denotes the costate variable associated with $K^i(t)$. The current value Hamiltonian of the ith agent is

$$H^i(t) = \log C^i(t) + \widetilde{\lambda}_1(t)[r(t)(1-\tau^i(t))K^i(t) + w(t)l^i - C^i(t)],$$

where $\widetilde{\lambda}_1(t)$ is the costate variables associated with $K^i(t)$. The necessary condition for optimum with respect to consumption is

$$\partial H^i(t)/\partial C^i(t) = 0 \text{ or } \widetilde{\lambda}_1(t) = 1/C^i(t).$$

Taking total derivatives and rearranging we get the following relationship between the rate of growth of consumption and the costate variable $\widetilde{\lambda}_1$:

$$-\frac{d\widetilde{\lambda}_1(t)/dt}{\widetilde{\lambda}_1(t)} = \frac{dC^i(t)/dt}{C^i(t)}.$$

Let α_{C^i} and $\alpha_{\widetilde{\lambda}_1}$ denote the rate of growth of C^i and $\widetilde{\lambda}_1$. The above condition can be written more comapctly as $-\alpha_{\widetilde{\lambda}_1} = \alpha_{C^i}$. First order condition with respect to $K^i(t)$ gives us

$$\frac{d\widetilde{\lambda}_1(t)}{dt} = \rho\widetilde{\lambda}_1(t) - \partial H^i(t)/\partial K^i(t),$$

or,

$$\alpha_{C^i} = r(t)[1-\tau(t)] - \rho.$$

Along balanced growth paths τ and α_{C^i} are constants. This implies $r(t) = r$ and $\tau(t) = \tau$ for all t. Thus, the rate of growth of consumption of every agent same regardless of his initial endowment of capital or σ^i. The transversality condition and the budget constraint imply that

$$\alpha_{C^i} = \alpha_{K^i} = r[1-\tau] - \rho.$$

where α_{K^i} denote the rates of growth of capital stock of the ith agent. If all agents accumulate capital at the same rate then the aggregate capital stock of the economy will be growing at the same rate i.e., $\alpha_K = \alpha_{K^i}$, where α_K denotes the rate of growth of capital stock of the economy. Constancy of r implies (K/G) ratio is constant over time. Hence $\alpha_K = \alpha_G$ along balanced growth paths where α_G denotes the rate of growth of infrastructure. From equation (1) it follows easily that the rate of growth of output $\alpha_Y = \alpha_G$. ■

Proof of Proposition 2:

The current value Hamiltonian for the ith agent's problem is

$$H^i(t) = \log C^i(t) + \lambda_1(t)[s^iY(t) - C^i(t)] + \lambda_2(t)[\frac{dG(t)}{dt}],$$

where $\lambda_1(t)$ and $\lambda_2(t)$ are the costate variables associated with $K^i(t)$and $G(t)$ and $s^i = [a+(1-a)/\sigma^i]l^i$. The necessary condition for optimum with respect to consumption yields $-\alpha_{\lambda_1} = \alpha_{C^i}$. First order condition with respect to τ^i gives us

$$\lambda_1(t)\frac{s^iaY(t)}{(1-\tau)} = \lambda_2(t)\frac{b(dG(t)/dt)}{\tau} \tag{22}$$

First order condition with respect to $K^i(t)$ is

$$\frac{d\lambda_1(t)}{dt} = \rho\lambda_1(t) - \partial H^i(t)/\partial K^i(t) \ .$$

Using (22) and the fact that $-\alpha_{\lambda_1} = \alpha_{C^i}$ we get,

$$\alpha_{C^i} = \frac{s^i a Y(t)}{(1-\tau^i)K^i(t)} - \rho.$$

We can simplify the above expression by substituting for s^i and writing $K^i(t)$ as $\frac{l^i}{\sigma^i}K(t)$. After necessary manipulations we get

$$\alpha_{C^i} = [a\sigma^i + (1-a)]r - \rho. \tag{23}$$

First order condition with respect to $G(t)$ gives us

$$\frac{d\lambda_2(t)}{dt} = \rho\lambda_2(t) - \partial H^i(t)/\partial G(t).$$

From equation (22) we can write the above condition as

$$\alpha_{\lambda_2} = \rho - \alpha_G \frac{(1-a)(1-\tau^i)}{a\tau^i} - (1-b)\alpha_G. \tag{24}$$

