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Effect of Population Density, Division and Distance on Regional Economic Growth

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Abstract

The three basic concepts which are fundamental to the framework of this study are the 3Ds –Density, Distance and Division. These Variables was introduced by World Development Report 2009.Population Density refers to the Population mass per unit of land area, or the geographic compactness of population. Distance refers to the ease or difficulty for goods, services, labor, capital, information, and ideas to traverse space. Distance, in this sense, is an economic concept, not just a physical one. Division is the most important dimension internationally. Religion, ethnicity, and language are among the main attributes that lead to divisions between places. Thus, the main aim of this paper is analysis of the effect of population density, economic distance and division on regional economic growth. For this aim, this study was proposed a simple theoretical framework to study the impact of population density, economic distance and division on regional economic growth. The framework has presented in a unified way the main insights of NEG models with endogenous growth and free capital mobility.

Keywords: Population Density, Division, Economic Distance

1- Introduction

The three basic concepts which are fundamental to the framework of this paper are the 3Ds– Density, Distance and Division. These Variables were introduced by World Development Report 2009.

Population Density refers to the Population mass per unit of land area, or the geographic compactness of population. The negative effects of

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population density are well known: less farmland per farmer and consumer, and more congestion. The positive effects of population density have been discussed less and studied almost not at all.

Higher population density to have dense social networks and institutions that would facilitates communication and exchange (Fingleton,2007), increases the size of markets and the scope for specialization and creates the required demand for innovation, all of which should promote the creation and diffusion of new technologies and economic growth(Klasen and Nestmann, 2006).

Population creates the need and ability to use a new technology. Assuming that a certain population density is necessary to generate the demand for technological change, this population density promotes technological change particularly for countries (or regional) with low levels of technology. Similarly, higher density increases returns to investments in public goods such basic infrastructure and these investments in turn could also work as catalysts for the rate of technological change. Once the basic infrastructure has been built, the effect of population density is concentrated largely on the diffusion process and less on the demand factors and the basic infrastructure necessary for efficient technological spillovers, which could account for the falling marginal returns from population density. Moreover, if population density becomes too high, the costs of selecting the right information increase, and this could lower the benefits of a faster knowledge transfer [Klasen and Nestmann, 2006; Simon 1977; Frederiksen, 1981].

Ideas and new discoveries drive growth in regional and stock of ideas is directly proportional to worldwide research effort which, in turn, is a function of total population of innovating areas (Jones, 2002).

These growth-enhancing effects of population density are not only theoretically plausible but are supported empirically. For example, Carlino et al (2004) show that patent intensity is positively related to the density of employment. If all else equal, a city with twice the employment density of another city, then it will exhibit a patent intensity that is 20 percent higher. Ciccone and Hall (1996) argue density can give rise to increasing returns in production due to the greater variety of intermediate products available. Simon (1977) and Frederiksen (1981) find population density has positive effect on building infrastructure.

Distance is another important concept for this paper. It refers to the ease or difficulty for goods, services, labor, capital, information, and ideas to traverse space. Distance, in this sense, is an economic concept, not just a physical one. Although economic distance is generally related to Euclidean distances between two locations. For trade in goods and services, distance captures time and monetary costs. The quality of transport infrastructure and the availability of transport can affect the economic distance between any two areas (World Development Report, 2009).

Economic theory also suggests that economic outcomes across regions will not be independent; the existence of inter-regional trade is considerable empirical support to this claim. Recent models of regional growth emphasize the important of technology and human capital spillovers (for example see Lucas (1990); Romer (1991); minerva and ottaviano (2009); martin and Baldwin (2004), etc). Economic distance is an important factor that affect on spillover between regions.

Conley and ligon (2002) decompose the spatial covariance function of growth rates into a function of each country's own observable characteristics, its unobservable characteristics, and cross-country spillover. They estimate relationship between economic distance and cross-country spillovers. Economic distance is very different for goods and physical capital and ideas. Transportation cost and communication cost use for transporting goods and ideas, respectively.

Division is the most important dimension internationally. Religion, ethnicity, and language are among the main attributes that lead to divisions between places. While divisions are greatest across nations, they can be considerable within countries as well (World Development Report, 2009).

