

Trade Reform, Capital Mobility, and Efficiency Wage in a Harris-Todaro Economy

TITAS KUMAR BANDOPADHYAY

The main purpose of this paper is to analyse the impact of trade reform on unemployment and social welfare in a Harris-Todaro (1970) economy with efficiency wage and capital mobility. The analysis shows that capital mobility plays an important role to influence the impact of trade reform on unemployment and social welfare. We find that trade reform raises urban unemployment and produces an ambiguous effect on social welfare when capital is perfectly mobile among the three sectors. However, such policy lowers unemployment and raises social welfare when capital is imperfectly mobile.

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1. INTRODUCTION

At the present juncture, the importance of the informal sector has gained momentum in the developing countries. In Africa, 60 percent of total urban employment is found in the informal sector. The figures reach 57 percent in Bolivia and Madagascar, 56 percent in Tanzania, 53 percent in Colombia, 48 percent in Thailand and 46 percent in Venezuela. In Uganda, we find 90 percent of the total non-farm private sector workers are engaged in the informal sector [see Haan (2002)]. According to the OECD, the Mexican informal units provide 44 percent of urban employment [see Franco (1999)]. In the European Union, 20 million workers are employed in informal sector. Thus, the inclusion of the informal sector in the analysis of economic development is highly justified for the developing countries.

Recently, researchers have paid adequate attention to trade liberalisation and its effects on the economy. In some countries, trade reform reduces unemployment and raises informal wage, while others experience the opposite. Thus, informal sector and trade policies are two important issues in development economics.

The Harris-Todaro framework is a very useful analytical tool to investigate a variety of questions relating to development economics, where informal economy and international trade are very prominent issues.

Urban informal sector has been included in the Harris-Todaro (1970) economy in a variety of models most important of which are Portes (1969), Chandra (1991), Chandra and Khan (1993), Grinols (1991), Stiglitz (1982), Fields (1989, 1990), Rauch (1991), Gupta

Titas Kumar Bandopadhyay <titasban@yahoo.co.in> teaches Economics at Bagnan College, Bagnan, Howrah, West Bengal, India.

(1993, 1997), and Bandopadhyay and Gupta (1995), Yabuuchi (2001, 2005), Chaudhuri (2003a) etc. Chandra and Khan (1993) develop a generalised Harris-Todaro (1970) model incorporating informal sector and capital mobility. Fields (1989, 1990) includes informal sector in a multisector labour market model. Rauch (1991, 1993) analyses poverty and inequality in a Harris-Todaro (1970) economy. Gupta (1993, 1997) also considers informal sector and capital mobility in a generalized Harris-Todaro (1970) economy. Bandopadhyay and Gupta (1995) make comparative static analysis in a Harris-Todaro (1970) model with capital mobility. Chaudhuri (2003b) also include informal sector and investigate some policy effects in a Harris-Todaro (1970) economy. Grinols (1991) re-examines the welfare impact of tariff policy in a Harris-Todaro (1970) economy.

Khan (1993) develops a multisector Harris-Todaro (1970) model to analyse some issues relating to international trade and economic development. Jones and Marjit (1992) also reconsider the Khan (1991) model. Kar and Marjit (2001), Marjit (2002, 2003), Marjit, Kar, and Sarkar (2003), Marjit and Acharyya (2003) investigate the impact of trade reform on the informal economy and they show that such effect depends upon the nature of capital mobility between formal and informal sector and the global exposure of all the goods produced in the economy. Trade liberalisation expands informal sector if capital is specific to the formal sector and all the goods are internationally traded.

Further, a number of trade related issues have been analysed in a variety of models which are purely Harris-Todaro (1970) in nature. For instance, Khan and Lin (1982), Chao and Yu (1997, 1999) show that gains from trade depends on the nature of the rural as well as urban commodity. Bhagwati and Srinivasan (1977) and Chaudhuri and Mukopadhyay (2003) analyse the effects of education policy in a trade theoretic model of the Harris-Todaro economy. Panagariya and Succi (1986), Beladi (1988) and Choi (1999) discuss trade related issues in a Harris-Todaro (1970) model with variable returns to scale. Gupta and Gupta (1998) develop a Harris-Todaro (1970) model incorporating foreign enclave to analyse various trade related issues. Khan and Naqvi (1983), Chao and Yu (1992) describe a trade theoretic Harris-Todaro (1970) model with capital market distortion. Khan (1979, 1991), Khan and Chaudhuri (1985) consider interaction of ethnic groups in a Harris-Todaro (1970) framework. Beladi and Ingene (1994) introduce risk and uncertainty in a Harris-Todaro (1970) economy.

