TECHNOLOGICAL PROGRESS AND INCOME PER CAPITA IN DEVELOPING COUNTRIES
- FINDLAY (1980) REVISITED -

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Findlay (1980) constructs a structurally asymmetric North-South model and claims that technological progress in the South reduces its per-capita income in the long-run steady state. The purpose of this paper is to show how and under what conditions Findlay’s proposition is brought about from a wider perspective. We consider first the introduction of generalized factor augmenting technological progress in the South, and next the case where Southern countries also face labor market constraints. In Findlay (1980) these two characteristics, Solow neutral technological progress and labor surplus, are considered as the basic characteristics of the South. It is true that these properties are still prevalent, however due to recent high growth experiences the circumstances of developing countries are undergoing gradual changes with respect to Findlay’s settings. The main finding in this paper is that if these conditions are modified, technical progress in the South can lead to an increase in its per-capita income.

1. Introduction

Since the publication of Prebisch (1959) and Singer (1950), global attention has been drawn to the issue of how and by what factors asymmetries between the North and South are brought about. Prebisch and Singer did not give a formal analysis which later engendered many theoretical investigations of the issue including Findlay (1980) as the most-seminal one.

Findlay (1980) characterizes the structural differences between North and South according to the following features.

1. The North produces a composite commodity used for either consumption or investment, whereas the South produces only primary goods.
2. The South imports capital goods from the North as inputs for its production.
3. The South is a labor-surplus economy. This surplus suppresses the real wage rate in the South at the subsistence level.

Assuming these asymmetries between regions, Findlay develops a vigorous formal analysis and shows that trade is the engine of growth for the South. The power of the engine is determined, however, by the natural growth rate of the North, and in this sense the South does not have its own growth engine. Technological improvements also have asymmetrical results. Hicks-neutral or Harrod-neutral shifts in the production function of the North leave the terms of trade unchanged in the long run and increase its real per-capita income. In the South, however, a Solow-neutral shift in the production function leads to a proportional

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decline in the terms of trade and brings about a decrease in its real per-capita income measured in terms of manufactured goods.

In this paper we try to ascertain what conditions are important to these asymmetric results for technological progress. We take up two factors in turn. The first is the type of technological change in the South, and the second is the assumption of a labor surplus in the South. Findlay assumes Hicks-neutral or Harrod-neutral technical changes in the North and Solow-neutral in the South. This assumption seems natural for countries in the first stage of development. Notwithstanding, over time technical changes in the South tend to become more affected by technologies in the North through innovation and imitation, and as a result South countries also introduce Hicks or Harrod neutral types of technical change. Moreover, as Findlay (1980) has already pointed out, the assumption of surplus labor in the South changes because of high growth.

In the next section we assume a generalized factor augmenting production function in the South and consider the conditions that lead to asymmetric conclusions for technical progress in the South. In the third section, we examine the effects of relaxing the surplus labor assumption in the South. Lastly, we summarize our findings in this paper.

A large literature relating to the North-South economy deals with these asymmetric issues from various viewpoints. There are, however, few papers examining the topics discussed in this paper.1)

2. Factor augmenting technical progress in the South

Our model is based on Findlay’s structuralist North-South model. We modify the production function in the South to permit more general types of technological progress.

2.1 Production in the North and South

The North, using labor $L$ and capital $K$, produces manufactured goods used for either consumption or investment purposes. Denoting $A$ as Hicks or Harrod neutral technological progress in the North, the production function is expressed as

$$Y = AF(K, L).$$ (1)

Constant-returns-to-scale (CRS hereafter) with respect to capital and labor are assumed, so we can rewrite (1) as the following per-capita output function:

$$y = Af(k), \quad k = \frac{K}{L}, \quad y = \frac{Y}{L}. \quad (2)$$

1) Adachi (1995) and Sarkar (1998)(2001) discuss technological progress in the South, but they do not pay attention to income per capita. Abe (2005) considers the case where the South is also constrained by labor supply like North.
In the South, we assume a generalized factor augmenting production function with CRS.