The potential costs of diversity are clear. Conflict of preferences, racism, and prejudices often lead to policies that counterproductive for society as a whole. The oppression of minorities may lead to civil wars. The lack of communication stemming from linguistic diversity or social tensions could hinder the diffusion of ideas and technological innovation, which in turn adversely affects growth (Eris, 2010). Also the private and public allocation of physical and human capital based on ethnicity, race or social class rather than merit could lead to inefficiencies. But population diversity brings about variety in abilities, experiences, and cultures that may be productive and may lead to innovation and creativity (Alesina and Ferrara.2005). So, there is trade off between the benefits of diversity and the costs of heterogeneity of preferences in a diverse multiethnic society.

These effects of population diversity (Division) have been considered theoretically and empirically. For example, Levine (1997) argued that the public policy choices in ethnically fragmented societies are not economically optimal due to the conflict of preferences. Alesina et al. (2003) showed that ethnic and linguistic fragmentation measures have a negative impact on per capita growth. also Alesina and Ferrara (2005) showed that there is trade off between benefits and costs of population heterogeneity. Ratna et al (2009) examined the macroeconomic effects of social diversity in the United States. They found racial diversity reduces Gross State Product growth (GSP), while linguistic diversity raises GSP growth. Collier (2000) argued that the level of democratization shapes the effect of ethnic diversity on economic indicators. Ottaviano and Peri (2005) showed that linguistic diversity contributes positively to hourly wages and employment density of US natives. They argued that different skills originating from different cultures contribute to the productivity of native workers.

In spite of that there are some studies about 3D Variables and effects of these variables on economic growth but any study does not consider all of the three variables. Therefore, the main aim of this article is theoretical analysis of the effects of population density, economic distance and division on regional economic growth. For this aim, this study proposes a simple theoretical framework to study these three variables on regional economic growth. The framework has presented in a unified way of the main insights of NEG[1] models with endogenous growth and free capital mobility.

1- The NEG is an analytical framework initiated by Paul Krugman in early 1990s in order to explain the formation of a large variety of such economic agglomerations in geographical space, and has grown as one of the major branches of the spatial economics today. To date, the NEG remains to be the only general equilibrium framework (Fujita and mori, 2005).
There are four key terms for the (first-generation) NEG. The first is the general equilibrium modeling of an entire spatial economy. The second is increasing returns. Increasing returns in turn lead to the market structure characterized by imperfect competition. The third is transport costs, which makes location matter. Finally, the locational movement of productive factors and consumers is a prerequisite for agglomeration. but the first-generation models of the NEG are essentially static: once the economy reaches an equilibrium, no further change occurs in the economy unless parameters are exogenously varied. In other words, first-generation models do not account for the possible impact of agglomeration on the rate of innovation, which in turn is likely to influence further the geographical distribution of economic activities and welfare. It is, therefore, essential to extend the NEG framework into a dynamic setting. So, invention sector enter to first generation models of the NEG and these models were been dynamic.

The remainder of this paper is organized as follow. Section 2 we design new model that include 3D variable on regional growth model. This model is contribution of this paper. Section 3 is conclusion.

2- The Theoretical Model

We follow Minerva and Ottaviano (2009) in modeling a spatial economy where long run growth is sustained by ongoing product innovation and knowledge spillovers.In this model study the impact of infrastructure (Distance) on economic growth. Our model has two different from Minerva and Ottaviano's model. First, we enter population density to their framework that we follow Klasen and Nestmann[1] (2006). Second, we enter division to Minerva and Ottaviano's model[2].

our framework has presented in the main insights of NEG models with endogenous growth and free capital mobility.

We assume that country has two regions, 1 and 2, with the same given number L of workers. Area (G) and initial Knowledge capital(W_0). Workers are geographically immobile and who perform the tasks of consumer, workers and researchers.

Knowledge capital (patent) is accumulated by research and development (R&D) laboratories and is freely mobile between regions. Laboratories finance their efforts by selling bonds to workers in a perfect interregional capital market and we call *r* (*t*) the riskless return on those bonds.

In this model, we assume that two group goods produce. One group is traditional goods (T) and another group is modern goods (M). One patent is required to start producing one modern good. Two regions are initial identical, so we focus on the region 1.