Thus, the use of Harris-Todaro (1970) model to analyse the issues relating to the informal sector and international trade is justified.

It is almost known that labour standards signal job quality. Compliance with labour standard ensures job in high productivity formal sector, whereas low-productive informal sector employs workers having no compliance with labour standard.¹ The, formal-informal distinction with respect to Government regulation has been observed in the works of Marcouiller and Young (1995), Dessy and Pallage (2003), Azuma and Grossman (2002), Boeri and Garibaldi (2002), Goldberg and Pavenik (2003) and Rauch (1991). Goldberg and Pavenik (2003) offer an efficiency wage model of the informal sector. In their model, regulation protecting formal sector workers ensures they can not be monitored and they receive above-market wages in order to discourage shirking.

¹It is assumed that the rural sector is more productive than the urban informal sector and this is reflected in the capital intensity assumption of the two sectors.

It is universally accepted that employers can raise workers' productivity by paying higher wages and this is justified for the low wage sector having no labour standard. Thus, the efficiency-wage relation is applicable to the urban informal sector.² The idea of the efficiency-wage theory first developed by Leibenstein (1957) and then Stiglitz (1976), Bliss and Stern (1978), Akerlof and Yellen (1986) and Weiss (1990). The basic idea of the efficiency-wage theory is that a worker's efficiency is positively related to the wage rate he receives. This is generally valid in the case of low income workers who consume the whole wage income and suffer from malnutrition. The employers use this wage as an instrument of profit maximisation and the optimum wage appears to be unique and independent of other economic variables. Urban unemployment may be explained by the efficiency-wage relation in the urban informal sector.³

In this paper, we introduce efficiency-wage and capital mobility in a trade theoretic generalised Harris-Todaro (1970) economy. Two types of capital mobility are considered here: (1) capital is perfectly mobile among the three sectors; (2) capital is mobile between the formal sector and the rural sector, while the urban informal sector uses sector specific capital.⁴

Our model differs from the existing works on informal economy and trade reform on the following grounds: (1) we distinguish between formal and informal sector by compliance with labour regulation; (2) we consider urban unemployment and explain this in terms of efficiency-wage relation in the urban informal sector; (3) we introduce two types of intersectoral mobility of capital which are usually absent in the standard literature on trade reform.

The general equilibrium effects of trade reform on urban unemployment, on the size of the informal sector and on the social welfare are also examined in this paper. Our analysis reveals that the nature of intersectoral mobility of capital plays important role to determine the impact of reformatory policy on urban unemployment and social welfare in the post-reform period.

Section 2 describes the model and the results. The concluding remarks are given in Section 3.

2. MODEL AND RESULTS

We consider a small open economy consisting of three sectors: the urban formal sector (u), the urban informal sector (i) and the rural sector (r). The products (X_u) of the urban formal sector is import-goods and the product (X_r) of the rural sector is export-goods. The product prices of these two goods are exogenously given by the rest of the world. However, the informal sector produces non-traded goods (X_i), the prices of which is determined within the domestic market.

The production functions of all the three sectors exhibit constant returns to scale and have positive and diminishing marginal productivity to each input. Each sector uses only two inputs—Capital and Labour. Capital is measured in physical unit, while labour is measured in efficiency unit.⁵

²It is assumed that the rural sector is more capitalised which ensures higher efficiency for the workers.

³Fields (1989) explains urban unemployment in a framework where people remain unemployed for full time searching for urban formal sector jobs. Gupta (1993) explains this in terms of market clearing for the rural sector's product whose price is fixed.

⁴We find this type of capital mobility in Gupta (1997) and Grinols (1991).

⁵The efficiency-wage theory implies that the physical unit of labour differs from the efficiency unit of labour.