\[ Y^* = F^* (A^* L^*, A^* K^*) \]  

(3)

We can control the type of technological improvements such as Solow-neutral, Harrod-neutral, or more general types by changing \( \lambda_L \) and \( \lambda_K \) as in Osumi (2001). The per-capita production becomes

\[ y^* = A^* \lambda_L \left[ f^* (A^* k^*) - f^* (z) \right] \]  

(4)

\[ z = A^* \lambda_K k^*, \quad y^* = \frac{Y^*}{L^*}, \quad k^* = \frac{K^*}{L^*}. \]

Under perfect competition in the South, we set the marginal productivities of labor and capital equal to the real wage rate, \( w^* \), and the profit rate, \( r^* \), respectively.

\[ w^* = A^* \lambda_L \left[ f^* (z) - f^* (z^*) \right] \]  

(5)

\[ r^* = p A^* \lambda_K f^* (z). \]  

(6)

Here \( p \) is the price of primary goods measured in manufactured goods, and describes the terms of trade of the South. Note that from the labor surplus assumption for the South the real wage rate, \( w^* \), is constant.

### 2.2 Trade

In this section we set up the trade equilibrium. As the South produces consumption goods, the per-capita imports of the North depend on its per-capita consumption as well as on the terms of trade. Assuming the North saves a constant fraction, \( s \), of per-capita income, its per-capita consumption becomes \( (1 - s) A f (k) \). Thus, its per-capita imports, \( M = M / L \), are expressed as

\[ M = m \left[ p, (1 - s) A f (k) \right] L, \]  

(7)

where we assume that an increase in the southern terms of trade lowers the import demands of the North, \( dm / dp < 0 \), and that the import elasticity with regard to per-capita consumption is equal to unity.

Next, the per-capita import demand of the South is made up of both capital goods and consumption goods, and expressed as

\[ M^* = [ps^* f^* (z) A^* \lambda_K k^* + \mu(\frac{1}{p}, w^* + (1 - s) f^* (z) A^* \lambda_K k^*)]L^*. \]  

(8)
The first term in brackets on the R.H.S is investment demand, where South’s per-capita investment imports demand corresponds to savings from profit income with a saving rate $s^*$. The second term is South’s per-capita consumption imports, $\mu$, which depend negatively on the terms of trade $1/p$, $d\mu/d(1/p) < 0$, and positively on per-capita income, which is composed of wage and profit income. Here laborers in the South are assumed to spend all of their wage income and the income elasticity of import demand is assumed to be unity, just as it was for the North.

The balance of trade is expressed as

$$pM = M^*.$$  \hspace{1cm} (9)

Substituting equations (7) and (8) into (9), the trade balance is rewritten as

$$pm[p, (1-s)Af(k)] = [ps^* f''(z)A^* A^* k^* + \mu \left( \frac{1}{p^*}, w^* + (1-s^*) f''(z)A^* A^* k^* \right)] \lambda.$$  \hspace{1cm} (10)

Here $\lambda = \frac{L^*}{L}$ is the population ratio of the South to the North.

2.3 Capital Accumulation

Capital accumulation in the North is assumed to be financed through domestic saving. Then the movement of the capital-labor ratio in the North, $k$, is given as follows, where $n$ is the growth rate of labor in the North:

$$\dot{k} = sAf(k) - nk.$$  \hspace{1cm} (11)

Next, from (5), $k^*$ remains constant when the real wage rate $w^*$ is fixed at the subsistent level. Therefore, both employment $L^*$ and capital $K^*$ in the South grow at the same rate, and the dynamic equation for the employment ratio of the South to the North, $\lambda$, is given as

$$\dot{\lambda} = \{ps^* f''(z)A^* A^* k^* - n\} \lambda.$$  \hspace{1cm} (12)

Thus, Findlay’s model with generalized technological progress in the South is composed of seven equations: (2), (4), (5), (6), (10), (11) and (12). The endogenous variables are $y, k, y^*, k^*, \lambda, r^*$ and $p^*$.