The utility of representative worker in region 1 is:

$$U^i = \int_0^\infty \log(M(t)^\alpha T(t)^{1-\alpha}) e^{-\rho t} dt \qquad (1)$$

In equation (1), T is traditional goods. it is the numeraire good and M is modern good that is composite good which following the frame work of

1- Klasen and Nestmann (2006) enter population density to endogenous growth model.

2- According to arguments of Eris(2010) and Ratna et al (2009) and Alesina and Ferrara (2005).

Dixit and Stiglitz (1977) is made up of a large number of differentiated products. where

$$M(t) = [\int_{i=0}^{N(t)} M_i(t)^{1-\frac{1}{\sigma}} di]^{\frac{1}{1-\frac{1}{\sigma}}} \quad (2)$$

the constant elasticity of substitution (CES) consumption basket of the different varieties of good . N is total number of modern goods(M) produced by region 1 and 2. $M_i(t)$ is the consumption of variety(modern good) i.

the value of total expenditure Y is:

$$Y = \int_{i=1}^{n} P_i M_i + \int_{j=n+1}^{N} P_j M_j + P_T T$$

Where, P_T is traditional goods price and P_i, P_j are modern goods price in region 1 and 2, respectively. n is number of varieties(modern) of good that made up in region1.

utility maximization subject to expenditure constraint implies that in

each period workers allocate a share $\alpha \in (0,1)$ of their individual expenditure Y(t) to the consumption of the modern good and the share 1-α to to the consumption of the traditional good (t). For any variety *i*, the result is individual demand:

$$M_i = \frac{p_i(t)^{-\sigma}}{P(t)^{1-\sigma}} \alpha Y(t) \quad (3)$$

$$T = (1-\alpha)Y(t)$$

where:

$$P(t) = [\int_{i=0}^{N(t)} p_i(t)^{1-\sigma} di]^{\frac{1}{1-\sigma}}$$

(4)is the exact price index associated with the CES consumption basket (2) and $\sigma > 1$ is both the own- and cross-price elasticity of demand(Minerva and ottaviano, 2009, Martin and Ottaviano (1999 , 2001).

If we maximize indirect intertemporal utility maximization subject to intertemporal budget according to a standard Euler equation, we have[1]:

$$\frac{\dot{Y}(t)}{Y(t)} = r(t) - \rho \qquad (5)$$

In Production side, The traditional good is produced under perfect competition and constant returns to scale labor is only input to produce traditional good. for simplifying, we assume that one unit input requirement is one unit of labor. Profit as a follow:

$$\pi = TR - TC = P_T T - WL = P_T L - WL$$

So the profit-maximizing price of T equals the wage. Traditional good is numeraire good, so its price normalizes to one. The common wage is also one.

We assume the traditional good is freely traded both between and within regions, which implies that its price and therefore its wage are the same in both regions.

The modern goods are produced in monopolistically competitive sector and increasing returns to scale due to fixed and variable costs. The supply of one unit of each variety requires the use of one patent (Fix cost) and λ units labor per unit of output (Variable cost).

This assumption with costless differential, this ensures that each firm will produce only it's own variety and will produce one and only one variety. So, global capital stock $W^T(t)$ determines the total number of varieties available in the economy (total number firms)[2].

Transportation costs are limitation for exchanging modern goods. These are modeled

in Samuelson (1954) and they are in the form of iceberg cost that absorb part of the quantity shipped: $\gamma_{11} > 1$ and $\gamma_{12} > 1$ units have to be shipped by a firm of region 1 for one unit to be received to a region1 and to a region 2

1- For extracting this equation, please see appendix

2- As knowledge capital is freely mobile, where varieties are actually produced is endogenously determined by the entry decisions of firms.

customer respectively. $\gamma_{22} > 1$, $\gamma_{21} > 1$ units have to be sent by a firm of region 2 for one unit to be delivered to consumer of region 2 and to a customer of region 1, respectively.

We follow from Minerva and ottaviano (2009) and assume that intra-regional transportation is better than interregional transportation and infrastructure of region 1 better than region 2. So, we have:

$$\gamma_{11} < \gamma_{22} < \gamma_{21} = \gamma_{12}$$

By this assumption, region 1 identifies as the developed 'core' region and region 2 as the developing peripheral region.

