DIRECTED TECHNICAL CHANGE, TECHNOLOGY ADOPTION AND THE RESOURCE CURSE HYPOTHESIS

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Abstract:

This paper analyses the effect of asymmetry in factor endowments between resource-rich and resource-poor countries on equilibrium bias of technology development and adoption possibilities. First, we show that the bias in equilibrium technology in the resource-poor North is determined by its relative abundance of human capital and physical capital. Secondly, we show that the equilibrium bias in technology in the resource-abundant South is dependent positively (negatively) on the relative abundance (scarcity) of skilled (unskilled) labour and the relative abundance (scarcity) of physical (natural) capital in the North. This force is dampened by the relative scarcity of skilled labour and physical capital in the South. These forces drive wage inequality, high cost of capital and skill technology mismatch in the South, all of which are bad for growth. These effects cumulatively explain part of the observed differences in growth performance between resource-rich and resource-poor countries.

Keywords: directed technical change, directed technology adoption, human capital, natural capital, physical capital, North, South

JEL Classification: O31, O33, O41, Q33

1. Introduction

A number of empirical studies[1] over the past two decades or so have revealed the fact that resource-poor economies tend to outperform resource-rich economies in terms of growth (and ultimately economic development). The immediate conclusion from these studies is that resource abundance is an important determinant of economic development failure. This finding is quite surprising and is in stark contrast to the optimism with which countries have tended to welcome resource discoveries[2]. It is thus hard to explain what appears to be an empirical regularity from theoretical standpoint.

This notwithstanding, some theoretical explanations have been offered in the literature. In the existing theoretical literature, four channels of causation from natural resources abundance to poor economic performance have been identified. First, natural resources generate rents which lead to rapacious rent-seeking and increased corruption which

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1 See for instance Sachs and Warner (1995; 2001), Gylfason (2001), Gylfason and Zoega (2002) and Brunnschweiler and Bulte (2008). However, the findings of Brunnschweiler and Bulte did not support the existence of the resource curse.

2 Further, this finding is inconsistent with the *Monotonicity* property of production functions, all things being equal. According to this property, more inputs (including natural resources) are at least as good as less, and hence resource abundance should not decrease output (and ultimately its growth rate).

adversely affects long-run growth. On the contrary, resource-poor countries go into a virtuous economic cycle: they embark on manufacturing-driven growth earlier, pass through the demographic transition faster and adopt more open trade policies. This effect is referred to more broadly as the institutional/political economy impact of natural resources (Sala-i-Martin and Subramanian, 2003). Second, natural resource endowments expose countries to volatility, particularly in commodity prices, which could have an adverse impact on growth through an increase in uncertainty and macroeconomic instability. Third, natural resource endowment makes countries susceptible to Dutch Disease - the tendency for the real exchange rate to become overly appreciated in response to positive shocks – which leads to a contraction in the tradable sector. This effect, coupled with the belief that the tradable sectors, particularly manufacturing, are the engine of growth because of learning-by-doing and other positive externalities, leads to the conclusion that natural resource abundance exerts a drag on long-run growth. Finally, it has been shown that natural resource abundance harms long-run growth through its negative effect on education and hence human capital accumulation.

Although all the above points could be potential channels of transmission through which the curse of natural resources manifests itself, they do not make a complete explanation of the curse. The objective of this paper is to offer a theoretical explanation of the resource curse hypothesis using the directed technical change modelling framework of Acemoglu (2002) that will complement the existing theories in explaining the resource curse hypothesis. In particular, applying a North-South[3] perspective to this framework, we argue that the curse may be the result of skill/capital-biased technological change that makes technologies developed to suit the needs of the skilled/capital-abundant North inappropriate for the natural resource/unskilled labour-abundant South. This channel of transmission has become more relevant in explaining the curse of natural resources as it is evident that the direction of technical change over the last 60 years or so has been skilled-biased (Acemoglu, 1998; 2002). This coupled with the lack of intellectual property right protection in Southern countries have made new technologies inappropriate for the South. That is, the lack of property rights protection in the South drives technological change in a direction that is not beneficial for the South. The reason is that the market for new technologies is limited to intermediate and final good producers in the North only. The Southern firms only imitate without paying. This then suggests that the South is partially responsible for its own poor growth record by not guarding intellectual property rights to a sufficient extent (see Acemoglu and Akcigit, 2012).

The literature that links natural resource abundance and the direction of technological change is not very expansive. Among the earlier literature on this subject are Di Maria and Valente (2008), Segal (2008) and Peretto and Valente (2011). Di Maria and Valente (2008) analysed a two-sector growth model (for a single economy) with directed technical change in which man-made capital and exhaustible resources are essential for production. In a setting in which the relative profitability of factor specific innovations endogenously determines whether technological progress is capital-augmenting or resource-augmenting, they show that convergence to balance growth implies zero capital-augmenting innovations: in the long run the economy exhibits purely resource-augmenting technological change.

3 Acemoglu and Zilibotti (2001), Gancia and Bonfiglioli (2008), Gancia and Zilibotti (2009), Afonso and Alves (2008), and Afonso (2012) also use the North-South framework to study the implications of technological change for cross-country productivity and/or wage inequalities.

Segal (2008) analysed the effect of endogenous directed technical change in a resource-rich economy using a three-by-three trade theory model. In his model, technological progress depends on entrepreneurs who either produce or adopt technology and who endogenously choose which sector to operate in. He showed that the static effect of a resource discovery is de-industrialization and a rise in non-resource factor incomes. According to Segal (2008), the dynamic effect is to exacerbate the de-industrialization over time, but unless the discovery is large enough, it leads to a lower growth in non-resource factor incomes which in the long run are lower than in the absence of the resource discovery.

More recently, Peretto and Valente (2011) analysed the relative growth performance of open economies in a two-country model where different endowments of labour and a natural resource generate asymmetric trade. In their setup, productivity growth in both countries is driven by endogenous innovations. The effect of a sudden increase in resource endowments depends crucially on the elasticity of substitution between resources and labour in the intermediates' production. They show that under substitution (complementarity), a resource boom generates higher (lower) resource income, lower (higher) employment in the resource intensive sector and higher (lower) knowledge creation and faster (slower) growth in the resource-rich economy. The resource poor economy, on the other hand, adjusts to the shock by increasing (reducing) the relative wage and experiences a positive (negative) growth effect that is exclusively due to trade.

The present paper differs from the previous literature in a number of ways. Whilst the existing literature emphasize on trade as the main mechanism through which resource abundance affect growth (as in Segal, 2008; Peretto and Valente, 2011), we emphasize on skill/capital biased technological change in the resource-poor North and its implication for adoption possibilities in the unskilled labour and natural resource-rich South. In particular, the North differs from the South in the following aspects: (i) the relative ability to undertake frontier innovations; (ii) the relative abundance of skilled labour (human capital); (iii) the relative abundance of natural resources (natural capital); (iv) and the degree of intellectual property rights protection. In what follows, we demonstrate how these differences between the two regions of the world interact with each other to explain differences in growth performance between resource-poor Northern countries and the resource-rich Southern countries.

Our analysis of the effect of asymmetry in factor endowments between resource-rich and resource-poor countries on the equilibrium bias of technology development and adoption possibilities revealed the following. First, we show that the bias in equilibrium technology in the resource-poor North is determined by its relative abundance of human capital and physical capital. Secondly, we show that the equilibrium bias in technology in the resource abundant South is dependent positively (negatively) on the relative abundance (scarcity) of skilled (unskilled) labour and the relative abundance (scarcity) of physical (natural) capital in the North. This force is damped by the relative scarcity of skilled labour and physical capital in the South.