We distinguish between formal and informal sector by compliance with labour regulation. We assume that formal sector complies with labour regulation. Such regulation maintains labour standard by paying minimum wage (ω_u), which is higher than the market-clearing level. However, the urban informal sector is unregulated and do not comply with labour standard and pay lower wage (ω_i). Urban formal sector's wage rate is institutionally fixed⁶ and is higher than the rural sector's wage rate which is again higher than the wage rate in the urban informal sector.

Workers' efficiency (h) is positively related to the wage rate he receives. Such efficiency-wage relations is more pronounced when the wage rate is low due to the absence of labour standard. It is assumed that the workers' efficiency is equal to unity after a certain level of wage ($\bar{\omega}$) and is less than unity below that specified level. The wage rates in the rural sector (ω_r) and the urban formal sector (ω_u) are assumed to be higher than this specified level.⁷ The wage rate in the urban informal sector is assumed to be lower than this level.⁸ Thus, for the urban formal sector and the rural sector, the labour expressed in labour time unit is identical to that expressed in efficiency unit. However, for the urban informal sector, efficiency units of labour differ from the labour time units of labour.

All the markets are assumed to be perfectly competitive. The assumption of CRS production function and profit maximising behaviour of the firm implies the equality between price and unit cost in each of the three sector and the minimisation of cost of one efficiency unit of labour.

Workers migrate from the rural sector to the urban region. But some of them are absorbed either in the urban formal sector or in the urban informal sector and a portion of the migrants remains unemployed in the urban region. The migration mechanism is of Harris-Todaro (1970) type. So, in migration equilibrium, the actual rural wage rate is equal to the expected urban wage rate.

It is assumed that the urban formal sector is more capital intensive than the rural sector which is again more capital intensive than the urban informal sector.⁹

The common equation structure used in the two models is as follows

The intensive production functions in the three sectors are given by the following equations:

$$X_u = L_u f_u(k_u) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (1)$$

$$X_i = L_i f_i(h, k_i) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (2)$$

$$X_r = L_r f_r(k_r) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (3)$$

The efficiency-wage relation is given by

$$h = h(\omega_i) \quad \text{with } h' > 0, h'' < 0, h < 1, \text{ for } \omega < \bar{\omega} \text{ and } h = 1 \text{ for } \omega > \bar{\omega} \quad \dots \quad (4)$$

⁶This is set by labour standard.

⁷Urban formal sector wage is higher due to labour standard and rural wage is higher due to its capitalistic structure of production.

⁸This is due to the absence of labour standard in the urban informal sector.

⁹This the stability condition of the model.

The cost of one efficiency unit of labour in the urban informal sector is:

$$v_i = \omega_i / h(\omega_i) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (5)$$

The condition for minimisation of the cost of one efficiency unit of labour is:

$$h'(\omega_i)\omega_i / h(\omega_i) = 1 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (6)$$

The Harris-Todaro (1970) migration equilibrium condition is given by the following equation:

$$\omega_r = \omega_u L_u / (1 - L_r) + \omega_i L_i / (1 - L_r) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (7)$$

where L_u, L_i, L_r are the level of employment in the three sectors and the total labour endowment in the economy is assumed to be 1.

The labour endowment equation is given by the following:

$$L_u + L_i + L_r + U = 1 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (8)$$

Where U is the level of urban unemployment.

We consider the welfare measure of Sen (1974). Thus, the social welfare is given by

$$SW = E(1 - M) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (9)$$

Where E is the average income of all workers and M is the Gini-coefficient of the income distribution of the workers.

Using Equations (7), (8) and (9) we get,¹⁰

$$SW = \omega_r (L_u + L_r) - L_u L_r (\omega_u - \omega_r) + \omega_i L_i (1 - U) \quad \dots \quad \dots \quad \dots \quad (9.1)$$

It should be noted that the set of Equations given by (1) – (8) and (9.1) are independent of the nature of capital mobility assumptions to be discussed below.

2.1. Capital Mobility among the Urban Formal Sector, Urban Informal Sector, and the Rural Sector

In this section, we assume perfect mobility of domestic capital among the three domestic capital using sector. Thus, we have a common rate of return on domestic capital. We also assume that u -sector is more capital intensive than the r -sector which is more capital intensive than the i -sector in value terms.