2.4 Findlay’s proposition

First, in short-run equilibrium, $y, y^*, k^*, r^*$ and $p$ are determined by equation (2), (4), (5), (6) and (10), where $k$ and $\lambda$ are predetermined. From (4) and (5), and the fact that $w^*$ is fixed at the subsistent level, the capital labor ratio, $k^*$, and per-capita income in the South, $y^*$, are determined solely by southern parameters as follows:

2) Hereafter, $\dot{x}$ expresses a time derivative.

3) \( \dot{x} \) denotes an elasticity, \( \dot{x} = \frac{dx}{x} \).
\[
\hat{w}^* = \left[ \lambda_L \left( 1 - \frac{\xi_f}{\sigma} \right) + \lambda_K \frac{\xi_f}{\sigma} \right] \dot{A}^* + \frac{\xi_f}{\sigma} \dot{k}^*,
\]
(13)

\[
y^* = \left[ \lambda_L \left( 1 - \frac{\xi_f}{\sigma} \right) + \lambda_K \frac{\xi_f}{\sigma} \right] \dot{A}^* + \frac{\xi_f}{\sigma} \dot{k}^*,
\]
(14)

where \( \xi_f := -\frac{f'' z^*}{f^*} \) is the elasticity of the marginal product with respect to \( z \), and

\[
\sigma := -\frac{(f^* - f'' z^*) f''}{z^* f''} \]

is the elasticity of substitution.

Findlay (1980) assumes Solow-neutral technological progress in the South, \( \lambda_L = 0 \), \( \lambda_K = 0 \) and \( \lambda_K = 1 \). Then, from (13), a rise in \( A^* \) brings about a proportional decrease in \( k^* \) and, from (4), per-capita income in the South remains intact because \( z = A^* k^* \) remains constant. Next, we can show that the terms of trade remain constant in the short-run because \( A^* \lambda_L k^* = A^* k^* = z \) is constant in (10). Therefore, in the short-run, Solow-neutral technological progress in the South leaves its per-capita income measured in terms of manufactured goods, \( p y^* \), constant.

Next, we turn to the long-run steady state equilibrium (see the Appendix for stability conditions). In the steady state, the capital labor ratio in the North is determined by

\[
s Af(k) = nk,
\]
(15)

and from (12) we have

\[
ps^* f''(z) A^* - n = 0.
\]
(16)

Note that \( z \) still remains constant from (5). Thus, from (16), an increase in \( A^* \) leads to a proportionate decrease in \( p \). Therefore, technological progress in the South brings about a decrease in its per-capita income in the long-run equilibrium. This is what Findlay shows in his 1980 article.

### 2.5 Generalized factor augmenting technical progress

Findlay’s proposition shows an important asymmetric property between the North and South. This is a strong trait when we consider that in the long run technological progress in the North necessarily raises per-capita income in the North and leaves it intact in the South. This perverse result comes from deterioration in the terms of trade for the South, which results from technological progress in the South.

The problem here stems from how the perverse effects of technical change in the South relate to its factor augmenting parameters. We have the following proposition.

**Proposition 1** In the long-run steady state factor augmenting technical progress in the South
raises its per-capita income, measured in terms of manufactured goods, if and only if

\[
\left(1 - \sigma + 1 - \frac{f^*}{f^* z^*} \right) \lambda_L - \lambda_K > 0 .
\]  

(17)

**Proof** From (16)

\[
\hat{P} + f^* \frac{z}{f^*} \left( (\lambda_K - \lambda_L) \dot{A}^* + \dot{k}^* + \lambda_K A^* \right) = 0 .
\]  

(18)