Furthermore, we show that factor endowments of the North affect wage inequality in the South. Specifically, if the elasticity of substitution between the resource-sector and manufacturing sector in final good production is greater than one, then wage inequality in the South will decrease in the relative abundance of skilled labour and physical capital in the North. This is due to the resultant skill-technology mismatch in the South. However, this effect is reversed if the output of the resource and manufacturing sector are gross complements in final goods production. The own factor endowments effect on the skill premium is however ambiguous. For sufficiently low degree of international property rights protection, the relative abundance of unskilled labour increases wage inequality in the South. If the derived elasticity of substitution is larger than one, then the relative abundance of natural capital in the South increases wage inequality and slows down the growth rate of the economy.

With regards to the relative return to physical capital in the South, this variable decreases in the relative abundance of skilled labour and physical capital in the North provided that the derived elasticity of substitution is greater than one. However, the relative abundance of unskilled labour and natural capital increases the relative return to physical capital and slows down capital accumulation in the South and hence leads to poor growth. Last but not least, we show that relative profitability of adopting *manufacturing sector complementary* technology decreases in the relative abundance of skilled labour and physical capital in the North if the elasticity of substitution is larger than one. Also, the relative profitability of adopting *manufacturing sector complementary* technology is inversely related to the relative abundance of unskilled labour and natural capital in the South. This is as a result of a skill-technology mismatch. These findings cumulatively explain part of the observed growth differentials between resource-poor Northern countries and the resource-abundant Southern region.

The rest of the paper is organised as follows: Section 2 presents the basic model of directed technological change and the equilibrium of the North. Section 3 analyses the directed technology adoption possibilities in the resource-abundant South. Section 4 extends our baseline model to allow for trade in the outputs (inputs) of the manufacturing and resource (final goods) sectors between the North and the South while Section 5 concludes the paper.

2. The Baseline Model

The production sector of our model uses four inputs: two kinds of capital (physical *versus* natural) and two kinds of labour (skilled and unskilled). With the exception of natural capital, the other productive factors are owned by households. Natural capital is assumed to be under the control of the government. For simplicity, we assume that government distributes natural resource rent evenly to households in lump-sum. Other than this, there is no role for the government in our model.

2.1 The consumers

We assume that the North and the South have identical consumers with same preferences. We therefore adopt the usual representative household modelling approach. The economy is populated by infinitely-lived households who derive utility from consumption C and supply labour inelastically. Households are composed of two types of agents: highly-skilled workers, with aggregate supply of H and low-skilled workers, with aggregate supply of L. Assuming constant population, the utility function of the representative household is:

$$U(C)=\int_0^\infty \frac{C^{1-\theta}-1}{1-\theta}e^{-\rho t}dt, \tag{1}$$

where ρ is the rate of time preference and θ is the inverse of the intertemporal elasticity of substitution. To simplify notations, we supress the time argument in the utility function and will do so throughout as long as this causes no confusion. The output of the final goods is allocated between consumption, investment and research and development (R&D) expenditure. Thus, the aggregate resource constraint of the economy is;

$$Y \geq C + I + Z \,, \tag{2}$$

where Y is the aggregate output of the final goods sector, I is total investment and Z is total R&D expenditure. We also impose the usual no-Ponzi game condition, requiring the lifetime budget constraint of the representative consumer to be satisfied. More specifically, the representative household maximizes (1) subject to the following asset accumulation equation.

$$\dot{B} = rB + \gamma w_L L + (1-\gamma) w_H H + \tau - C \tag{3}$$

where B is the total household assets, r is the interest rate, γ is the share of low-skilled workers in the household, w_L is the wage for low-skilled workers (L) and w_H is the wage for high-skilled workers (H) and τ is the lump-sum resource rent paid to households by the government. The usual intertemporal utility maximization problem gives the standard consumption Euler equation in (4).

$$\frac{\dot{C}}{C} = \frac{1}{\theta}\left(r - \rho\right) \tag{4}$$

The expression in (4) is also the aggregate growth rate of the economy since at the steady state, aggregate output and consumption must grow at a common rate. Even in the absence of trade as we assume in this paper (until Section 4 where we allow for trade), the South and the North will have the same interest rate at the steady state and hence a common steady state growth rate.

2.2 Final and intermediate goods production

Following Copeland and Taylor (1994), Acemoglu (1998), Acemoglu and Zilibotti (2001), Gancia and Bonfiglioli (2008), Afonso and Alves (2008), and Afonso (2012), we adopt the North-South framework to analyse the effect of factor biased technological change and technology adoption. As in Acemoglu and Zilibotti (2001), Gancia and Bonfiglioli (2008), Gancia and Zilibotti (2009), Afonso and Alves (2008), and Afonso (2012), we divide the world into two regions: the North and the South. The North is developed and is capable of innovating at the world technology frontier. On the contrary, the South is less developed and incapable of innovating at the frontier although it can adopt technology that is developed in the North at a cost. Thus all the new technologies are developed in the North, the South only copies them since there is weak (no) intellectual property right protection in this part of the world.

We assume two sectors in both parts of the world: the resource sector and the manufacturing sector. The resource sector is labour and natural capital intensive whilst the manufacturing sector is human and man-made capital intensive. We further assume that the natural resource sector is relatively less important (in terms of its contribution to GDP) in the North but it is the dominant sector in terms of its contribution to GDP in the South. However, the manufacturing sector (hence forth the M-sector) constitutes the largest sector in the North. Additionally, we assume that all factors are in constant supply and machines depreciate fully after use. A key assumption that will play crucial role in this paper is that some machines can only complement the inputs in the resource sector (unskilled labour and natural capital) while some other machines can only complement the inputs in the manufacturing sector (human and physical capital). This implies that the relative productivity of technology depends on the sector in which it is used.

2.3 Optimal input-output choices by firms

In this section of the paper, we set up and solve the profit maximization problem facing final, intermediate and technology firms and derive the corresponding equilibrium conditions. Since the production functions for both the final good sector and the intermediate sectors have the same form in both regions of the world, the South also has equilibrium conditions similar to those we derive in this subsection. In our discussion in the rest of this section we omit any regional indexes so far as it causes no confusion (we will introduce such regional indexes from the next section on). In the rest of our discussion we also interpret R as *natural capital* and K as *physical or man-made capital. H* has the usual interpretation as human capital whilst L can rightfully be interpreted as raw/unskilled labour, as already indicated above. We use these terms and the previous definitions of these variables interchangeably in the rest of the paper.

2.3.1 Maximization problem for final goods producers

We begin our analysis here with production and maximization problem facing the firms in the final goods sector. The unique final goods are assumed to be produced with a CES production function of the form:

$$Y = \left[\varsigma_E Y_E^{\frac{\varepsilon-1}{\varepsilon}} + \varsigma_M Y_M^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{5}$$

where Y_E is the output of (input from) the resource sector (E-sector) and Y_M is the output (input) of the M-sector, ε is the elasticity of substitution between these two inputs in the production of the final goods. If $\varepsilon >$ (<) 1, then the outputs of the E-sector and the M-sector are gross substitutes (complements) in the production of the final goods. Also, ς_E and ς_M (with $\varsigma_M + \varsigma_E = 1$) are the distribution parameters that measure the relative importance of the two sectors in final goods production. Due to the asymmetry in the relative importance of the two sectors in the production of the final goods in the two regions of the world, the North and the South will have different values for the distribution parameters. Without loss of generality, we normalize the price of the final good at unit. This normalization implies:

$$\left[\varsigma_E^{\varepsilon} P_E^{1-\varepsilon} + \varsigma_M^{\varepsilon} P_M^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}} = 1,$$

where the left hand side is the unit cost of production.