As above say modern good is produced under monopolistic competition. Optimal pricing for each variety by producer's profit-maximizing is $p = \frac{w\lambda\sigma}{\sigma - 1}$ and operating profits are[1]:

$$\pi(t) = pH - w\lambda H = \frac{\lambda H(t)}{\sigma - 1} \tag{6}$$

Where H(t) is optimal output of a typical firm that is include quantity of output that absorbed by the iceberg frictions.

the consumer price ('delivered price') simply reflects different transport costs:

$$p_1 = p\gamma_{11}, p_2 = p\gamma_{22}, p_{12} = p\gamma_{12} \tag{7}$$

Finally, given (7), the price index (4) can be rewritten as:

$$P(t) = pN(t)^{\frac{1}{1-\sigma}} [(\gamma_{11})^{1-\sigma} \beta_t + (\gamma_{12})^{1-\sigma} (1 - \beta_t)]^{\frac{1}{1-\sigma}} \tag{8}$$

Where $\beta(t) = \frac{n(t)}{N(t)}$ is the share of firms of region 1 and $N(t) = W^T(t)$ is the global number of firms. The parameters $\theta_{11} = (\gamma_{11})^{1-\sigma}$ $\theta_{22} = (\gamma_{22})^{1-\sigma}$,

1 - For extracting this equation, please see appendix.

$\theta_{12} = (\gamma_{12})^{1-\sigma}$ measure the efficiency of transportation intra and inter regions respectively. They are between zero and one, and ranked $\theta_{11} > \theta_{22} > \theta_{12}$.

The innovation of new varieties is the source of growth in this model that is produced by research and development (R&D) sector. Innovation sector produce under perfect competition.

In the long run, you remember that ongoing innovation is sustained by knowledge spillovers that increase the productivity of researchers as knowledge accumulates.

A general specification of the R&D production function (technology) is as follow:

$$\dot{W}(t) = A(t)[\frac{M(t)}{\varepsilon}]^{\varepsilon}[\frac{L_I}{1-\varepsilon}]^{1-\varepsilon} \tag{9}$$

In equation (9), $\dot{W}(t) = \frac{dW}{dt}$ is the flow of knowledge created at time, L_I is researcher in R&D sector, and M(t) is the basket of modern goods. Existence of modern goods in R&D production function implies that cumulative agglomeration process will be generate in this way when capital movement occur. This will enable us to equlibria core-periphery. $0 < \varepsilon < 1$ is the share of modern good in R&D production.

The term A(t) is total factor productivity in R&D, which is affected by knowledge spillovers.

$$A(t) = Ad^{\omega} w^{T}(t)^{\mu}[(1-w^{1}_{11})\beta + (1-w^{1}_{12})(1-\beta)]^{\mu} \quad \text{We}$$
$$[(1+w^{2}_{11})\beta + (1+w^{2}_{12})(1-\beta)]^{\mu} \tag{10}$$

where A is a positive constant. A(t) is an increasing function of the global stock of knowledge $w^{T}(t)$. The positive parameter μ measures the intensity of the knowledge spillover and ω is positive parameter that shows elasticity of technology to population density. The diffusion of knowledge is limited by communication costs and population division. The communication cost presents with w^1 and population division with w^2 the w^1 are positive and smaller than one: $(1-w^{1}_{11})$ measures the knowledge diffusion from firms of region 1 to laboratories of region 1, and $(1-w^{1}_{12})$ the knowledge diffusion from firms of region 2 to laboratories of region 1 that limit with communication costs. Region that has larger (1-w's), it have the better communication infrastructure. As in the case of transportation, we assume that communication is more efficient intra-regions than inter-regions and region 1is better than region2:

$$w^1{}_{12} < w^1{}_{22} < w^1{}_{22}$$

Also, $(1+w^2{}_{11})$ and $(1+w^2{}_{12})$ measure the knowledge diffusion from firms of region 1 to laboratories of region 1, and $(1+w^2{}_{12})$ the knowledge diffusion from firms of region 2 to laboratories of region 1 that limit or promote by population division. $w^2{}_{11}$ and $w^2{}_{12}$ can positive or negative.