Along with the Equations (1) to (8) and (9.1) the following additional Equations are to be considered here:

The long-run equilibrium of a competitive firm implies that price is equal to the unit cost. Hence we have the following equations:

$$P_u (1 + t) = C_u (\omega_u, R) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (10)$$

$$P_i = C_i (v_i, R) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (11)$$

$$P_r = C_r (\omega_r, R) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (12)$$

¹⁰ The derivation is shown in the Appendix (A).

The full utilisation of capital stock leads to the following equation:

$$k_u L_u + k_i L_i + K_r L_r = K \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (13)$$

The equilibrium of informal sector is characterised by the equality between the demand for and the supply of its product because this sector produces a non-traded good. Thus, we have,

$$L_i f_i(h, k_i) = D(p_i) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (14)$$

Here, $D(p_i)$ represents the demand for the product of the urban informal sector; and $D'(p_i) < 0$. For the sake of simplicity, we assume that the income effect of the demand for this non-traded good is nil.

The profit maximising capital intensities in the three sectors are related to the factor price ratios in the corresponding sectors. So we have,

$$k_u = k_u(\varpi_u / R), \quad k'_u > 0 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (15)$$

$$k_i = k_i(v_i / R), \quad k'_i > 0 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (16)$$

$$k_r = k_r(\omega_r / R), \quad k'_r > 0 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (17)$$

This completes the equation structure of the model.

The working of the model is described as follows:

Equation (9) determines the equilibrium value of ω_r . Then, we get the value of v_i from Equation (8) and of h from Equation (4). Equation (5) yields the value of R , given P_u and ϖ_u . So, ω_i is obtained from Equation (7), given P_r . Equation (6) determines the value of P_i , given the equilibrium values of v_i and R . Thus, we get (ϖ_u / R) , (ω_i / R) , (ω_r / R) . So, we can determine the equilibrium values of k_u, k_i, k_r from Equations (15), (16) and (17). Equation (13) yields L_i , given the equilibrium values of h, k_i, P_i . We can solve for L_u, L_r from Equations (7) and (8).

The equilibrium values of X_u, X_i, X_r are obtained from Equations (1), (2) and (3) respectively. Now, Equation (8) yields equilibrium values of U . Finally, we can solve for S.W. from Equation (9.1).

Proposition 1. A fall in t raises urban unemployment. However, its effects on the level of employment in the urban informal sector and social welfare are ambiguous.

Proof. If t is reduced, Equation (5) shows that R will fall. From Equation (7), we find that ω_r will rise. Equation (6) shows that P_i will also fall when R falls, given v_i . Thus, $(\varpi_u / R), (\omega_i / R), (\omega_r / R)$ will rise; and so also k_u, k_i, k_r .

When P_i falls, $D(p_i)$ rises. Looking at the Equation (13) we find that L_i may move in any direction when P_i falls and k_i rises, given h . Hence, the KK curve shifts downward because k_u, k_i, k_r rise. However, the LL curve may shift in any direction. Hence, we do not get unambiguous effects on L_u^*, L_r^* .

However, looking at the Equation (11), we find that (L_u, L_i, L_r) falls when k_u, k_i, k_r rise and K is given. Thus, Equation (12) shows that U will rise in the new equilibrium. The effect on S.W. is ambiguous, since L_u^*, L_r^*, L_i^* may move in any direction when t falls.

2.2. Capital Mobility between Urban Formal Sector and Rural Sector

In this section, we relax the assumption of perfect mobility of capital. Here, we follow Grinols (1991); and assume that the informal sector uses only informal capital, while both the rural sector and the formal sector use formal capital. Thus, in equilibrium, we have a common rate of return on formal capital in these two sectors. However, the urban informal sector uses the informal capital which is sector-specific. So there exists a different interest rate in the informal capital market.

Along with the Equations (1) to (8), and Equation (9.1) the following additional Equations are to be considered here:

As the unit cost is equal to the effective price in competitive equilibrium in each of the three sectors, we have the following three equations:

$$P_u(1+t) = C_u(\omega_u, R_f) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (10a)$$

$$P_i = C_i(v_i, R_i) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (11a)$$

$$P_r = C_r(\omega_r, R_f) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (12a)$$