Taking total derivatives of (22) and dividing through to get rates of growth we get,

$$\alpha_{\lambda_2} = -\alpha_G. \tag{25}$$

Substituting in (24) we get

$$\frac{\tau^i}{1-\tau^i} = \left(\frac{(1-a)b}{a}\right)\frac{\alpha_G}{\rho+\alpha_G} \tag{26}$$

From equation (2), we have $\frac{\tau^i K(t)}{G(t)} = \left(\frac{\alpha_G}{B}\right)^{\frac{1}{b}}$ and from equation (23) we have $\frac{G(t)}{(1-\tau^i)K(t)} = \left(\frac{\alpha_{C^i}+\rho}{aA[\sigma^i a+(1-a)]}\right)^{\frac{1}{1-a}}$. Multiplying the above two equalities we get

$$\frac{\tau^i}{1-\tau^i} = \left(\frac{\alpha_{C^i}+\rho}{aA[\sigma^i a+(1-a)]}\right)^{\frac{1}{1-a}}\left(\frac{\alpha_G}{B}\right)^{\frac{1}{b}}. \tag{27}$$

Along balanced growth paths $\alpha_{C^i} = \alpha_G = \alpha^i$ therefore equations (26) and (27) reduce to our (GG) and (KK) schedules respectively. ■

Proof of Proposition 3:

Write the (KK) equation as

$$\frac{\tau^i}{1-\tau^i} = h(\alpha, \sigma^i)$$

where $h(\alpha,\sigma^i) = \left(\frac{\alpha+\rho}{aA[\sigma^i a+(1-a)]}\right)^{\frac{1}{1-a}} \left(\frac{\alpha}{B}\right)^{\frac{1}{b}}$. The function h is convex in α and exhibits following properties: $h(0,\sigma^i) = 0$. The first partial derivative with respect to α; $h_1(\alpha,\sigma^i) = h(\alpha,\sigma^i)[\frac{1}{(1-a)(\alpha+\rho)} + \frac{1}{b\alpha}]$. There fore $h_1(0,\sigma^i) = 0$. and The second partial derivative with respect to α; $h_{11}(\alpha,\sigma^i) = h(\alpha,\sigma^i)[(\frac{1}{(1-a)^2}-1)\frac{1}{(\alpha+\rho)^2} + (\frac{1}{b^2}-1)\frac{1}{\alpha^2} + \frac{2}{(\alpha+\rho)\alpha}] > 0$ since $(1-a)$ and b are less than 1. Hence $\lim_{\alpha\to\infty} h(\alpha,\sigma^i) = \infty$. Write the (GG) equation as

$$\frac{\tau^i}{1-\tau^i} = f(\alpha)$$

where $f(\alpha) = \left(\frac{(1-a)b}{a}\right)\frac{\alpha}{\rho+\alpha}$. The function f is concave in α and exhibits following properties: $f(0) = 0$, and $f^{'}(\alpha) = \left(\frac{(1-a)b}{a}\right)\frac{\rho}{(\rho+\alpha)^2}$. Therefore, $f^{'}(0) > 0$ and $\lim_{\alpha\to\infty} f^{'}(\alpha) = 0$. Define a new function $z(\alpha,\sigma^i)$

$$z(\alpha,\sigma^i) = f(\alpha) - h(\alpha,\sigma^i) \tag{28}$$

From the properties of functions f and h it follows that there exists an ϵ sufficiently small such that $z(\epsilon) > 0$. Also as $\alpha \to \infty$, $z(.) \to -\infty$. Since $z(.)$ is a continuous and strictly concave function, it follows from the Intermediate Value Theorem that there exists a unique $\overline{\alpha}^i > 0$ such that $z(\overline{\alpha}^i) = 0$, or, $f(\overline{\alpha}^i) = h(\overline{\alpha}^i, \sigma^i)$. Since $z(.)$ is a strictly concave function, it follows that $\overline{\alpha}^i$ is unique. The associated unique choice of $\overline{\tau}^i$ is established by plugging $\overline{\alpha}^i$ into (GG) or (KK) equation. Note that the pair $(\alpha^i = 0, \tau^i = 0)$ also solves the reduced form equations (KK) and (GG). However, for $\tau^i = 0$ does not constitute a maximum. Hence $(\alpha^i = 0, \tau^i = 0)$ does not qualify as a solution. ■

Proof of Proposition 4:

Notice the partial derivative of function $z()$ with respect to σ^i is $z_2(\alpha,\sigma^i) = -h_2(\alpha,\sigma^i) > 0$. Therefore the solution to $z(\alpha,\sigma^i) = 0$, $\overline{\alpha}(\sigma^i)$ is an increasing function of σ^i. ■