We can obtain cost function of innovation sector by using production function and duality proposition. The marginal cost associated with the R&D technology (10) is equal [1]to:

$$S(t) = \frac{P(t)^{\varepsilon} w^{1-\varepsilon}}{A(t)}$$

$$= \frac{\eta}{N(t)d^{\omega}[(1-w^1{}_{11})\beta + (1-w^1{}_{12})(1-\beta)]^{1-\frac{\varepsilon}{\sigma-1}}[(1+w^2{}_{11})\beta + (1+w^2{}_{12})(1-\beta)]^{1-\frac{\varepsilon}{\sigma-1}}[(\gamma_{11})^{1-\sigma}\beta(t) + (\gamma_{12})^{1-\sigma}(1-\beta(t))]^{\frac{\varepsilon}{\sigma-1}}} \quad (11)$$

Where $\eta = \dfrac{P^{\varepsilon}}{A}$ a positive constant and equilibrium wage is equals one. Equation (11) implies that the cost of innovation depends on the number of past innovations (N) so that a learning curve exists. We have also constrained parameters so that in the long run

The spatial economy develops along a balanced growth path, namely[2] $\mu + \dfrac{\varepsilon}{1-\sigma} = 1$

Assumption on w11's and θ 's, (11) implies that the marginal cost of innovation is lower in region 1. Therefore in equilibrium the region 1 will

1- For extracting this equation, please see appendix.

2- As shown in lucas (1988), endogenous growth models generate constant steady state growth rate only under Knife-edge assumption on parameters. Our assumption on μ is just an example of this (martin and ottaviano, 2001).

attract all laboratories, so that long-run growth will be entirely driven by innovation of region 1.

The value of patent is the value of firm which it use this patent. So, net present value of profit of a firm is:

$$v = \int_t^{\infty} e^{-(R(s)-R(t))} \frac{\beta x(s)}{\sigma - 1} ds \qquad (12)$$

Where R(t) is cumulative discount factor. By differential equation (12), we have:

$$r(t) = \frac{\dot{v}(t)}{v(t)} + \frac{\pi(t)}{v(t)} \qquad (13)$$

This equation is arbitrage condition. This condition say the bond yield r(t) which consists of the percentage capital gain $\frac{\dot{v}(t)}{v(t)}$ and the percentage dividend $\frac{\pi(t)}{v(t)}$ as each unit of knowledge gives the right to the operating.

By maximizing profit under perfectly competitive laboratories, we have $v(t) = S(t)$.

In equilibrium the arbitrage condition (13) implies that all firms generate the same operating profits independently from their actual locations. By equation (7), that requires all firms should reach the same scale of output, H(t) , independently from their locations. by using (3) and (7), the market clearing conditions for firms of region 1 and region 2 can be written as[1]:

$$H(t) = \frac{P^{-\sigma}(\gamma_{11})^{1-\sigma}}{P(t)^{1-\sigma}}[\alpha Y(t)L + \varepsilon S(t)\dot{N}(t)] + \frac{P^{-\sigma}(\gamma_{12})^{1-\sigma}}{P^{*}(t)^{1-\sigma}}\alpha Y^{*}(t)L \qquad (14)$$

(15)

Where variables show with star use fo region 2.

1- For extracting this equation, please see appendix

We define the growth rate of knowledge capital as $g = \frac{\dot{W}^T(t)}{W^T(t)} = \frac{\dot{N}(t)}{N(t)}$.

Then, using $p = \frac{w\lambda\sigma}{\sigma - 1}$ and (8), the market clearing conditions (13) can be solved together to yield output scale:

$$H = \frac{(\sigma-1)}{\lambda\sigma} * \frac{2\alpha YL + \varepsilon SNg}{N} \qquad (16)$$

And locations of firms as follow:

$$\beta = \frac{1}{2} + \frac{1}{2} * \frac{\theta_{12}(\theta_{11} - \theta_{22})}{(\theta_{11} - \theta_{12})(\theta_{22} - \theta_{12})} + \frac{\theta_{11}\theta_{22} - \gamma^2{}_{12}}{(\theta_{11} - \theta_{12})(\theta_{22} - \theta_{12})}(\delta - \frac{1}{2}) \qquad (17)$$

where:

$$\delta = \frac{\alpha YL + \varepsilon SNg}{2\alpha YL + \varepsilon SNg}$$

δ is the share of modern sector expenditures accruing to firms of region 1. Since regions share the same initial endowments, we have also set $Y = Y^*$. Expression (17) shows that the region 1 hosts a larger number of firms because it is larger $\varepsilon SNg > 0$ and because it has a better intra-regional transport infrastructure $\gamma_{11} < \gamma_{22} < \gamma_{12}$. So, $\beta > \frac{1}{2}$

