

EXCHANGE RATE CHANGES AND INCOME DISTRIBUTION*

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This paper analyzes the impact of policy-induced exchange rate changes (devaluations) on the distribution of income between owners of different production factors in a dynamic specific factors model of the small open economy that produces traded and non-traded goods. In the model, workers are assumed to move freely between the sectors with a flexible wage rate while installed capital is sector-specific and new capital goods are constructed by combining non-traded inputs with imported machines. Various simulation results show that real return on capital in the nontradables sector always falls while that in the tradables sector invariably jumps up on impact following devaluation. Interestingly, real wage jumps up, stays unchanged, or falls on impact following devaluation depending mainly on relative factor intensity of the two sectors and the share of imported capital goods in production of capital goods. In the long run, of course, real factor incomes return to their new steady-state levels that are the same as their pre-devaluation levels.

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I. INTRODUCTION

Many historical episodes, including CFA franc and Mexican peso devaluations in 1994, vividly show that policy-induced changes in exchange rate¹ (devaluations) have profound effects on the distribution of income between owners of different production factors. However, there are very few theoretical studies that have dealt with this potentially important issue in a serious manner. Until now, research on the effects of exchange rate changes has focused mainly on their effects on aggregate variables such as output, employment, and the balance of payments.² In this regard, it would be interesting and worthwhile in a socio-economic sense to investigate the ways in which, and how much, unexpected exchange rate changes affect distribution of income between owners of different production factors. This is especially so in less developed countries (LDCs) that should pursue economic development, maintaining social stability at the same time.

Important contributions have been made by several authors, including Alexander (1952), Diaz Alejandro (1963), Cooper (1971), Krugman and Taylor (1978), and Barbone and Rivera-Batiz (1987), among others. By assuming fixed money wage at least in the short run, however, they simply see the distributive effects of devaluation as transferring income always from fixed wage earners to capitalists, and only as a part of aggregate demand changes in a class of static models. Moreover, they pay little attention to the consequences of sectoral difference by assuming a single aggregate production sector. Following them, Buffie (1992) analyzes the income redistribution effects of commercial policies in a dynamic trade model. As such, however, his model is concerned primarily with the real side of the economy, having little to do with macroeconomic aspects - money or inflation. Moreover, as acknowledged by himself, he

¹ IMF (2005) reports that more than a half of the countries in the world, mostly less-developed countries (LDCs), maintain a sort of fixed exchange rate system in various forms. Thus, the role of devaluation implemented under the fixed exchange rate system is still at the heart of policy debates in development economics.

² In particular, there have been heated debates regarding whether devaluation is expansionary or contractionary, especially in the context of LDCs. (see, for example, Hirschman [1949], Hanson [1983], Gylfason and Schmid [1983], Buffie [1986], Risager [1988], Montiel and Lizondo [1989], Morley [1992], Buffie and Won [2001], Won [2005], and Tovar [2005]).

didn't take different sectoral responses into account in the model either. This is due to the analytical complexity of dynamic equations system involved.

On the other hand, traditional empirical studies pioneered by Diaz Alejandro (1965) and then followed by Twomey (1983), Bigsten (1987), Edwards (1989), Bahmani-Oskosee (1997), Casero and Seshan (2006) support the conventional view that, through inflation, devaluation tends to hurt low-income groups in the short run more than high-income groups that are supposed to own real assets. As Edwards (1989) pointed out, however, this result is not free from criticism, in that the country-level income data used by the previous studies may not be reliable. Facing this criticism, recent simulation studies based on household living standards survey data such as Minot (1998), Friedman and Levinsohn (2002), and Haughton and Hoang (2003) show different but interesting results. These simulation experiments reveal that devaluations are likely to bring different distributive consequences for the countries with different economic structures, thus warning of the risk of hasty generalization of their impacts on income distribution.