The maximization problem facing final goods producers is:

$$\max \Pi = Y - P_E Y_E - P_M Y_M .$$

Taking the first order conditions and rearranging, we obtain the following expression for the relative price of the manufacturing sector

$$\frac{P_M}{P_E} = \frac{\varsigma_M}{\varsigma_E}\left[\frac{Y_M}{Y_E}\right]^{-\frac{1}{\varepsilon}}. \tag{6}$$

The expression in (6) is the usual relative inverse demand curve with a negative slope as expected.

2.3.2 Maximization problem of intermediate goods producers

We now move from the final output to intermediate input production. The output of the E-sector is produced with unskilled labour, natural capital and a continuum of labour and natural capital complementary machines x_E in the $(0, A_E]$ interval. We thus have the following production function for the *E*-sector.

$$Y_E = \frac{L^\alpha R^\beta}{1-\alpha-\beta}\int_0^{A_E} x_E(i)^{1-\alpha-\beta}\,di \tag{7}$$

Similarly, we write the production function for the M-sector as:

$$Y_M = \frac{H^\alpha K^\beta}{1-\alpha-\beta}\int_0^{A_M} x_M(i)^{1-\alpha-\beta}\,di. \tag{8}$$

Here, A_E and A_M capture the states of E-sector complementary and M-sector complementary technologies, respectively. E-sector complementary technologies increases the physical productivity of labour and natural capital and hence the output of the resource sector whereas M-sector complementary technologies increases the physical productivity of skilled workers and man-made capital and hence the output of the manufacturing sector.

The maximization problem facing the firms in the resource sector can be stated as:

$$\max P_E Y_E - w_L L - p_R R - \int_0^{A_E} q_E(i) x_E(i) di;$$

where p_R and q_E are the prices of natural capital (R) and E-sector (labour and natural capital) complementary machines, respectively. The first order conditions for maximization are:

$$\alpha\frac{P_E Y_E}{L} - w_L = 0 \tag{9}$$

$$\beta\frac{P_E Y_E}{R} - p_R = 0 \tag{10}$$

$$P_E L^\alpha R^\beta x_E(i)^{-(\alpha+\beta)} - q_E(i) = 0 \tag{11}$$

Equation (11) can be rearranged to obtain the demand for machine type *i* used in the resource sector as

$$x_E(i) = \left(\frac{P_E}{q_E(i)} L^\alpha R^\beta\right)^{\frac{1}{\alpha+\beta}} \tag{12}$$

As it is common in the literature on endogenous technological change (see for instance Aghion and Howitt 1992; 2009), we assume that each intermediate firm uses only one type of machine. Using this simplifying assumption, we combine (12) with (9) and (10) to derive the inverse demand functions for labour and natural capital inputs in the resource sector.

$$w_L = \frac{\alpha}{1-\alpha-\beta} P_E^{\frac{1}{\alpha+\beta}} q_E(i)^{-\frac{1-\alpha-\beta}{\alpha+\beta}} \left(\frac{L}{R}\right)^{-\frac{\beta}{\alpha+\beta}} \tag{13}$$

Similarly;

$$p_R = \frac{\beta}{1-\alpha-\beta} P_E^{\frac{1}{\alpha+\beta}} q_E(i)^{-\frac{1-\alpha-\beta}{\alpha+\beta}} \left(\frac{L}{R}\right)^{\frac{\alpha}{\alpha+\beta}} \tag{14}$$

We now turn to the maximization problem facing the intermediate firms in the manufacturing sector. The maximization problem is stated as follows:

$$\max \pi_m = P_M Y_M - w_H H - p_K K - \int_0^{A_M} q_M(i) x_M(i) di$$

Following the same procedure as in the resource sector we obtain the following expressions as factor demand functions for the manufacturing sector.

$$x_M(i) = \left(\frac{P_M}{q_M(i)} H^\alpha K^\beta\right)^{\frac{1}{\alpha+\beta}} \tag{15}$$

$$w_H = \frac{\alpha}{1-\alpha-\beta} P_M^{\frac{1}{\alpha+\beta}} q_M(i)^{-\frac{1-\alpha-\beta}{\alpha+\beta}} \left(\frac{H}{K}\right)^{-\frac{\beta}{\alpha+\beta}} \tag{16}$$

$$p_K = \frac{\beta}{1-\alpha-\beta} P_M^{\frac{1}{\alpha+\beta}} q_M(i)^{-\frac{1-\alpha-\beta}{\alpha+\beta}} \left(\frac{H}{K}\right)^{\frac{\alpha}{\alpha+\beta}} \tag{17}$$

2.3.3 Maximization problem facing innovators

As a final step, we consider the profit maximization problem facing innovators in the economy. The price of machines, *q(i)*, is chosen by the entrepreneur/innovator to maximize profits. Assume that the marginal costs of building a machine is the same across sectors and is given by χ. Each entrepreneur sells machines at the monopoly price by maximizing profit subject to the demand for machines. For the resource sector, we have the maximization problem as

$$\max x_E(i)[q_E(i) - \chi].$$

Substituting for $q_E(i)$ using Equation (11) we obtain the following expression for the price of the machines that is valid for the manufacturing sector as well.

$$q_E(i) = q_M(i) = \frac{\chi}{1-\alpha-\beta} \tag{18}$$

Following Acemoglu (2002), we set $\chi = 1 - \alpha - \beta$, which simplifies the notation without any loss of generality. This and the previous condition on machine prices in (18) imply that the profit maximizing price of machines is equal to one unit of the final goods.

2.4 Equilibrium conditions for the North

We now derive the equilibrium expressions under constant technology assumption. This assumption will be relaxed when we allow for endogenous technology in the next subsection. Using the profit maximizing prices of machines from (18) in (12) and (15), we obtain the following expressions for the demand for machines in the two sectors:

$$x_E(i) = \left(P_E L^{\alpha} R^{\beta}\right)^{\frac{1}{\alpha+\beta}}, \tag{19}$$

$$x_M(i) = \left(P_M H^{\alpha} K^{\beta}\right)^{\frac{1}{\alpha+\beta}}. \tag{20}$$

By substituting Equations (19) and (20) into (7) and (8), the production functions for the two intermediate sectors can also be rewritten as

$$Y_E = \frac{A_E}{1-\alpha-\beta}\left(P_E^{1-\alpha-\beta} L^{\alpha} R^{\beta}\right)^{\frac{1}{\alpha+\beta}}, \tag{21}$$

$$Y_M = \frac{A_M}{1-\alpha-\beta}\left(P_M^{1-\alpha-\beta} H^{\alpha} K^{\beta}\right)^{\frac{1}{\alpha+\beta}}. \tag{22}$$

Due to our choice of parameter values such that the machine price is unity, the inverse demand functions for *R, L, H* and *K* above boil down to

$$p_R = \frac{\beta}{1-\alpha-\beta} P_E^{\frac{1}{\alpha+\beta}} \left(\frac{L}{R}\right)^{\frac{\alpha}{\alpha+\beta}} \tag{23}$$

$$w_L = \frac{\alpha}{1-\alpha-\beta} P_E^{\frac{1}{\alpha+\beta}} \left(\frac{L}{R}\right)^{-\frac{\beta}{\alpha+\beta}} \tag{24}$$

$$w_H = \frac{\alpha}{1-\alpha-\beta} P_M^{\frac{1}{\alpha+\beta}} \left(\frac{H}{K}\right)^{-\frac{\beta}{\alpha+\beta}} \tag{25}$$

$$p_K = \frac{\beta}{1-\alpha-\beta} P_M^{\frac{1}{\alpha+\beta}} \left(\frac{H}{K}\right)^{\frac{\alpha}{\alpha+\beta}} \tag{26}$$