For characterizing the long-run growth of the economy, we focus on a balanced path along that expenditure as well as the growth rate is constant. Constant expenditure present with $\dot{Y} = 0$ so that (5) gives $r = \rho$. Given SN and β are constant in equation (11), (17), $\frac{\dot{v}}{v} = \frac{\dot{S}}{S} = -g$ which shows that the marginal cost (F) and the marginal benefits of innovation (v) both fall at the same constant rate. Then, by (6) and (17), the arbitrage condition (13) can be rewritten as[1]:

1- For extracting this equation, please see appendix.

$$\rho = -g + \frac{2\alpha YL + \varepsilon SNg}{\sigma SN} = \frac{2\alpha YL}{\sigma SN} - g(\frac{\sigma - \varepsilon}{\sigma}) \tag{18}$$

The model is closed if we impose the labor market clearing condition. The global endowment of labor 2L is fully employed in innovation $L_I = (1-\varepsilon)SNg$, in modern production $L_D = [\frac{(\sigma-1)}{\sigma}][2\alpha YL + \varepsilon SNg]$, and in traditional production. $L_Y = 2(1-\alpha)YL$. Simplification leads to the full employment condition:

$$2L = \frac{\sigma - \varepsilon}{\sigma} SNg + 2\frac{\sigma - \alpha}{\sigma} YL \tag{19}$$

Solving (18) together with (19) shows that in equilibrium expenditure equals permanent income:

$$2YL = 2L + \rho SN \tag{20}$$

Where 2L is labor income and ρSN is the additional income from the initial stock of knowledge capital. By (18) or (19) the corresponding growth rate is:

$$g = \frac{\alpha}{\sigma - \varepsilon} * \frac{2L}{SN} - \rho \frac{\sigma - \alpha}{\sigma - \varepsilon} \tag{21}$$

which shows that location affects growth through the cost of innovation *FN*.

by substituting (11) into(21) which allows us to write growth as function of location[1]:

$$g = \frac{\alpha}{\sigma-\varepsilon} * \frac{2Ld^{\varpi}}{\eta}[(1-w^{1}11)\beta + (1-w^{1}12)(1-\beta)]^{1-\frac{\varepsilon}{\sigma-1}}[(1+w^{2}11)\beta + (1+w^{2}12)(1-\beta)]^{1-\frac{\varepsilon}{\sigma-1}}[(\gamma_{11})^{1-\sigma}\beta(t) + (\gamma_{12})^{1-\sigma}(1-\beta(t))]^{\frac{\varepsilon}{\sigma-1}} - \rho\frac{\sigma-\alpha}{\sigma-\varepsilon} \tag{22}$$

1- For extracting this equation, please see appendix.

Equation (22) shows that population density (d), economic distance ($w^1_{11}, w^1_{12}, \gamma_{11}, \gamma_{12}$) , division ($w^2_{11}, w^2_{12}$) and location ($\beta(t)$)affect on economic growth.

Conclusion

Recognition of factors that effect on regional growth is very important because this helps regional economic planner to regulate socio-economic development plans and allocate resource so that decreasing unbalance and gap between regions. one of the important factors is Economic-Geographic factor. This factor shows strength, weakness, opportunity and threat points of each region. Density, Distance and Division are Economic-Geographic variables. So, economic planners should pay attention about these variables.

Therefore, We have proposed a theoretical framework to show and to study the impact of population density, economic distance and division on economic growth. The framework has presented within NEG models with endogenous growth and free capital mobility.

We develop Minerva and ottaviano (2009)'s model and enter population density and population division in their model.

The growth equation (22) shows that population density, economic distance and population division have effect on economic growth.

