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Population Growth and the Tragedy of the Commons: Can Trade Prevent Natural Resource and Welfare Collapse?

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ABSTRACT

Population Growth and the Tragedy of the Commons: Can Trade Prevent Natural Resource and Welfare Collapse?*

Many developing countries depend crucially on open-access renewable natural resources (NR). Trade is generally viewed as hurting the long-term health of NR in commodity-exporting countries. I examine whether trade might be beneficial in the case of population growth. Dynamic general equilibrium NR models have typically assumed constant return to scale in the manufacturing sector. I examine trade's impact under constant, decreasing and increasing returns. While population growth always results in NR and welfare collapse under autarky, the impact under trade depends critically on the manufacturing sector's returns-to-scale technology. Under trade, NR and welfare are unaffected by population growth under constant returns, collapse under decreasing returns, and increase under increasing returns. Empirical studies have typically found constant or increasing returns. Thus, countries experiencing rapid population growth may obtain long-term benefits from opening up to trade, though they experience short-term NR costs.

JEL Classification: D62, F18, Q22, Q27, Q56

Keywords: population growth, renewable natural resources (NR), trade vs autarky, NR and welfare or societal collapse

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I. Introduction

Many developing countries obtain a significant share of their income from renewable natural resources (*NR*), such as arable land, fisheries, forests, grazing grounds and water resources. Imperfect property rights for *NR* results in excessive use of variable inputs and excessive pressure and depletion of *NR*, at times dramatically so – e.g., the North American bison's near-extinction associated with open-access lands in the US and a tanning innovation in Europe (Taylor, 2011), population growth-related massive deforestation in the Philippines (Bee, 1987), etc. The problem has affected many developing countries and has led to the decline or collapse of some communities – due, among other reasons, to rapid population growth.

The classic case of *NR* depletion is fisheries, and early analyses focused on the sector's open access and optimal regulation (Gordon 1954, Scott 1955). Some more recent studies have extended the analysis, using general equilibrium models to examine steady states and transition dynamics in economies with open-access *NR* (e.g., Brander and Taylor 1997, 1998; López and Schiff, 2013).

This paper focuses on population growth's impact on *NR* in a *NR*-based commodity-exporting country. An issue of increasing concern in recent years has been trade's environmental impact. A common view is that trade worsens *NR* degradation for commodity exporters (Chichilnisky, 1994; Brander and Taylor, 1997; Smulders et al., 2004; Eisenbarth, 2021; Schiff, 2021).[1] The question addressed here is whether this result holds in the case of population growth or whether trade can help dampen or prevent the collapse of *NR* and welfare.

[1] An overview of studies of trade and *NR* under different types of property rights for *NR* is Bulte and Barbier (2005).

The paper is organized as follows. Section II provides some population projection figures, Section III presents the model and Section IV the solution. Section V looks at trade pattern reversals, which occur in several scenarios. Given their central role in the analysis, Section VI reviews some of the literature on returns to scale. Section VII concludes.

II. Population Growth

Population has increased across the developing world in recent decades, particularly in Sub-Saharan Africa (SSA). Of the 20 countries with the highest growth rate in 2012-2022, 15 are in SSA and each one has an annual growth rate of three percent or more. Moreover, the 2020 fertility rate, equal to 4.6 children in SSA, was twice the level in South Asia, 2.3 times that in Latin America and the Caribbean (LAC), and 2.6 times that in East Asia and the Pacific (EAP).

Based on UN (2019) projections, population growth will continue to be a major issue for many developing countries, until 2100 for SSA and at least until 2050 for many non-SSA countries.[2] The UN population growth medium projection for Africa (Asia) (LAC) is 87 (41) (46) percent for 2000-2050, 78 (–12.3) (–10.8) percent for 2050-2100, and 233 (24) (30) percent for 2000-2100.