The profit of technology monopolist in the resource and manufacturing sectors respectively are:

$$\pi_E^* = (\alpha+\beta)\left(P_E\right)^{\frac{1}{\alpha+\beta}} L^{\frac{1}{\alpha+\beta}} R^{L^{\frac{1}{\alpha+\beta}}} \tag{27}$$

$$\pi_M^* = (\alpha+\beta)\left(P_M\right)^{\frac{1}{\alpha+\beta}} H^{\frac{1}{\alpha+\beta}} K^{L^{\frac{1}{\alpha+\beta}}} \tag{28}$$

Substituting Equations (21) and (22) into (6), we obtain the relative price of the manufacturing sector as:

$$\frac{P_M}{P_E} = \varsigma^{\frac{\varepsilon(\alpha+\beta)}{\sigma}} \left[\left(\frac{A_M}{A_E}\right)^{\alpha+\beta} \left(\frac{H}{L}\right)^{\alpha} \left(\frac{K}{R}\right)^{\beta}\right]^{-\frac{1}{\sigma}}, \tag{29}$$

where $\sigma = 1+(\varepsilon-1)(\alpha+\beta)$ is the derived elasticity of substitution between the inputs employed in the manufacturing sector and the resource sector (*i.e.* substitution between skilled and unskilled labour and substitution between physical and natural capital) and $\varsigma = \varsigma_M / \varsigma_E$. Note that $\sigma >$ (<) 1 if $\varepsilon >$ (<) 1 . The relative price of manufacturing output decreases in the relative abundance of human capital (*H/L*), the relative abundance of physical capital (*K/R*) and the relative bias of technology. However, this relationship between the relative price of the manufacturing output and relative supplies of factors may change when the bias in technology is endogenized.

We now turn to the examination of the relative factor returns. By combining Equations (24) and (25) and substituting Equation (29), the relative return on human capital (the skill premium) is

$$\frac{w_H}{w_L} = \varsigma^{\varepsilon/\sigma}\left(\frac{A_M}{A_E}\right)^{-\frac{1}{\sigma}}\left[\left(\frac{H}{L}\right)^{-\frac{\alpha+\beta\sigma}{(\alpha+\beta)}}\left(\frac{K}{R}\right)^{\frac{\beta(\sigma-1)}{(\alpha+\beta)}}\right]^{\frac{1}{\sigma}} \tag{30}$$

The relative supply of human capital makes the relative wage lower due to the usual substitution effect, given the state of technology and the relative supply of physical capital. The relative supply of physical capital, on the other hand, makes the relative wage higher (lower) if the production factors are gross substitutes (complements). The technological gap between the two sectors reduces wage inequality whiles the relative importance of the manufacturing sector in the production of the final good increases wage inequality.

Similarly, we compute the relative return of physical capital to natural capital by dividing Equation (26) by (23) and substituting Equation (29) into the resulting expression as

$$\frac{p_K}{p_R} = \left[(\varsigma)^{-\varepsilon}\left(\frac{A_M}{A_E}\right)\left(\frac{H}{L}\right)^{-\frac{\alpha(\sigma-1)}{(\alpha+\beta)}}\left(\frac{K}{R}\right)^{\frac{\alpha\sigma+\beta}{(\alpha+\beta)}}\right]^{-\frac{1}{\sigma}} \tag{31}$$

While the returns to both types of capital increase in the relative price of the manufacturing output, relative returns to physical capital increase in both the relative abundance of skill and natural capital. It is not surprising that the relative returns to human capital and man-made capital all increase in the relative price of the manufacturing output: both factors are employed by this sector, hence increase in relative price of the sector raises the demand for these inputs.

Finally we compute the relative profitability of innovators in the manufacturing sector by combining Equations (27) and (28) and substituting Equation (29) into the resulting expression for the relative profitability above, we obtain the expression in (32).

$$\frac{\pi_M^*}{\pi_E^*} = \varsigma^{\frac{\varepsilon}{\sigma}}\left(\frac{A_M}{A_E}\right)^{-\frac{1}{\sigma}}\left[\left(\frac{H}{L}\right)^{\alpha}\left(\frac{K}{R}\right)^{\beta}\right]^{\frac{(\sigma-1)}{(\alpha+\beta)\sigma}} \tag{32}$$

The relative profitability has three components, price effect, human capital effect, and natural capital effect. Profits are higher in the sector that has the higher relative price, which is captured in (32) by the A_M / A_E term. It is relatively profitable to innovate in the manufacturing sector if a region is richer in human and physical capital but poorer in labour and natural capital, given that $\sigma > 1$. It is this latter effect that generates the resource curse.

2.5 Directed technological change

Innovation takes the form of the introduction of new varieties of intermediate inputs which either complements low-skilled labour (*L*) and natural capital (*R*) or highly-skilled labour (*H*) and physical capital (*K*) but not both. According to the literature on endogenous growth, there are two alternative specifications of the innovation possibilities frontier that allow for steady state growth in the long run. These, as labelled by Ravera-Batiz and Romer (1991), are the lab equipment[4] (which involves only the final good being used in generating new innovations) and the knowledge-based R&D specifications. Following Acemoglu (2002; 2009), the innovations possibilities frontier – which determines how new machine varieties are developed – is assumed to take the lab-equipment specification form. The preference for the lab equipment specification of the innovations possibility frontier over the more popular knowledge-based R&D specification is due to its analytical tractability. Moreover, Acemoglu (2002) has shown that the two specifications yield similar conclusions with respect to the direction of technological change. One undesirable feature of the knowledge-based R&D specification is that it suffers from the severe scale effects by making the growth rate proportional to the number of scientists in the R&D sector. We thus specify the evolution of technologies that complement the resource and the manufacturing sectors over time according to the Equations of motion in (33):

$$\dot{A}_E = \lambda_E Z_E \quad \text{and} \quad \dot{A}_M = \lambda_M Z_M \, ; \tag{33}$$

where Z_E (Z_M) is the *R&D* expenditure directed at discovering a new E-sector (M-sector) augmenting machines. Thus, total *R&D* expenditure (*Z*) satisfies $Z = Z_E + Z_M$. To simplify our analysis, we assume that $\lambda_E = \lambda_M = \lambda$, *i.e.* the productivity of research is equal in both sectors. The value function of a technology monopolist that discovers one of these machines satisfies the following Hamilton-Jacobi-Bellman condition

$$rV_j(i) - \dot{V}_j(i) = \pi_j(i) \quad \text{for all } j = E, M.$$

The instantaneous profits for sector $j = E, M$ are given in (27) and (28), respectively, and *r* is the market interest rate. To simplify our notation we have dropped time arguments as before.

Along the balanced growth path (BGP), $\dot{V}_j(i) = 0$ and the interest rate is constant. This and free entry into the innovations sector implies the following:

$$V_E = \frac{\pi_E}{r} \quad \text{and} \quad V_M = \frac{\pi_M}{r}. \tag{34}$$

For the relative price to remain constant, A_E and A_M must grow at the same rate, which requires innovators to be indifferent between the sector in which they innovate. Thus, $V_E = V_M = \lambda$, which requires that $\pi_M = \pi_E$.

The free entry and BGP conditions together with Equation (32) combined with (29) imply the following relative value for the technology monopolist in the M-sector.