Proof of Proposition 5:

It is easy to check that $H^i(t)$ is strictly concave in $C^i(t)$ and $\tau^i(t)$, given $\lambda_1(t)$, $\lambda_2(t)$. Hence, by Cass(1965), the first order conditions characterize a unique optimal path provided the following transversality conditions hold. In the class of balanced growth paths there is only one solution $(\overline{\alpha}^i > 0)$ to the ith agent's problem. Hence, agent i's preferences are single peaked in τ^i. ■

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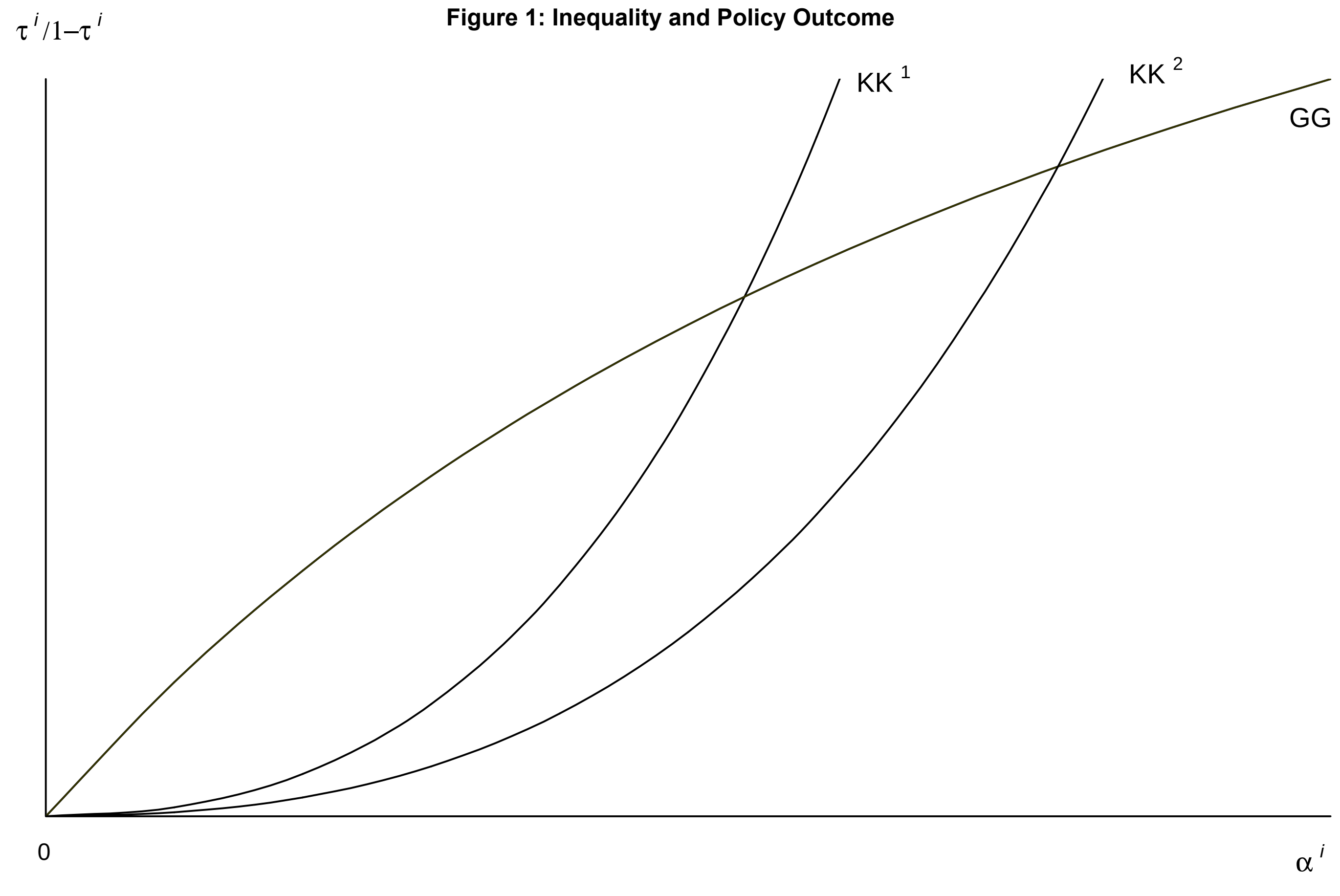
Figure 1: Inequality and Policy Outcome



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