The population of Nigeria (DRC) (Tanzania) (Ethiopia) is projected to increase by 525 (263) (220) (160) millions from 2022 to 2100, or by some 1.2 billion for these four SSA countries. In fact, Africa is projected to have six of the 10 most populous developing countries in 2100, with Nigeria being the third largest after India and China. And the UN projects population in 36 (or two thirds of) SSA countries to increase by at least 50 percent from 2050 to 2100, and to double in ten.[3]

[2] For 2020-2050, these include, among the larger countries, Bangladesh, India, Indonesia, Pakistan, the Philippines and Vietnam in South and South-East Asia; Argentina, Brazil, Colombia, Mexico and Venezuela in LAC; Iran, Iraq, Syria, Turkey and Yemen in Western Asia; and Uzbekistan and Kazakhstan in Central Asia.
[3] The projected growth rate for SSA's ten most populous countries is 88 percent for 2022-2050, 72 percent for 2050-2100, and 224 percent for 2022-2100.

Thus, the high population growth rates are expected to put considerable pressure on *NR* in SSA and in a number of countries in other developing areas (e.g., see fn. 2). In fact, of the world's 16 most populous low-income to upper middle-income countries, the only ones with negative population growth projections from 2020 to 2050 are China (-2.5 percent) and Russia (-7 percent).

III. Model

A model of a small open economy is developed that captures the essence of the problem while being as simple as possible.

1. <u>Production</u>

Countries have diversified production structures, the conditions for which are provided later in this section. Assume a small economy consisting of two sectors, a *NR*-based commodity sector, Q, and a manufacturing sector, M, and two factors of production, labor and *NR*. Access to *NR* is open. Population, $\mathbb{L}$, is assumed to be exogenous.[4] Each individual is endowed with one unit of labor. Denote *NR* by N, returns to scale by ϕ, population (or labor) by $\mathbb{L}$, and employment by L in sector Q and by l in sector M, with $L + l = \mathbb{L}$.

Brander and Taylor (1998), López and Schiff (2013), Schiff (2021) and others have assumed a constant-returns-to-scale production function in manufacturing, M. I assume $M = l^{\phi} = (\mathbb{L} - L)^{\phi}$, with $\phi \gtreqless 1$, and $l > 1$. The latter ensures that an increase in returns to scale ϕ raises output M.

[4] Diamond (2011, Ch. 10) examines some of the causes of Africa's rapid population growth that are exogenous to *NR*, including improved hygiene, preventive medicine, greater vaccination, use of antibiotics, controls for malaria and other endemic diseases, and more. Studies where population is endogenous include Brander and Taylor (1997, 1998).

In the case of $N > 0$, and following Schaefer's (1957) seminal study and many others after him, *NR* growth is specified as $\dot{N} \equiv dN/dt = \rho N\left(1 - \frac{N}{K}\right) - \mu Q, N > 0$, where $\rho > 0$ is N's natural growth rate, K is the environment's carrying capacity – or maximum sustainable *NR*, given the environment – and $\mu > 0$ is the rate of *NR* depletion per unit of commodity output Q. For fisheries, μ is the rate at which the fish stock is harvested. Assume also that once the *NR* is totally depleted, it cannot grow back.[5]

The *NR* enters the production of the commodity, Q, as conventionally done in the literature (Gordon 1954; Schaefer 1957; Copeland and Taylor 1994; etc.), namely $Q = LN$. Thus, $\dot{N} = \rho N\left(1 - \frac{N}{K}\right) - \mu LN, N > 0$, and N reaches a steady state, $\dot{N} = 0$, at $N = \left(1 - \frac{\mu L}{\rho}\right)K$. Thus:

$$M = l^{\phi} = (\mathbb{L} - L)^{\phi};\ Q = LN;\ N = \alpha - \beta L, N > 0;\ \ \alpha = K, \beta = \frac{\mu K}{\rho};\ \ \alpha, \beta > 0, \qquad (1)$$

where α is the environment's carrying capacity and $-\beta L$ is labor's negative externality. The analysis focuses on steady states where equation (1) is satisfied.[6]

The conditions for an interior solution regarding labor allocation between sectors Q and M – i.e., for a diversified production structure – are that $VAP_L(L = 0) > VMP_l(l = \mathbb{L})$ and a value of L, $0 < L < \mathbb{L}$, exists where $VAP_L = VMP_l$.