4 According to the lab equipment specification, as argued by Rivera-Batiz and Romer (1991), use the same inputs and in the same proportions as in the final goods sector. This then implies that the innovations are a direct function of the final goods.

$$\frac{V_M^*}{V_E^*}=\frac{\pi_M^*}{\pi_E^*}=\varsigma^{\frac{\varepsilon}{\sigma}}\left(\frac{A_M}{A_E}\right)^{-\frac{1}{\sigma}}\left[\left(\frac{H}{L}\right)^{\alpha}\left(\frac{K}{R}\right)^{\beta}\right]^{\frac{(\sigma-1)}{\sigma(\alpha+\beta)}} \tag{35}$$

The relative profitability of developing technologies that complement human and man-made capital and hence the manufacturing sector decreases in the relative equilibrium bias of skill complementary technologies. The effect of the relative abundance of human capital and natural capital on relative profitability depends on the size of the derived elasticity of substitution, σ. If this elasticity is greater than one, then the relative profitability increases in the relative abundance of human capital but decrease in the relative abundance of natural capital. However, if $\sigma < 1$, then this effect is reversed and relative profitability decreases in the relative abundance of human capital but increases in the relative abundance of natural capital.

Note that by our assumption the relative profitability is equal to one along the balanced growth path. This and the previous expression give the equilibrium relative bias of technology as:

$$\frac{A_M}{A_E}=\varsigma^{\varepsilon}\left[\left(\frac{H}{L}\right)^{\alpha}\left(\frac{K}{R}\right)^{\beta}\right]^{\frac{(\sigma-1)}{(\alpha+\beta)}} \tag{36}$$

The ratio determines the relative productivity of *M-sector* (human and physical capital) and *E-sector* (unskilled labour and natural capital) technologies, and will be the measure of *M-sector* bias of equilibrium technology in the Northern economy. This expression shows that the direction of technological change is endogenized and the relative bias of equilibrium technology is determined by the relative supply of human capital to raw labour and physical capital to natural capital. When $\sigma > 1$, (the factors used in the two intermediate sectors are gross substitutes), an increase in H/L will increase A_M / A_E , and hence the physical productivity of the human capital, for a given relative supply of natural to man-made capital. Also, for a given H/L, the relative bias of equilibrium technology increases in the relative abundance of physical capital, K/R if $\sigma > 1$. Since the North is rich in both human and physical capital by assumption, the direction of technological change will be biased towards the manufacturing sector. It is worth noting that the relative importance of the output of the manufacturing sector in final goods production makes equilibrium technology more biased towards the manufacturing sector. This effect is independent of the size of the elasticity of substitution between the two sectors in the production of the final goods.

On the other hand, when $\sigma < 1$, the endogenous bias in equilibrium technology will increase if H/L decreases or if R/K increases. Note that in this case the factors (H *vs.* L and K *vs.* R) are gross complements; hence technologies that complement human and physical capital are *E-sector biased* whereas technologies that complement raw labour and natural capital are *M-sector biased*.

To capture the implications of the endogenous bias in equilibrium technology, we now substitute the solution for A_M/A_E in (36) back into the equilibrium expressions above, to get the solutions in terms of exogenous constants. We begin by substituting (36) into Equation (30) to obtain the premium to human capital in (37).

$$\frac{w_H}{w_L}=\left(\frac{H}{L}\right)^{-1} \tag{37}$$

With the direction of technical change endogenous, the relative wage is inversely proportional to the relative supply of human capital. The relative supply of physical capital has no role in driving the relative wage schedule. Note also that the strong induced bias hypothesis (the possibility of the relative demand for a factor sloping upwards) of Acemoglu (2002, 2009) is completely wiped out with the augmentation of the model with two additional variables – physical and natural capital. Note that this conclusion is based on the fact that we have setup the model in such a way that the parameters in the production functions in the resource and manufacturing sectors are the same. The results may change if we allow the parameters to differ between the sectors. However, the algebra for such an approach will be more demanding.

Finally, we examine how the endogenous bias in technology affects the relative return on man-made capital. To do this, we substitute Equation (36) into Equation (31) to obtain (38).

$$\frac{p_K}{p_R} = \left(\frac{K}{R}\right)^{-1} \tag{38}$$

According to Equation (38), the relative return to physical capital is directly proportional to the relative abundance of natural capital. The implication of this is that scarcity of natural capital has damping effect on income inequality between owners of natural capital and physical capital. The consequence of this effect on the resource abundance South is obvious. We, however, defer such discussions to the next section.

3. The Resource-Abundant South

In this section, we extend the baseline model to incorporate technology adoption in the developing resource-abundant Southern countries and use it to explore an alternative theoretical explanation of the natural resource curse hypothesis. From this section on, we use superscript N (S) to distinguish the North (South) from the South (North). Since by our assumption the natural resource sector is relatively more important in the South in terms of contribution to GDP, we assume that the distribution parameters in the CES function in Equation (5) take different values in the two regions of the world. Specifically, we assume that the following conditions hold.

$$\varsigma^N = \frac{\varsigma_M^N}{\varsigma_E^N} > 1 \quad \text{and} \quad \varsigma^S = \frac{\varsigma_M^S}{\varsigma_E^S} < 1.$$

As Gancia and Zilibotti (2009) do, we assume that the South is skill scarce so that $H^S/L^S < H^N/L^N$ and to have a population size not larger than the North ($H^S + L^S \leq H^N + L^N$). As further extension of the work of Gancia and Zilibotti (2009), we augment the model to account for both physical and natural capital with the South being relatively rich in natural capital. These imply the following:

$$\frac{H^N}{L^N} > \frac{H^S}{L^S} \quad \text{and} \quad \frac{K^N}{R^N} > \frac{K^S}{R^S}.$$

We also assume that there is limited (or no) international protection of intellectual property rights. This latter assumption implies that innovators in the North cannot sell their copyrights to firms located in the South. This limits the market size of new technologies to the North only. The implication of this is that the factor endowments of the South do not influence the direction of frontier innovations. Hence the South takes the state of technology in the North as given in its adoption decisions. The implication of this is that the factor endowments of the South do not affect the direction of technical change in the North. As a result, technologies that originate from the North are less likely to be appropriate to the needs of the South. This could be an implicit barrier to technology adoption and use in the South and may be relevant in explaining the differences in growth performance between the North and the South. The equilibrium conditions for the South are analogous to those derived for the North; hence we do not present the static equilibrium results here.

3.1 Directed technology adoption

The way we model technology adoption here follows directly from Gancia and Zilibotti (2009). We model technology adoption as costly investment activity that is similar to frontier innovation. As Gancia and Zilibotti do, we follow Nelson and Phelps (1966), Barro and Sala-i-Martin (1997) and Acemoglu, *et al.* (2012) and assume that, due to technological spillovers, the cost of adopting a technology in a given sector is inversely related to the technological gap in that sector. Specifically, we assume that the cost of adopting technology in the resource and manufacturing sectors respectively are:

$$c_E = \lambda^S \left(\frac{A_E^S}{A_E^N} \right)^{\eta} \quad \text{and} \quad c_M = \lambda^S \left(\frac{A_M^S}{A_M^N} \right)^{\eta}, \quad \eta \geq 0 \tag{39}$$

We assume that the South is less efficient at innovating than the North so that $\lambda^S > \lambda^N$. Since the cost of adopting a new technology is positive, it has the implication that once a firm adopts a new intermediate input to the South, it is not profitable for any other firm to do so. Hence all intermediate inputs in the South are sold by local monopolists just as in the North. As in Gancia and Zilibotti (2009), we interpret η as an inverse measure of barriers to technology adoption which is assumed here to be inversely related to the degree of intellectual property rights protection. Thus, in the present paper, we will alternatively interpret it as a measure of the degree of international property right protection on the interval $(0, \infty)$, with the degree of protection increasing in η.