From (5)

\[
\lambda^L \dot{A}^* + \frac{1}{\sigma} \left( f^* \frac{z}{f^*} (\lambda_K - \lambda_L) \dot{A}^* + \dot{k}^* \right) = 0 .
\]  

(19)

From (4)

\[
\frac{d (py^*)}{py^*} = \hat{p} + \lambda_L \dot{A}^* + f^* \frac{z}{f^*} \left( (\lambda_K - \lambda_L) \dot{A}^* + \dot{k}^* \right) .
\]  

(20)

Substituting (18) and (19) into (20), we have

\[
\frac{d (py^*)}{py^*} = \left[ \left(1 - \sigma + 1 - \frac{f^*}{f^* z^*} \right) \lambda_L - \lambda_K \right] \frac{d A^*}{A^*} .
\]  

(21)

**QED**

Findlay’s conclusion is obtained when \(\lambda_L = 0\) and \(\lambda_K = 1\). But in the case of generalized technological progress, Findlay’s conclusion does not hold.

**Proposition 2** If Harrod-neutral technological progress is introduced in the South and if the elasticity of production with respect to \(z\) is sufficiently large, condition (17) is satisfied.

**Proof** When \(\lambda_L = 1\) and \(\lambda_K = 0\), condition (21) is rewritten as

\[
\frac{d (py^*)}{py^*} / \frac{d A^*}{A^*} = -\xi_f \frac{2 + (2 \xi_f + 1) \xi_f - \xi_f^*}{\xi_f \xi_f^*} ,
\]  

(22)

where \(\xi_f = f''' z / f'^*\) and \(\xi_f^* = f'''' z / f'^*\). As illustrated in FIGURE 1 the RHS of (22) becomes positive when \(\xi_f\) is greater than \(\xi_f^*\).
3. Non-Surplus Labor in the South

In this section, we consider the case where the labor market becomes restrictive in the Southern economy, similar to the North, to examine whether labor market asymmetry supports Findlay’s proposition. For this purpose we continue to assume that technological progress in the South is Solow-neutral.

First, we delete the assumption of a fixed real wage in the South and assume that the labor supply is fully employed in the South just as it is in the North. We assume that labor supply in the South, $L^*$, grows at the same rate as that of the North, although this assumption will be removed later in this section. Labor in both regions grows at the same rate, $n$, so that the labor ratio of the two regions, $\lambda$, remains constant. Instead, we now have to consider the dynamic movement of $k^*$. We write down the complete model as follows:

\[ y = Af(k), \]  
\[ y^* = f^*(z), \]  
\[ w^* = f^*(z) - f^{**}(z)z, \]  
\[ r^* = pA^* f^{**}(z), \]  
\[ pm \left[ p, (1-s)Af(k) \right] = \frac{psf^{**}(z)z}{p^*} + \mu \left( \frac{1}{p^*} , w^* + (1-s)f^{**}(z)z \right) \lambda, \]  
\[ k = sAf(k) - nk, \]
\[ k^* = \{ s f''(z) A^* p - n \} k^*, \]  
\[ z = A^* k^*. \]  

Using the above eight equations, we derive the movements of endogenous variables: \( y, k, y^*, k^*, z, w^*, r^* \) and \( p \) \).

### 3.1 Short-run effect of technological progress

In the short-run, \( k \) and \( k^* \) are predetermined from (28) and (29). Therefore from \( z = A^* k^* \) we know that an increase in \( A^* \) raises \( z \) proportionately so that \( y^* \) increases. In order to find the effect on per-capita income in the South, we have to know the effect on the terms of trade. The terms of trade are determined from trade equilibrium (27). From (27) we have

\[
T_1 \dot{p} + T_2 A^* = 0, 
\]

\[
T_1 = \eta_S + \eta_N \frac{pm}{\lambda \mu} - 1 > 0, \tag{32} 
\]

\[
T_2 = \left( \frac{pm}{\lambda \mu} - 1 \right) (1 + \xi_{F^*}) + \xi_f \left( 1 - \frac{s^*(1 + \xi_{F^*})}{1 - s^* \xi_f} \right) > 0, \tag{33} 
\]