2. Preferences

Individuals have Cobb-Douglas preferences over $m = M/\mathbb{L}$ and $q = Q/\mathbb{L}$. Denoting the share of income spent on q by γ, preferences are given by:

[5] For instance, once all the fish in a lake have been caught, their stock remains nil.
[6] *NR* dynamics for $N > 0$ are as follows. Population $\mathbb{L}$ changes exogenously, affects employment L in Q, and *NR* changes until it reaches a new steady state where equation $N = \alpha - \beta L$ is satisfied, after which the cycle resumes.

$$U = q^{\gamma} m^{1-\gamma}, 0 < \gamma < 1. \tag{2}$$

IV. Solution

1. Autarky

Manufacturing, M, is chosen as the numéraire. Q's demand price is $p_d = \frac{U_q}{U_m} = \frac{\gamma m}{(1-\gamma)q} = \frac{\gamma M}{(1-\gamma)Q} = \frac{\gamma(\mathbb{L}-L)^{\phi}}{(1-\gamma)L(\alpha-\beta L)}$, where the last equality makes use of the fact that demand equals supply under autarky. The supply price is Q's average cost over M's marginal cost, i.e., $p_s = \frac{AC_Q}{MC_M} = \frac{\phi(\mathbb{L}-L)^{\phi-1}}{\alpha-\beta L}$. In equilibrium, $p_d = p_s = p$, implying:

$$L = \frac{\gamma\mathbb{L}}{\gamma+\phi(1-\gamma)} = \frac{\gamma\mathbb{L}}{Z}; Z \equiv \gamma + \phi(1-\gamma) \gtreqless 1 \Leftrightarrow \phi \gtreqless 1, \tag{3}$$

where L is positively related to γ and negatively to ϕ. From (3), $\frac{\partial L}{\partial \mathbb{L}} = \frac{\gamma}{Z} > 0$, and thus $\frac{\partial N}{\partial \mathbb{L}} = -\frac{\beta\gamma}{Z} < 0$, i.e., growth in $\mathbb{L}$ leads to *NR* depletion, with $N = Q = U = 0$ for $\mathbb{L} = \frac{\alpha Z}{\beta\gamma}$ (and $L = \frac{\alpha}{\beta} = \frac{\rho}{\mu}$).[7]

Thus, *population growth results in the collapse of NR and welfare over time* under autarky, irrespective of the returns to scale ϕ (though the speed of collapse declines with ϕ).

2. Trade

Denote variables by subscript T and the exogenous world price by p_w. The supply price, p_s, equals the world price, i.e., $p_w = \frac{\phi(\mathbb{L}-L_T)^{\phi-1}}{\alpha-\beta L_T}$. Since p_w is given for a small economy, one can derive the impact of $\mathbb{L}$ on L_T. The solution, which is given in Appendix 1, is:

$$\frac{\mathrm{d}L_T}{\mathrm{d}\mathbb{L}} = \frac{(1-\phi)(\alpha-\beta L_T)}{(1-\phi)(\alpha-\beta L_T) + \beta(\mathbb{L}-L_T)}. \tag{4}$$

[7] Under constant returns to scale ($\phi = 1$), $Z = 1$, $L = \gamma\mathbb{L}$, $N = \alpha - \beta\gamma\mathbb{L} = 1/p$, $q = \frac{LN}{\mathbb{L}} = \gamma(\alpha - \beta\gamma\mathbb{L}) = \gamma/p$, $m = 1 - \gamma$, and $U = [\gamma(\alpha - \beta\gamma\mathbb{L})]^{\gamma}(1-\gamma)^{1-\gamma} = (\gamma/p)^{\gamma}(1-\gamma)^{1-\gamma}$, $\partial U/\partial\mathbb{L} < 0$. Note also that $\partial p/\partial\mathbb{L} > 0$.