Equation (34) and the fact that at the steady state innovators are indifferent between the sector in which they innovate and free entry into innovation (zero profit condition) implies that profits from innovating in the two sectors are equalized. This and Equation (39) then implies

$$\frac{\pi_M}{\pi_E} = \frac{c_M}{c_E} = \left(\frac{A_M^S}{A_M^N} \right)^{\eta} \left(\frac{A_E^S}{A_E^N} \right)^{-\eta} = \left(\frac{A_M^S}{A_E^S} \right)^{\eta} \left(\frac{A_M^N}{A_E^N} \right)^{-\eta}. \tag{40}$$

Substituting the expression for relative profitability in Equation (35), we have;

$$\varsigma^{S\left(\frac{\varepsilon}{\sigma}\right)} \left(\frac{A_M^S}{A_E^S} \right)^{-\frac{1}{\sigma}} \left[\left(\frac{H^S}{L^S} \right)^{\alpha} \left(\frac{K^S}{R^S} \right)^{\beta} \right]^{\frac{(\sigma-1)}{\sigma(\alpha+\beta)}} = \left(\frac{A_M^S}{A_E^S} \right)^{\eta} \left(\frac{A_M^N}{A_E^N} \right)^{-\eta}.$$

This can be solved to obtain the equilibrium bias of technology in the South as

$$\frac{A_M^S}{A_E^S} = \varsigma^{S\left(\frac{\varepsilon}{\sigma\eta+1}\right)} \left(\frac{A_M^N}{A_E^N} \right)^{\frac{\eta\sigma}{\eta\sigma+1}} \left[\left(\frac{H^S}{L^S} \right)^{\alpha} \left(\frac{K^S}{R^S} \right)^{\beta} \right]^{\frac{(\sigma-1)}{(\alpha+\beta)(\eta\sigma+1)}}. \tag{41}$$

Since the relative bias in the direction of technical change is endogenous, we substitute Equation (36) into (41) to eliminate the equilibrium bias of technology in the North. This gives the following expression of relative equilibrium bias in technology in the South as

$$\frac{A_M^S}{A_E^S} = \varsigma^{S\left(\frac{\varepsilon}{\sigma\eta+1}\right)} \varsigma^{N\left(\frac{\varepsilon\eta\sigma}{\eta\sigma+1}\right)} \left[\left(\frac{H^N}{L^N}\right)^{\alpha\eta\sigma} \left(\frac{H^S}{L^S}\right)^{\alpha} \left(\frac{K^N}{R^N}\right)^{\beta\eta\sigma} \left(\frac{K^S}{R^S}\right)^{\beta} \right]^{\frac{(\sigma-1)}{(\alpha+\beta)(\eta\sigma+1)}} . \tag{42}$$

According to the expression in (42), technology adoption in the South depends on both the factor endowments of the North as well as the South, for a given level of property rights protection. Interestingly the equilibrium bias of technology in the South increases in the skill endowment of the North. Furthermore, the bias in equilibrium technology decreases in the relative abundance of unskilled labour and natural capital.

Our measure for the degree of international protection of property rights in the South plays an important role here. If intellectual property rights are fully protected so that $\eta \to \infty$, then the South uses the same technology as the North. On the other hand, if there is complete lack of property rights protection in the South ($\eta \to 0$), then the innovators in the North designed new technologies such that adoption to the South is impossible. In this case the South uses entirely different technology from that of the North. Even under full property rights protection, technologies developed in the North may not be appropriate for the needs of the South due to the asymmetry in factor endowments. Specifically, there will be a problem of skill-technology mismatch. This then emphasizes the crucial role of human capital in the growth and development process of any given country. Thus, intellectual property rights protection will have significant growth effect if it is accompanied by investments in human capital.

By recalling that the South has equilibrium conditions analogous to those for the North, we analysed the effect of equilibrium bias in technology adoption on relative prices of factors and relative profitability to innovators. To do this, we substitute (42) into (30), (31) and (32), starting with (30).

$$\frac{W_H^S}{W_L^S} = \left(\frac{\varsigma^N}{\varsigma^S}\right)^{-\frac{\varepsilon\eta}{\eta\sigma+1}} \left[\left(\frac{H^N}{L^N}\right)^{\alpha} \left(\frac{K^N}{R^N}\right)^{\beta} \right]^{-\frac{\eta(\sigma-1)}{\omega}} \left[\left(\frac{H^S}{L^S}\right)^{-\kappa} \left(\frac{K^S}{R^S}\right)^{\varphi} \right]^{\frac{1}{\omega}} , \tag{43}$$

where $\kappa = \alpha(\eta+1) + \beta(\eta\sigma+1)$, $\varphi = \beta\eta(\sigma-1)$ and $\omega = (\alpha+\beta)(\eta\sigma+1)$. The relative wage in the South depends on its own factor supplies and factor endowments of the North. If the elasticity of substitution across factors is less than one (production factors are gross complements), relative abundance of human and physical capital endowments of the North will increase wage inequality in the South. However, if the production factors are gross substitutes so that the elasticity of substitution is higher than one, then the relative abundance of human and physical capital endowments of the North reduce wage inequality in the South. The relative scarcity of human capital in the South increases wage inequality irrespective of the magnitude of the elasticity of substitution. The relative abundance of natural capital in the South increases (reduces) wage inequality if the production factors are gross complements (substitutes).

We now compute the relative return to physical capital for the South in Equation (44).

$$\frac{p_K^S}{p_R^S} = \left(\frac{\varsigma^N}{\varsigma^S}\right)^{-\frac{\varepsilon\eta}{\eta\sigma+1}} \left[\left(\frac{H^N}{L^N}\right)^{\alpha\eta} \left(\frac{K^N}{R^N}\right)^{\beta\eta} \left(\frac{H^S}{L^S}\right)^{\alpha\eta} \left(\frac{K^S}{R^S}\right)^{\frac{\psi}{(\sigma-1)\sigma}}\right]^{-\frac{(\sigma-1)}{(\alpha+\beta)(\eta\sigma+1)}}, \tag{44}$$

where $\psi = \sigma[\alpha(1+\eta\sigma)+\beta(1+\eta)]$, which is unambiguously positive. The relative return on physical capital in (44) also increases in the skill endowments of the North if and only if the derived elasticity of substitution is less than one. If this elasticity is larger than one, then the skill endowments in the North will lower the relative return on physical capital in the South. The relative scarcity of natural capital in the North increases the premium to physical capital in the South, given that the elasticity of substitution between sectors is larger than one. Thus, there is an inverse (positive) relationship between natural capital endowment in the North and the relative return to physical capital in the South provided the elasticity of substitution is larger (less) than one. The effect of the factor endowments in the South on the relative return to physical capital also depends on the elasticity of substitution between the two sectors. If the elasticity of substitution in larger (less) than one, then the relative return to physical capital is lowered (increased) by the relative abundance of unskilled labour and natural capital in the South.

With regards to relative profitability, the effect of factor endowments on this variable in the two regions of the world is reversed as can be seen from Equation (45)

$$\frac{\pi_M^S}{\pi_E^S} = \left(\frac{\varsigma^N}{\varsigma^S}\right)^{-\frac{\varepsilon\eta}{\eta\sigma+1}} \left[\left(\frac{H^N}{L^N}\right)^{\alpha} \left(\frac{K^N}{R^N}\right)^{\beta} \left(\frac{H^S}{L^S}\right)^{-\alpha\sigma} \left(\frac{K^S}{R^S}\right)^{-\beta\sigma}\right]^{-\frac{\eta(\sigma-1)}{(\alpha+\beta)(\eta\sigma+1)}}. \tag{45}$$

If the elasticity of substitution is larger than one, then the relative profitability of the innovators in the South decreases in the factor endowments of the North but increase in the factor endowments in the South. However, due to the asymmetry in relative factor endowments, relative profitability will turn to be lower if the two sectors are gross substitutes in final goods production. In the reverse case, where the elasticity of substitution is less than one, the relative abundance of labour and natural capital will make relative profitability of innovating and adopting technology in the *M-sector* larger, other things being equal.