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Appendix

Equation (5): $\frac{\dot{Y}(t)}{Y(t)} = r(t) - \rho$

we set equation(3) into (1) and obtain indirect utility function:

$$v^i = \int_0^\infty \log(\alpha y^i(t)P(t))^\alpha ((1-\alpha)y^i(t))^{1-\alpha} e^{-\rho t} dt$$

In temporal budget constrain is:

$$\int_0^\infty y^i(t)e^{-\bar{r}(\tau)t} d\tau = a^i + W^i$$

$$W^i = \int_0^\infty e^{-\bar{r}(t)t} w^i(t)dt$$

$$\bar{r}(t) = \frac{1}{t}\int_0^t r(t)dt$$

We maximize indirect utility function with respect to intemporal budget constrain. So we have:

$$\frac{\dot{y}(t)}{y(t)} = r(t) - \rho$$

If we consider all of consumer then we have:

$$\frac{\dot{Y}(t)}{Y(t)} = r(t) - \rho$$

Equation (6): $p = \frac{P_L \lambda \sigma}{\sigma - 1}$

If marginal cost (MC) equal marginal revenue(MR) then we have maximum profit in monopoly market($MC = P_L \lambda$ and $MR = P(1 - \frac{1}{\sigma})$).so we have: $P_L \lambda = P(1 - \frac{1}{\sigma}) \Rightarrow p = \frac{P_L \lambda \sigma}{\sigma - 1}$

Equation (8): $P(t) = pN(t)^{\frac{1}{1-\sigma}}[(\gamma_{11})^{1-\sigma}\beta_t + (\gamma_{12})^{1-\sigma}(1-\beta_t)]^{\frac{1}{1-\sigma}}$

$P(t)$ is price index of modern goods that is $P(t) = [\int_{i=0}^{N(t)} p_i(t)^{1-\sigma} di]^{\frac{1}{1-\sigma}}$ .N(t), n(t) and N(t)-n(t) are number of total modern goods that made up in both regions, region (1) and region (2) , respectively. $p_N = p\tau_N, p_S = p\tau_S$ are goods price in region 1 and 2, respectively.

we put goods price in region 1 and 2 into $P(t) = [\int_{i=0}^{N(t)} p_i(t)^{1-\sigma} di]^{\frac{1}{1-\sigma}}$ and compute this integral. So we can obtain

$$P(t) = pN(t)^{\frac{1}{1-\sigma}}[(\gamma_{11})^{1-\sigma}\beta_t + (\gamma_{12})^{1-\sigma}(1-\beta_t)]^{\frac{1}{1-\sigma}}.$$

Equation (11):

$$S(t) = \frac{P(t)^{\varepsilon} w^{1-\varepsilon}}{A(t)}$$

$$= \frac{\eta}{N(t)d^{\omega}[(1-w_{11}^1)\beta + (1-w_{12}^1)(1-\beta)]^{1-\frac{\varepsilon}{\sigma-1}}[(1+w_{11}^2)\beta + (1+w_{12}^2)(1-\beta)]^{1-\frac{\varepsilon}{\sigma-1}}[(\gamma_{11})^{1-\sigma}\beta(t) + (\gamma_{12})^{1-\sigma}(1-\beta(t))]^{\frac{\varepsilon}{\sigma-1}}}$$

$\dot{W}(t) = A(t)[\frac{M(t)}{\varepsilon}]^{\varepsilon}[\frac{L_I}{1-\varepsilon}]^{1-\varepsilon}$ is R&D production function. We use duality theorem and obtain cost function, so we have:

$$TC = A(t)^{-1}[pN(t)^{\frac{1}{1-\sigma}}[(\gamma_{11})^{1-\sigma}\beta_t + (\gamma_{12})^{1-\sigma}(1-\beta_t)]^{\frac{1}{1-\sigma}}]^{\varepsilon}(1)^{1-\varepsilon}K(t)$$

We drive TC with respect to N(t) and obtain marginal cost

$$S(t) = MC = \frac{p^{\varepsilon}N(t)^{\frac{\varepsilon}{1-\sigma}}[(\gamma_{11})^{1-\sigma}\beta_t + (\gamma_{12})^{1-\sigma}(1-\beta_t)]^{\frac{\varepsilon}{1-\sigma}}}{Ad^{\omega}N(t)^{\mu}[(1-w_{11}^1)\beta + (1-w_{12}^1)(1-\beta)]^{\mu}[(1+w_{11}^2)\beta + (1+w_{12}^2)(1-\beta)]^{\mu}}$$

We take $\mu + \frac{\varepsilon}{1-\sigma} = 1$ and $\eta = \frac{P^{\varepsilon}}{A}$. So we can obtain equation 12.