The cases of constant, decreasing and increasing returns are examined below.

2.1. Constant returns to scale: $\phi = 1$

In this case, $M_T^s = l_T$ and $p_w = p_s = \frac{1}{\alpha - \beta L_T}$ or:

$$L_T = \frac{1}{\beta}\left(\alpha - \frac{1}{p_w}\right). \tag{5}$$

Thus, L_T is a function of p_w and not of $\mathbb{L}$. Both (4) and (5) imply $\frac{\partial L_T}{\partial \mathbb{L}} = \frac{\partial N_T}{\partial \mathbb{L}} = \frac{\partial Q_T^s}{\partial \mathbb{L}} = 0$, and $\frac{\partial M_T^s}{\partial \mathbb{L}} = \frac{\partial l_T}{\partial \mathbb{L}} = 1$. So, population increases are fully absorbed by the manufacturing sector, which prevents long-term *NR* collapse. The reason is that $M = l$ for $\phi = 1$, so $MP_l = 1$ is constant, and since p_w is constant for a small economy, $AP_L = \alpha - \beta L_T = 1/p_w$ must also be constant ($VAP_L = 1$), implying a constant L_T.

What is the short-term employment, *NR* and welfare impact of opening up to trade? For a commodity exporter, the world price is higher than the autarky price, with $p_w = \frac{1}{\alpha - \beta L_T} > p = \frac{1}{\alpha - \beta L}$. Hence, $L_T > L$ and $N_T < N$. Thus, opening up to trade reduces the stock of *NR*.

Trade also reduces welfare. In the absence of negative externalities, opening up to trade raises welfare. However, since access to *NR* is open, the commodity sector's producer surplus is nil (price equals AC) while the consumer surplus declines with price, as does an improvement in the terms of trade.[8, 9] Finally, trade is balanced.[10]

Note also that U_T is independent of $\mathbb{L}$ (see fn. 7). Thus, under $\phi = 1$, *opening up to trade prevents NR and welfare collapse, though it reduces them in the short run.* [11, 12]

2.2. Decreasing returns to scale: $\phi < 1$

In this case, numerator and denominator of (7) are positive, so $\frac{\mathrm{d}L_T}{\mathrm{d}\mathbb{L}} > 0$,[13] and $\frac{\mathrm{d}N_T}{\mathrm{d}\mathbb{L}} = -\beta \frac{\mathrm{d}L_T}{\mathrm{d}\mathbb{L}} < 0$, i.e., population growth results in *NR* depletion and long-term collapse. As MP_l declines with l_T when $\phi < 1$ and AP_L declines with L_T, employment must increase in both sectors as population grows. This is clear from (3) since $0 < \frac{\mathrm{d}L_T}{\mathrm{d}\mathbb{L}} < 1$ under $\phi < 1$, and so $\frac{\mathrm{d}l_T}{\mathrm{d}\mathbb{L}} = 1 - \frac{\mathrm{d}L_T}{\mathrm{d}\mathbb{L}} > 0$.

As N_T declines with $\mathbb{L}$, so does the country's comparative advantage in Q. Thus, autarky price p increases with $\mathbb{L}$, reaches p_w where trade is nil, and eventually $p > p_w$, at which point M is

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[8] Individuals own one unit of labor and their income is $MP_l = 1$. From (2), it follows that they spend a share γ on Q and a share $1 - \gamma$ on M, i.e., $p_w q_T = \gamma$ and $m_T = 1 - \gamma$. Thus, utility is $U_T = (\gamma/p_w)^\gamma (1-\gamma)^{1-\gamma}$. Since $p_w > p$, it follows that $U_T < U$ (see fn. 7). And $\partial U_T / \partial p_w < 0$.

[9] If $L_T = \alpha/\beta$, $N_T = 0$. Assume $L_T < \alpha/\beta$, implying $N_T > 0$.