where \( \eta_N \) and \( \eta_S \) are the import elasticities of the North and South with respect to the terms of trade. The Marshall-Lerner condition in this model is modified by the investment demand from the South, which is formulated as (32). We assume this condition holds; \( T_1 > 0 \). Next From \( pm > \lambda \mu, 1 > \xi_{F^*} > 0 \) and \( 1/s^* > 1 + \xi_{F^*} > 0 \), we know that \( T_2 > 0 \). Therefore, we know that in the short-run technological progress in the South deteriorates its terms of trade. The overall effect on per-capita income measured in terms of manufactured goods, however, is ambiguous, because per-capita income, \( y^* \), and the terms of trade, \( p \), move in opposite directions. The larger import elasticities \( \eta_S \) and \( \eta_N \) become, the smaller the decline in the terms of trade is. Then an increase in \( y^* \) dominates a decline in \( p \), and thus an increase in per-capita income in the South results from its technological progress.

### 3.2 Long-run effect of technological progress

Is the short-run conclusion still preserved in the long-run steady state? First, we examine the stability of this dynamic model.

**Proposition 3** Dynamic equations of \( k \) and \( k^* \) described by (28) and (29) are stable and converge to the steady state equilibrium.

**Proof** The terms of trade, \( p \), depend on \( k \) and \( k^* \) from the trade balance (27). The Jacobian matrix becomes

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4) This model is already presented in Abe (2005), although in this section we extend the analysis to include the case where population growth rates differ between the North and South.
From the concavity of the production function we have

\[ sAf'(k_0) - n = sA \left( f'\left(k_0\right) - \frac{f'(k_0)}{k_0} \right) < 0, \]

where \( k_0 \) is the equilibrium. Moreover from (27) we have

\[ T_1 \dot{p} + T_2 \dot{k}^* + T_2 \dot{A}^* - \hat{\xi}/\hat{k} = 0. \]

Therefore \( \partial p / \partial k^* < 0 \). Thus the trace condition for stability is satisfied and the determinant condition \( |J| > 0 \) for stability is also satisfied.

Now we turn to the effects of technological progress in the South. In the steady state, the capital labor ratio \( k \) is determined solely by Northern parameters in (28). Hence, the terms of trade and the capital labor ratio in the South are determined simultaneously by trade balance (27) and capital labor equilibrium in the South (29), which are expressed as follows:

\[ (T) \quad T_1 \dot{p} + T_2 \dot{k}^* = -T_2 \dot{A}^*. \]

\[ (H) \quad \dot{p} + \hat{\xi}\dot{k}^* = -(1 + \hat{\xi} f^*) \dot{A}^*. \]

(37) describes the trade equilibrium, where \( p \) and \( k^* \) are downward sloping, and (38) expresses equilibrium between capital and labor in the South, where \( p \) and \( k^* \) are upward sloping (FIGURE 2). Technological progress in the South shifts both (T) and (H) downwards. Thus, the terms of trade are sure to decline but the change in \( k^* \) is ambiguous.

From (37) and (38) we have

\[ \frac{d (py^*)}{py^*} / \frac{dA^*}{A^*} = \left(1 - \hat{\xi} \frac{T_1}{T_2}\right) \frac{dp / p}{dA^*/A^*}. \]

As we know that \( dp / dA^* < 0 \), the change in per-capita income in the South measured in terms of manufactured goods depends on the sign of the terms in parenthesis on the RHS. \( T_1 \) describes the effect of terms of trade on the trade balance. On the other hand, \( T_2 \) describes the effect of per-capita production on the trade balance. Therefore, we can say that if the
price effect $T_1$ is larger than the income effect $T_2$, technological progress in the South leads to a rise in per-capita income in the long-run. In other words, in this case the deteriorating change in the terms of trade becomes smaller so that the production accelerating effect of technological improvement dominates the deteriorating effect of the terms of trade. In this sense the short-run property is sustained in the long-run steady state.