4. Trade, Technological Change and the Resource Curse

Trade openness has been identified as one of the key drivers of long-run economic growth and a major source of cross country income differences. Technology transfer is one of the channels of transmission mechanisms from trade openness to economic growth. It is important to note further that trade and globalization can have first-order effects on the direction of technological change that can have significant effects on productivity differences (Acemoglu and Zilibotti, 2001; Gancia and Zilibotti, 2009). In this section, we show how globalization accounts for productivity differences between the resource-poor North and the resource-abundant South by extending our baseline model to allow for trade in goods between the North and the South. The goods that are involved in the trade between the North and the South are Y_E and Y_M, the inputs in final goods production.

For the sake of the derivations and analysis in this section, we define the world endowments of the four inputs in our basic model as follows:

$$L^W = L^N + L^S, \quad H^W = H^N + H^S, \quad K^W = K^N + K^S \quad \text{and } R^W = R^N + R^S,$$

where L^W, H^W, K^W, and R^W are the world supplies of unskilled labour, human capital, physical capital and natural capital, respectively. In this section we demonstrate that trade in goods between the resource abundant South and the resource poor North will lead to skill/capital biased technological change that benefits the North and hence creates an income gap between the North and the South. It turns out that this effect is stronger than what pertains under autarky due to the terms of trade effects that tends to favour the manufacturing sector.

With the North and the South integrated into a single market (the world market) for Y_E and Y_M (outputs of the resource and manufacturing sectors, respectively), the relative price of goods is determined by the world demand and supply. This and Equation (29) imply the following terms of trade between the outputs of the manufacturing sector and resource sector in the global economy.

$$\frac{P_M}{P_E} = \varsigma^{\frac{\varepsilon(\alpha+\beta)}{\sigma}} \left(\frac{A_M}{A_E}\right)^{-\frac{\alpha+\beta}{\sigma}} \left[\left(\frac{H^W}{L^W}\right)^{\alpha} \left(\frac{K^W}{R^W}\right)^{\beta}\right]^{-\frac{1}{\sigma}} \tag{46}$$

The above expression indicates that the relative price of manufacturing output increases in the world supply of raw labour and natural capital since the elasticity of substation between goods is larger than zero. This means that exogenous increases in natural resource supplies or unskilled labour results in unfavourable terms of trade effects for the Southern countries, for a given state of technology. The effect of equilibrium bias of technology on the terms of trade is negative irrespective of the magnitude of the elasticity of substitution. If the elasticity of substitution is less (more) than one, then the negative effect of an increase in technological gap between the two sectors on the terms of trade becomes stronger (weaker).

We showed in Equation (32) that the profitability of a skill /capital-complementary innovation depends on both the size of the market for skill/capital complementary technologies which is proportional to the skill and capital endowments of the North and the relative price of skill/capital intensive goods. The reasons is that profit to innovations continue to come only from the firms in the North even after world market integration due to inadequate intellectual property rights protection in the South.

$$\frac{\pi_M^*}{\pi_E^*} = \left(\frac{P_M}{P_E}\right)^{\frac{1}{\alpha+\beta}} \left(\frac{H^N}{L^N}\right)^{\frac{\alpha}{\alpha+\beta}} \left(\frac{K^N}{R^N}\right)^{\frac{\beta}{\alpha+\beta}}$$

This and Equation (46) gives the following expression for the relative profitability of M-sector complementary innovations under global product market integration.

$$\frac{\pi_M^*}{\pi_E^*} = \varsigma^{\frac{\varepsilon(\alpha+\beta)}{\sigma}} \left(\frac{A_M}{A_E}\right)^{-\frac{\alpha+\beta}{\sigma}} \left[\left(\frac{H^W}{L^W}\right)^{\alpha} \left(\frac{K^W}{R^W}\right)^{\beta}\right]^{-\frac{1}{\sigma}} \left(\frac{H^N}{L^N}\right)^{\frac{\alpha}{\alpha+\beta}} \left(\frac{K^N}{R^N}\right)^{\frac{\beta}{\alpha+\beta}} \tag{47}$$

This change in relative profitability to innovate due to terms of trade shock that follows from market integration leads to a transition dynamics with skill/capital biased technological change along which A_M / A_E grows (given that inputs are gross substitutes), until a new steady state is reached. The relative profitability of M-sector complementary innovations decreases in the technological gap between the two sectors since the elasticity of substitution between sectors is greater than zero. The world resource endowments also affect the relative profitability of the M-sector complementary innovations through its effect on the terms of trade (relative price of the traded goods). Since the market for new technology is limited to the North only[5], the factor endowments of the South does not appear as direct arguments in the expression for relative profitability. Rather, the factor endowments of the North have effect on relative profitability. Consistent with the market size effect on equilibrium bias of technology, the effect of relative abundance of human and physical capital in the North have unambiguous positive effect on relative profitability.

At the new steady state equilibrium, innovation in the M-sector would be as profitable as in the E-sector. This then implies that the left-hand side of Equation (47) is equal to one. Imposing this condition we obtain the following equilibrium bias of M-sector complementary innovations.

$$\frac{A_M}{A_E} = \varsigma^{\varepsilon} \left[\left(\frac{H^W}{L^W} \right)^{\alpha} \left(\frac{K^W}{R^W} \right)^{\beta} \right]^{-\frac{1}{\alpha+\beta}} \left[\left(\frac{H^N}{L^N} \right)^{\frac{\alpha}{\alpha+\beta}} \cdot \left(\frac{K^N}{R^N} \right)^{\frac{\beta}{\alpha+\beta}} \right]^{\frac{\sigma}{\alpha+\beta}} \quad (48)$$

According to Equation (48), the equilibrium bias of technology is a function of both the world resource endowments and the factor endowment of the North. Interestingly, the equilibrium bias of technology increases with the world endowments of unskilled labour and natural capital. Since the South is relatively rich in these factors, trade between the North and the South increases the bias in technological change in favour of the M-sector. The factor endowments of the North reinforce the relative bias of equilibrium technology, irrespective of the size of the elasticity of substitution between goods.

We also compute the effect of globalization on the skill premium and hence wage inequality. By combining Equations (24) and (25) and substituting Equation (46) into the resulting expression we obtain the skill premium for the global economy as:

$$\frac{W_H}{W_L} = \left(\frac{H^W}{L^W} \right)^{-\frac{\beta}{\alpha+\beta}} \left(\frac{K^W}{R^W} \right)^{\frac{\beta}{\alpha+\beta}} \left[\left(\frac{H^N}{L^N} \right)^{\frac{\alpha}{\alpha+\beta}} \left(\frac{K^N}{R^N} \right)^{\frac{\beta}{\alpha+\beta}} \right]^{-\frac{1}{\alpha+\beta}} \quad (49)$$

The skill premium in the global economy is also dependent on both the world resource endowments and the factor endowments of the North. In particular, wage inequality in the integrated world economy decreases in the relative abundance of skilled labour and physical capital endowments of the North. Also, an exogenous increase in the world supply of unskilled labour also causes wage inequality to rise. Since the South is rich in unskilled labour, an integration of the North and the South into a single large economy will increase wage inequality. Another interesting finding here is that increases in the world supply of

5 Here, the North and the South have access to the same technologies. However, the direction of technological change is purely determined by the factor endowments of the North. This can make new technologies less favourable to the factor endowments of the South.

natural capital (discovery of new resource deposits) reduce wage inequality. The reason is not far-fetched: increases in natural capital increases the productivity of unskilled labour.