[10] As aggregate income $Y = \mathbb{L}$, $M_T^d = (1-\gamma)\mathbb{L}$. With supply $M_T^s = \mathbb{L} - L_T$, imports $M_T^I = L_T - \gamma\mathbb{L} = L_T - L > 0$ (see (3) with $\phi = 1$). Output $Q_T^s = L_T(\alpha - \beta L_T) = \frac{L_T}{p_w}$, $Q_T^d = \gamma\left(\frac{\mathbb{L}}{p_w}\right)$, and $Q_T^X = \frac{L_T - \gamma\mathbb{L}}{p_w} = \frac{L_T - L}{p_w} > 0$. Exports $p_w Q_T^X = L_T - \gamma\mathbb{L} = M_T^I$. QED.

[11] Various studies have examined exports' negative impact on *NR*, both theoretically (e.g., Chichilnisky 1994; Brander and Taylor 1997) and empirically (e.g., Eisenbarth 2021).

[12] Commodity-exporting countries typically view terms-of-trade improvements as a benefit because of positive income and foreign exchange effects. However, under open access to *NR*, an increase in the terms of trade reduces *NR* and welfare, though these effects are typically less visible to the general population than those on income and foreign exchange.

[13] From (5), $\frac{\mathrm{d}L_T}{\mathrm{d}\mathbb{L}} = \frac{1}{\beta p_w^2} > 0$.

exported and Q is imported. As $\mathbb{L}$ increases, L_T eventually reaches α/β, where $N_T = Q_T^s = 0$. At that point, $VAP_{L_T} = p_w Q_T^s / L_T = 0$ and labor moves to sector M, with $l_T = \mathbb{L}$.

Since $Y_T = M_T^s = \mathbb{L}^\phi$ and $M_T^d = (1-\gamma)\mathbb{L}^\phi$, exports $M_T^X = \gamma\mathbb{L}^\phi$ and imports $p_w Q_T^I = p_w Q_T^d = \gamma\mathbb{L}^\phi$, with $Q_T^d = (\gamma/p_w)\mathbb{L}^\phi$. Individual values are as follows:

$$y_T = m_T^s = \mathbb{L}^{\phi-1}, m_T^d = (1-\gamma)\mathbb{L}^{\phi-1}, q_T^d = (\gamma/p_w)\mathbb{L}^{\phi-1}, U_T = (\gamma/p_w)^\gamma(1-\gamma)^{1-\gamma}\mathbb{L}^{\phi-1}. \quad (6)$$

Thus, all individual values in (6) decline with $\mathbb{L}$ under decreasing returns ($\phi < 1$) and *NR* collapses under both autarky and trade when population reaches α/β. However, though welfare is nil at $L = \alpha/\beta$ under autarky, it is positive under trade because commodity Q can be imported, i.e., $q_T^d = q_T^I > 0$. Nevertheless, since $\phi < 1$, welfare declines continuously as $\mathbb{L}$ increases.

Thus, *openness to trade does not prevent NR collapse as population grows when* $\phi < 1$*, though it significantly slows down the decline in welfare.*

2.3. Increasing returns to scale: $\phi > 1$

In this case, (4)'s numerator is negative and, as shown in Appendix 2, its denominator must be positive for a stable interior equilibrium, i.e., $\frac{\mathrm{d}L_T}{\mathrm{d}\mathbb{L}} < 0$. The reason is that as l_T increases, so does its marginal product. Hence, L_T's average product must increase as well, implying that L_T must decline as $\mathbb{L}$ increases. Thus, $\frac{\mathrm{d}l_T}{\mathrm{d}\mathbb{L}} > 1$. In the long run, $L_T = Q_T^s = 0$, $N_T = \alpha$, $l_T = \mathbb{L}$, and the country exports the manufacturing product M_T and imports the commodity Q_T.

The functions for y_T, m_T^d, q_T^d and U_T are identical to those in Section 2.2, as given in (6). The difference is that, with $\phi > 1$, all four variables increase over time as $\mathbb{L}$ increases.