The full utilisation of the stock of formal capital and the informal capital leads to the following two equations:

$$k_i L_i = K_i \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (13a)$$

$$k_u L_u + k_r L_r = K_f \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (14a)$$

$$k_u = k_u(\omega_u / R_f), \quad k'_u > 0 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (15a)$$

$$k_i = k_i(v_i / R_i), \quad k'_i > 0 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (16a)$$

$$k_r = k_r(\omega_r / R_f), \quad k'_r > 0 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (17a)$$

Equation (6) determines the equilibrium value of ω_i . Then, we get h from Equation (4), and v_i from Equation (5). R_i is obtained from Equation (11a), given P_i . Thus, (ω_i / R_i) is determined and hence, we get optimum k_i . L_i is obtained from Equation (13), given K_i . Equation (2) gives X_i . Equations (10a) and (12a) determine R_f and ω_r . Then Equations (15) and (17) determine k_u and k_r . Now, we can solve for L_u and L_r from Equation (7) and Equation (14a).

We assume that the urban region is more capital intensive than the rural region in value terms. The equilibrium value of U is obtained from Equation (8). Finally, we get SW from Equation (9.1).

Proposition 2. Reduction in t lowers urban unemployment and improves social welfare. However, it has no effect on employment in the urban informal sector.

Proof. Fall in t does not affect L_i because P_u does not enter into the system of determination of ω_i, R_i, k_i and L_i . If t is reduced, Equation (10a) shows that R_f will fall. t when R_f falls, ω_r has to rise to keep the Equation (12a) satisfied. Hence, (ω_u/R_f) and (ω_r/R_f) rise and so also k_u and k_r . This causes excess demand for mobile capital. Thus, the capital intensive sector contracts and the labour intensive sector expands. So, in equilibrium, L_u falls and L_r rises. This result is also derived mathematically in the Appendix (C).

The strict capital intensity condition also implies that L_r rises more than the fall in L_u . Thus, U falls, given L_i and L . This is also obtained from Equation (18).

As t falls, ω_r rises, L_u falls, L_r rises, $(L_u + L_r)$ rises, U falls and ω_i, L_i remain unchanged. From Equation (9.1), we find that the first term rises. The third term also rises. The second term falls if the elasticity of rural employment with respect to the urban-rural wage gap is less than 1.¹¹ This is shown in the Appendix (D). Thus, social welfare improves.

3. CONCLUSION

The reformatory policy produces ambiguous effects in different countries in the global economy. The present paper mainly focuses on the employment and welfare aspects of trade reform. Two types of capital mobility are considered in this paper: perfect capital mobility among the urban formal sector, the rural sector and the urban informal sector; and imperfect capital mobility between the urban formal sector and the rural sector, while urban informal sector uses sector-specific capital. Tariff reduction raises the problem of urban unemployment and produces ambiguous effect on social welfare in the case of perfect mobility of capital. However, such reformatory policy lowers urban unemployment and raises social welfare if capital is mobile only between the urban formal sector and the rural sector. Thus, our analysis shows that the degree of capital mobility plays important role when we examine the impact of trade reform on unemployment and social welfare. The theoretical results may shed light on the observed behaviour of the small globalised economies with respect to unemployment and social welfare.

APPENDIX A

The average income of all workers is:

$$E = \omega_u L_u + \omega_r L_r + \omega_i L_i = \omega_r \dots \dots \dots \dots \dots \dots \dots \dots (19)$$

$$EM = L_u L_r (\omega_u - \omega_r) + L_u L_i (\omega_u - \omega_i) + L_u U \omega_u + L_i L_r (\omega_r - \omega_i) + L_r U \omega_r + L_i U \omega_i (20)$$

¹¹ It is assumed that $L_r = f(\omega_u - \omega_r)$, where $f' < 0$.

Using Equations (7) and (8) and (20) we get,

$$EM = \omega_i(L_i + U) + L_u L_r (\varpi_u - \omega_r) - \omega_i L_i (1 - U) \quad \dots \quad \dots \quad \dots \quad (20.1)$$

Now, using Equations (9), (19) and (20.1) we get Equation (9.1).