As a final step, we next examine the relative price of natural capital in the world economy. Relative price of natural capital is obtained by dividing Equation (23) by (26) and substituting Equation (46) into the resulting expression.

$$\frac{p_R}{p_K} = \left[\left(\frac{H^N}{L^N} \right)^{\frac{\alpha}{\alpha+\beta}} \cdot \left(\frac{K^N}{R^N} \right)^{\frac{\beta}{\alpha+\beta}} \right]^{\frac{1}{\alpha+\beta}} \left(\frac{H^W}{L^W} \right)^{-\frac{\alpha}{\alpha+\beta}} \left(\frac{K^W}{R^W} \right)^{\frac{\alpha}{\alpha+\beta}} \tag{50}$$

From Equation (50), we observe again that the relative price of natural capital is also dependent on world factor endowments and the factor endowments of the North. The human and physical capital abundance of the North increases the relative price of natural capital. However, the effect of the world supply of natural capital is to decrease its relative price, discouraging further, resource-sector specific innovations. Since the South has abundant natural capital, this effect becomes stronger in the integrated world economy. Since increased unskilled labour increases the productivity of natural capital, the relative price of natural capital is a positive function of the world endowments of unskilled labour.

5. Conclusion

This paper analyses the effect asymmetry in factor endowments between resource-rich and resource-poor countries on equilibrium bias of technology development and adoption possibilities. First, we show that the bias in equilibrium technology in the resource-poor North is determined by its relative abundance of human capital and physical capital. This force is amplified by the relative abundance (scarcity) of physical (natural) capital. Secondly, we show that the equilibrium bias in technology in the resource abundant South is dependent positively (negatively) on the relative abundance (scarcity) of skilled (unskilled) labour and the relative abundance (scarcity) of physical (natural) capital in the North. This force is damped by the relative scarcity of skilled labour and physical capital in the South.

Furthermore, we show that factor endowments of the North affects wage inequality in the South. Specifically, if the elasticity of substitution between the resource-sector and manufacturing sector in final goods production is greater than one, then wage inequality in the South will decrease in the relative abundance of skilled labour and physical capital in the North. This is due to the resultant skill-technology mismatch in the South. However, this effect is reversed if the output of the resource and manufacturing sector are gross complements in final goods production. The own factor endowments effect on the skill premium is however ambiguous. For a sufficiently low degree of international property rights protection in the South, the relative abundance of unskilled labour increases wage inequality in the South. If the derived elasticity of substitution is larger than one, then the relative abundance of natural capital in the South increases wage inequality and slows down the growth rate of the economy.

With regards to the relative return to physical capital in the South, this variable decreases in the relative abundance of skilled labour and physical capital in the North provided that the derived elasticity of substitution is greater than one. However, the relative abundance of unskilled labour and natural capital increases the relative return to physical capital and slows down capital accumulation in the South and hence leads to poor growth. Last but not the least, we show that relative profitability of adopting manufacturing sector complementary technology decreases in the relative abundance of skilled labour and physical capital in the North if the elasticity of substitution is larger than one. Also, the relative profitability of adopting manufacturing sector complementary technology is inversely related to the relative abundance of unskilled labour and natural capital in the South. This is as a result of skill-technology mismatch. These cumulatively explain part of the observed growth differentials between resource-poor Northern countries and the resource abundant Southern region.

References

Acemoglu, D. (1998), "Why Do New Technologies Complement Skills? Directed Technical Change and Wage Inequality." *The Quarterly Journal of Economics,* Vol. 113, No. 4, pp. 1055–1090, http://dx.doi.org/10.1162/003355398555838

Acemoglu, D. (2002), "Directed Technical Change." *The Review of Economic Studies,* Vol. 69, No. 4, pp. 781–809.

Acemoglu, D. (2009), *Introduction to Modern Economic Growth.* Princeton University Press.

Acemoglu, D., Zilibotti, F. (2001), "Productivity Differences." *The Quarterly Journal of Economics,* Vol. 116, No. 2, pp. 563–606, http://dx.doi.org/10.1162/00335530151144104

Acemoglu, D., Gancia, G., Zilibotti, F. (2012), "Competing Engines of Growth: Innovation and Standardization." *Journal of Economic Theory*, Vol. 147, No. 2, pp. 570–601, http://dx.doi.org/10.1016/j.jet.2010.09.001

Acemoglu, D., Akcigit, U. (2012), "Intellectual Property Rights Policy, Competition and Innovation." *Journal of European Economic Association*, Vol. 10, No. 1, pp. 1–42, http://dx.doi.org/10.1111/j.1542-4774.2011.01053.x

Afonso, O., Alves, R. H. (2008), "Can North-South Trade Regime Explain Intra and Inter-Country Productivity Differences?" *International Trade and Economic Development*, Vol. 17, No. 4, pp. 561–595, http://dx.doi.org/10.1080/09638190802250365

Afonso, O. (2012), "Scale-Independent North-South Trade Effects on the Technological-Knowledge Bias on Wage Inequality." *Review of World Economies*, Vol. 148, No. 1, pp. 181–207, http://dx.doi.org/10.1007/s10290-011-0109-7

Aghion, P., Howitt, P. (2009), *The Economics of Growth.* Massachusetts: MIT Press.

Aghion, P., Howitt, P. (1992), "A Model of Growth through Creative Destruction." *Econometrica,* Vol. 60, No. 2, pp. 323–351, http://dx.doi.org/10.2307/2951599

Barro, R. J., Sala-i-Martin, X. (1997), "Technological Diffusion, Convergence and Growth." *Journal of Economic Growth,* No. 2, pp. 1–27.

Copeland, B. R., Taylor, M. S. (1994), "North-South Trade and the Environment." *The Quarterly Journal of Economics,* Vol. 109, No. 3, pp. 755–787, http://dx.doi.org/10.2307/2118421

Di Maria, C., Valente, S. (2008), "Hicks Meets Hotelling: The Direction of Technical Change in Capital-Resource Economies." *Journal of Environment and Development Economics,* Vol. 13, No. 6, pp. 691–717, http://dx.doi.org/10.1017/S1355770X08004567

Gancia, G., Bonfiglioli, A. (2008), "North-South Trade and Directed Technical Change." *Journal of International Economics,* Vol. 76, No. 2, pp. 276–295, http://dx.doi.org/10.1016/j.jinteco.2008.03.010

Gancia, G., Zilibotti, F. (2009), "Technological Change and Wealth of Nations." *Annual Review of Economics,* Vol. 1, No. 1, pp. 93–120, http://dx.doi.org/10.1146/annurev.economics.050708.143333

Nelson, R. R., Phelps, E. S. (1966), "Investment in Humans, Technological Diffusion and Economic Growth." *American Economic Review,* Vol. 56, No. 1/2, pp. 69–75.

Peretto, P. F., Valente, S. (2010), "Resources, Innovation and Growth in the Global Economy." *Journal of Monetary Economics,* Vol. 58, No. 4, pp. 387–399, http://dx.doi.org/10.1016/j.jmoneco.2011.07.001

Rivera-Batiz, L. A., Romer, P. M. (1991), "Economic Integration and Endogenous Growth." *The Quarterly Journal of Economics*, Vol. 106, No. 2, pp. 531–555, http://dx.doi.org/10.2307/2937946

Sala-i-Martin, X., Subramanian, A. (2003), Addressing the Natural Resource Curse: An Illustration from Nigeria, NBER Working Paper Series, No. 9804, Cambridge, Massachusetts.

Segal, P. (2008), Natural Resource Wealth and Directed Technical Change, Oxford Institute for Energy Studies, Oxford University.