### 3.3 Different population growth rates

In the above discussion we assumed that the population of the South grows at the same rate as that of the North. However, it is probable that the growth rate of the population in the South is larger than that of the North even after the South economy faces a labor constraint. We discuss this situation briefly.

Let the population growth rate in the South be $n^*$ and assume that $n^*$ is greater than $n$. Then the population ratio $\lambda$ becomes a variable that moves according to

$$
\dot{\lambda} = (n^* - n) \lambda.
$$

Therefore $\lambda$ increases indefinitely. On the other hand, the capital labor ratio in the North $k$ moves according to (28), and thus converges to the same equilibrium as before. As $k$ converges and $\lambda$ increases indefinitely, Southern import demand becomes greater than its exports. As a result the terms of trade for the South must deteriorate indefinitely in order to restore the trade balance.

As for the capital labor ratio in the South we have the following equations.

$$
\dot{k}^* = \{s^* f^*(z^*) A^* p (k, k^*, \lambda; A^*) - n\} k^*,
$$

where from (27) the terms of trade $p$ depend positively on $k$ and negatively on $k^*$, $\lambda$, and $A^*$. As illustrated in FIGURE 3, in the long-run $k^*$ declines indefinitely as a result of the
As a result of the continuing decline in $p$ and $k^*$, per-capita income in the South decreases indefinitely. Technological progress in the South can temporarily mitigate this decline but in the long run this deteriorating trend will dominate.

4. Conclusion

In this paper we discussed what factors relate to the perverse result of technological progress which Findlay (1980) claimed as typical for a North-South economy. We picked up two factors. The first is types of technological progress in the South and the second is the assumption of a labor surplus in the South. These seem to be natural assumptions and are considered to be the basic characteristics that retard development in the South. Although still different from developed countries, recently, conditions surrounding the South are changing. The South is more likely to introduce Northern oriented technological progress, including Harrod or Hicks neutral types. Moreover, as a result of high economic growth, southern countries are also facing labor market constraints.

We showed that if technological progress becomes Harrod or Hicks type then Findlay’s proposition is modified, and moreover if the South is constrained by the labor market, then per-capita income in the South can increase under some conditions. In this sense, these two characteristics are the key factors of Findlay’s proposition. As for the introduction of Northern technologies or labor shortage constraints, we should avoid overstating the significance of such changes. Findlay’s characterizations are still robust, but it seems
almost certain that the changes examined in this paper are sure to come. As is pointed out in Findlay (1980), capital movement is another important factor to be considered. We leave this problem for another paper.

Appendix

Stability of the long-run equilibrium

As \( w^* \) is assumed to be constant, \( z \) is constant from (5), and thus \( k^* \) is also constant. Then the Jacobian matrix of dynamic equations (11) and (12) becomes

\[
J = \begin{pmatrix}
  sAf'(k) - n & 0 \\
  \frac{\partial p}{\partial k} s f^{*\prime} A^{\cdot \lambda k} & \frac{\partial p}{\partial \lambda} s f^{*\prime} A^{\cdot \lambda k}
\end{pmatrix}.
\]

The terms of trade \( p \) is determined from (10) depending on \( k \) and \( \lambda \) as follows:

\[
\frac{\mu \lambda}{p} \left( 1 - \eta_S - \eta_N \right) \frac{m}{\mu \lambda} dp + p \frac{dm}{dy} (1-s)Af'^\prime dk = \frac{pm}{\lambda} d\lambda.
\]

If Marshall-Lerner conditions are satisfied, we know that \( \frac{\partial p}{\partial k} > 0 \) and \( \frac{\partial p}{\partial \lambda} < 0 \). As \( sAf' - n < 0 \), the trace condition for stability is satisfied. Next the determinant condition for stability \( |J| > 0 \) is also satisfied.

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