Equation (13): $r(t) = \frac{\dot{v}(t)}{v(t)} + \frac{\pi(t)}{v(t)}$

We take differentiation from $v = \int_t^{\infty} e^{-(R(s)-R(t))} \frac{\lambda H(s)}{\sigma - 1} ds$ (we can use Laybnets Formula) and obtain equation 14.

Equation (14):

$$H(t) = \frac{P^{-\sigma}(\gamma_{11})^{1-\sigma}}{P(t)^{1-\sigma}}[\alpha Y(t)L + \varepsilon S(t)\dot{N}(t)] + \frac{P^{-\sigma}(\gamma_{12})^{1-\sigma}}{P^{*}(t)^{1-\sigma}}\alpha Y^{*}(t)L$$

$H(t)$ is total modern goods demands.

$M_i = \frac{p_i(t)^{-\sigma}}{P(t)^{1-\sigma}}\alpha Y(t)$, $M^{*}i = \frac{p_i(t)^{-\sigma}}{P(t)^{1-\sigma}}\alpha Y^{*}E(t)$ are each consumer demands for modern goods in region (1) and (2), respectively (if each consumer demand multiples in size of population in each region then we can obtain total demands).

$p_i = p_1 = p\gamma_{11}$, $p_i = p_2 = p\gamma_{12}$ are modern goods price in region (1) and (2), respectively.

If we take differentiation from

$$TC = A(t)^{-1}[pN(t)^{\frac{1}{1-\sigma}}[(\gamma_{11})^{1-\sigma}\beta_t + (\gamma_{12})^{1-\sigma}(1-\beta_t)]^{\frac{1}{1-\sigma}}]^{\varepsilon}(1)^{1-\varepsilon}K(t)$$

With respect of modern price and obtain modern goods demand in R&D sector (we use shepard lema).

we plus total consumer demands of goods in region (1) ,(2) and R&D sector and find

$$H(t) = \frac{P^{-\sigma}(\gamma_{11})^{1-\sigma}}{P(t)^{1-\sigma}}[\alpha Y(t)L + \varepsilon S(t)\dot{N}(t)] + \frac{P^{-\sigma}(\gamma_{12})^{1-\sigma}}{P^{*}(t)^{1-\sigma}}\alpha Y^{*}(t)L$$

Equation (18): $\rho = -g + \frac{2\alpha YL + \varepsilon SNg}{\sigma SN} = \frac{2\alpha YL}{\sigma SN} - g(\frac{\sigma - \varepsilon}{\sigma})$

SN is constant in balanced growth path. So we have:

$$Ln(S) + Ln(N) = c \Rightarrow \frac{\dot{S}}{S} = -\frac{\dot{N}}{N} = -g$$

$v(t) = S(t)$. So we have:

$$\frac{\dot{S}}{S} = \frac{\dot{v}}{v} = \frac{\dot{N}}{N} = -g$$

if we consider $r(t) = \frac{\dot{v}(t)}{v(t)} + \frac{\pi(t)}{v(t)}$ (Arbitrage condition), $\pi(t) = \frac{\lambda H(t)}{\sigma - 1}, \dot{Y} = 0$ (because we are in balanced growth path), $H_M = \frac{(\sigma - 1)}{\lambda\sigma} * \frac{2\alpha YL + \varepsilon SNg}{N}$, $r = \rho$ and put these expression in $\frac{\dot{S}}{S} = \frac{\dot{v}}{v} = \frac{\dot{N}}{N} = -g$ then we obtain equation(20).

Equation (20): $2YL = 2L + \rho SN$

we can find g in equation 20, so we have: $g = \frac{\frac{2\alpha YL}{\sigma SN} - \rho}{\frac{\sigma - \varepsilon}{\sigma}}$. If we set g in equation (21) then we obtain equation 22.