Thus, *NR, individual income, consumption and welfare increase with population when* $\phi > 1$*, with NR reaching* α*, its maximum level, when* L_T *reaches zero.*

V. Trade Pattern Reversal

A question is the extent to which trade pattern reversal actually prevails. Regarding Africa's food trade, Rakotoarisoa et al. (2011) report declining net food exports turning into net imports in the mid-1970s, with total and per capita net imports growing since trade reversal occurred. Total net imports grew in real terms by 3.4 percent annually from 1980 to 2007, with 2.6 percent or over three quarters of net import growth associated with population growth, and per capita net imports growing at 0.8 percent annually. With per capita food production growing at less than 0.1 percent, increases in per capita consumption by close to 1 percent per year had to be satisfied by increased per capita imports. Thus, high population growth and low output growth seem to have played a major role in the early trade reversal and in the growth of net food imports in Africa.[14]

Ng and Aksoy (2008) report that the largest reversal occurred in the 51 non-oil-exporting, non-civil-conflict, non-small-island "Other middle-income countries," with net food exports turning into net imports in the early 1980s.[15]

[14] The causes of Africa's rapid population growth are examined in Diamond (2011, Ch. 10) – see fn. 4.

[15] On the other hand, growth of fruits and vegetables exports led to a change from net imports of 1.1 percent to net exports of 0.7 percent as a share of total imports by 2004/05. However, the food trade balance did not improve in SSA. Akiwumi (2020) reports for the 2000-2006 period that the vast majority of Africa's low-income countries, most of which located in SSA and whose population amounted to two thirds of that of the continent, were net food importers. Even a decade later, in 2016-2018, African countries still imported the bulk of their food from outside the continent.

Reversal in the case of fish trade occurred more recently. According to an African Development Bank report (AfDB 2016), Africa's fish trade changed between 2001 and 2014 from a surplus of US$ 1.172 billions to a deficit of US$ 294 millions, or a net fish trade decline of US$ 1.466 billions. The decline in SSA net fish trade was greater still, falling from a surplus of US$ 372 millions to a deficit of US$ 1.650 billions, or a net trade decline of US$ 2.022 billions.

VI. Returns to Scale

Studies below focus on developing countries or include them as part of the sample. Anguo et al. (2011) examined 17 sectors covering China's entire manufacturing industry for 1993-2008 and found that they all show increasing returns – and that their growth is largely due to industry-level increasing returns rather than technical change. Wang and Zhou (2020) found increasing returns for China's mining and light industry for 2000-2013, and returns-to-scale mean value for Chinese industry as a whole not significantly different from one. Similarly, Wang (2008) found either constant or increasing returns to scale in a study of China and five OECD countries. Elleithy (1997) examined the existence of increasing returns in small carpentry firms in a region of Ghana and found the ratio of costs to value declining with production scale. And van Dijk (2002) found that larger Indonesian firms were more competitive, with lower unit costs and greater penetration of foreign markets.

Crompton and Lesourd (2008) examined the global iron-making industry – the most expensive stage in steel making – for integrated steel plants. With panel data for 69 plants in developed, developing and transition economies across all regions, the authors find a significant scale effect associated with high fixed costs and a linear production cost function. Antweiler and Trefler (2002) used data for 34 sectors, 71 countries across all development levels, for five years from 1972 to

1992, and found industry-level increasing returns for a third of the industries, with scale elasticities averaging 1.15, and an economy-wide scale elasticity equal to 1.05, implying an average scale elasticity in the other two thirds of the industries of 1.0, i.e., exhibiting constant returns to scale. Thus, one third of the industries exhibits increasing returns and two thirds exhibit constant ones.

Thus, most industries appear to exhibit either constant or increasing returns. This would suggest that population growth would not result in a collapse of *NR* or welfare under trade.

VII. Conclusion

It is well-known that a country with a comparative advantage in the *NR*-based commodity sector which opens up to trade raises the sector's relative price and its employment, thereby contributing to *NR* depletion. The paper's objective was to examine whether, in the case of population growth, trade might help prevent a collapse of *NR* and welfare.