APPENDIX B

The total differential of Equations (7) and (13) are given by:

$$\omega_r dL_i + \omega_i dL_i = (L - L_r) d\omega_r - \varpi_u dL_u - L_i d\omega_i \quad \dots \quad \dots \quad \dots \quad (18)$$

$$k_r dL_r + k_i dL_i = dK_i - (L_r dk_r + L_i dk_i) \quad \dots \quad \dots \quad \dots \quad (19)$$

Let Δ be the determinant of the coefficient matrix of the endogenous variables in the system. So, $\Delta = \begin{bmatrix} \omega_r & \omega_i \\ k_r & k_i \end{bmatrix} = \omega_r k_i - \omega_i k_r < 0$ if $(R_i K_r / \omega_r L_r) > (R_i K_i / \omega_i L_i)$

This implies that the rural sector is more capital intensive than the urban informal sector in value terms. Hence,

$$dL_r = 1/\Delta [k_i \{(L - L_r) d\omega_r - \varpi_u dL_u - L_i d\omega_i\} - \omega_i \{dK_i - (L_r dk_r + L_i dk_i)\}] \quad \dots \quad (A.1.)$$

$$dL_i = 1/\Delta [\omega_r \{dK_i - (L_r dk_r + L_i dk_i)\} - k_r \{(L - L_r) d\omega_r - \varpi_u dL_u - L_i d\omega_i\}] \quad \dots \quad (A.2.)$$

Now put $d\omega_r = d\omega_i = dK_i = dk_r = dk_i = 0$ in the expressions (A.1.) and (A.2.). Then we get, $(dL_r / dL_u) = -\varpi_u k_i / \Delta > 0$.

APPENDIX C

$$\omega_u dL_u + \omega_r dL_r = (L - L_r) d\omega_r - \omega_i dL_i - L_i d\omega_i \quad \dots \quad \dots \quad \dots \quad (20)$$

$$k_u dL_u + k_r dL_r = dK_f - L_u dk_u - L_r dk_r \quad \dots \quad \dots \quad \dots \quad (21)$$

Let Δ' be the determinant of the coefficient matrix of the endogenous variables in the system. So, $\Delta' = \varpi_u k_r - \omega_r k_u < 0$ if $R_f K_u / (\varpi_u L_u + \omega_i L_i) > R_f K_r / \omega_r L_r$

This implies that urban region is more capital intensive than the rural region in value terms. Hence,

$$dL_u = 1/\Delta' [k_r \{(L - L_r) d\omega_i - \omega_i dL_i\} \omega_r (dK_f - L_u dk_u - L_r dk_r)] \quad \dots \quad \dots \quad (A.3.)$$

$$dL_r = 1/\Delta' [\varpi_u (dK_f - L_u dk_u - L_r dk_r) - k_u \{(L - L_r) d\omega_r - \omega_i dL_i - L_i d\omega_i\}] \quad \dots \quad (A.4.)$$

Put, $dL_i = d\omega_i = dK_f = 0$ in the expressions (A.3.), (A.4.). Then we get,

$$dL_u / d\omega_r = 1/\Delta' [(L - L_r) k_r + \omega_r \{L_u (dk_u / d\omega_r) + L_r (dk_r / d\omega_r)\}] < 0 \text{ and}$$

$$dL_r / d\omega_r = 1/\Delta' [\varpi_u \{L_u (dk_u / d\omega_r) + L_r (dk_r / d\omega_r)\} + k_u (L - L_r)] > 0$$

$$dL_j / dP_u = (dL_j / d\omega_r) (d\omega_r / dP_u) \text{ for } j=u, r.$$

APPENDIX D

The second term is:

$$L_u L_r (\omega_u - \omega_r) .$$

The total differential of the second term is

$$\begin{aligned} & L_r (\omega_u - \omega_r) dL_u + L_u (\omega_u - \omega_r) dL_r + L_u L_r d(\omega_u - \omega_r) \\ &= L_r (\omega_u - \omega_r) dL_u + L_u L_r d(\omega_u - \omega_r) \left[\left(\frac{dL_r}{L_r} (\omega_u - \omega_r) \right) + 1 \right] \\ &= L_r (\omega_u - \omega_r) dL_u - L_u L_r d\omega_r \left[1 - |e_{Lr}| \right] \\ &= L_r (\omega_u - \omega_r) dL_u - L_u L_r d\omega_r \left[1 - |e_{Lr}| \right] < 0 \text{ since, } dL_u < 0, d\omega_r > 0 \text{ and } |e_{Lr}| < 1 \\ & \text{(assumed).} \end{aligned}$$

Thus, the second term falls as t falls.

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