Studies using dynamic general equilibrium models of *NR* have typically assumed, for simplicity, that the manufacturing sector exhibits a constant-return-to-scale technology. By relaxing this constraint, I obtain some new results regarding the impact of population growth. I find that its impact depends critically on the returns to scale in the manufacturing sector. Empirical studies typically find constant or increasing returns, in which case trade can help prevent *NR* and welfare collapse. In the case of decreasing returns, which are more likely to prevail in small and remote states, trade does not help prevent the collapse of *NR*, though the possibility of trading dampens its negative welfare impact.

Thus, if the country's *NR* can sustain the initial shock of opening up to trade, as is clearly the case for existing *NR*-based commodity exporters, trade should either prevent *NR* collapse under population growth or at least delay welfare collapse even in the case where *NR* collapses.

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Appendix 1: Impact of Population $\mathbb{L}$ on Commodity Employment L_T Under Trade

The supply price, p_s, equals the world price p_w, i.e., $p_w = \frac{\phi(\mathbb{L}-L_T)^{\phi-1}}{\alpha-\beta L_T}$. As p_w is exogenous for the small open economy, we have $\mathrm{d}p_w = \left(\frac{\partial p_w}{\partial L_T}\right)\mathrm{d}L_T + \left(\frac{\partial p_w}{\partial \mathbb{L}}\right)\mathrm{d}\mathbb{L} = 0$, or $\frac{\mathrm{d}L_T}{\mathrm{d}\mathbb{L}} = -\frac{\partial p_w/\partial \mathbb{L}}{\partial p_w/\partial L_T}$.

Since $\frac{\partial p_w}{\partial L_T} = \frac{\phi(\mathbb{L}-L_T)^{\phi-2}[(1-\phi)(\alpha-\beta L_T)+\beta(\mathbb{L}-L_T)]}{(\alpha-\beta L_T)^2}$, and $\frac{\partial p_w}{\partial \mathbb{L}} = \frac{\phi(\phi-1)(\mathbb{L}-L_T)^{\phi-2}}{\alpha-\beta L_T}$, it follows that

$$\frac{\mathrm{d}L_T}{\mathrm{d}\mathbb{L}} = \frac{(1-\phi)(\alpha-\beta L_T)}{(1-\phi)(\alpha-\beta L_T)+\beta(\mathbb{L}-L_T)}. \qquad \text{(A1)}$$

Appendix 2: Stability of Short-Term Equilibrium for $\phi > 1$

The condition for equilibrium stability when $\phi > 1$ is $(1-\phi)(\alpha - \beta L_T) + \beta(\mathbb{L} - L_T) > 0$.

Proof: Population at time t is $\mathbb{L}_t$ and the labor market equilibrium condition is $p_w AP_{L_T} = MP_{l_T}$, or $p_w(\alpha - \beta L_T) - \phi {l_T}^{\phi-1} = 0$, $L_T + l_T = \mathbb{L}_t$. Say manufacturing employment, l_0, is above its equilibrium level, i.e., $l_0 > l_T$. As $L_0 + l_0 = \mathbb{L}_t$, we have $L_0 < L_T$. The equilibrium (L_t, l_t) is stable if, at (L_0, l_0), $p_w(\alpha - \beta L_0) - \phi {l_0}^{\phi-1} > 0$, in which case labor moves from the manufacturing to the commodity sector and its allocation moves to equilibrium values (L_t, l_t).

Thus, the equilibrium is stable if $\frac{\partial\left[p_w(\alpha-\beta L_T)-\phi {l_T}^{\phi-1}\right]}{\partial l_T} = \beta p_w + \phi(1-\phi){l_T}^{\phi-2} > 0$. Since $p_w = \frac{\phi {l_T}^{\phi-1}}{\alpha - \beta L_T}$, we have $\phi {l_T}^{\phi-2}\left[\frac{\beta l_T}{\alpha-\beta L_T} + (1-\phi)\right] > 0$, or $\beta(\mathbb{L} - L_T) + (1-\phi)(\alpha - \beta L_T) > 0$.

QED.