Taking the intriguing results of the aforementioned theoretical and empirical literature into consideration, the paper aims to construct a general equilibrium dynamic optimization model, and provide a useful tool to better understand the possibly different income distribution effects that devaluation may exert in a small, open developing economy. In the economy that produces traded and non-traded goods, workers are assumed to move freely between the sectors, while installed capital is sector-specific, and new capital goods are constructed by combining non-traded inputs with imported machines. Keeping the results of static specific factors model in mind, the paper traces fully articulated dynamic paths of real factor incomes after devaluation. At the same time, the paper intends to measure the extent to which real returns on capital in each sector would change over time, and to see which direction and how far real wage would move on impact and over time after devaluation. The implications drawn from the model are expected to serve as solid testable hypotheses for future empirical studies.

Various simulation results reveal that real return on capital in the

nontradables sector always falls on impact following devaluation, while that in the tradables sector invariably jumps up on impact, as expected. Interestingly enough, real wage jumps up, stays unchanged, or falls on impact following devaluation, depending largely on factor intensity of each sector and the share of imported machines in the production of capital goods. In the long run, real factor incomes return to their steady-state levels, which are same as their pre-devaluation levels.

The paper proceeds as follows. Section 2 lays out the model and derives the system of differential equations that govern the paths of variables of interest. Due to high dimensionality of the dynamic equations system, numerical methods are used to characterize the economy's dynamics. Section 3 describes how the model is calibrated with different sets of parameter values that reflect various economic characteristics of LDCs. Section 4 provides the results of calibrations in detail, interpreting them in economically sensible ways. Section 5 concludes the paper, suggesting some future research directions as well as policy implications.

II. THE MODEL

Built on Buffie and Won (2001), the model is in line with the monetary approach to the balance of payments, in that the balance of payments is essentially a monetary phenomenon in the model. In addition, real money balances enter the utility function explicitly to take the nonpecuniary services money yields into account in the spirit of Sidrauski (1967).³ Most importantly, the two-gap specification of the capital good is adopted and plays a critical role in the model.⁴ In order to highlight the private sector's response to devaluation and maintain the tractability, we deliberately put the government sector's behavior aside. The role of the government, or the central bank, is to simply convert foreign exchanges into domestic currency.

³ There has been a series of debates about the validity of the money-in-utility function formulation. However, Feenstra (1986) convincingly demonstrates that using real balance as an argument of the utility function and entering money into liquidity costs that appear in the budget constraint are functionally equivalent.

⁴ See Chenery and Bruno (1962) and McKinnon (1964) for the two-gap specification.

2.1. The economy

2.1.1. Technology

Two types of composite goods are produced and consumed domestically: traded goods and nontraded goods. The tradables sector can be considered the sector that produces rudimentary manufacturing or natural resource-related products. The nontradables sector includes services and import-competing manufacturing sectors that are highly protected by trade barriers, such as import quotas and tariffs, for fostering domestic production.

Capital and labor are factors of production in both sectors. Capital is assumed, even in the long run, to be sector-specific. Once installed, it evolves over time according to a law of motion defined later. Labor, on the other hand, is intersectorally mobile. More specifically, to simplify the analysis without limiting the possibility of various elasticities of factor substitution, we assume that both goods are produced according to a constant elasticity of substitution (CES) technology. Therefore, the production relation in each sector can be described as

$$Q_T = [a_1 L_T^{(\sigma_T-1)/\sigma_T} + a_2 K_T^{(\sigma_T-1)/\sigma_T}]^{\sigma_T/(\sigma_T-1)} \quad (1)$$

$$Q_N = [a_3 L_N^{(\sigma_N-1)/\sigma_N} + a_4 K_N^{(\sigma_N-1)/\sigma_N}]^{\sigma_N/(\sigma_N-1)}, \quad (2)$$

where $a_1 - a_4$ are constants determined by technology, and subscripts T and N denote the tradables and the nontradables sectors, respectively. σ_i , Q_i , K_i , and L_i denote the elasticity of factor substitution, output, sector-specific capital, and labor inputs used in sector i , respectively.

In the small open economy, the domestic price of the traded good is determined solely by the exchange rate, e , the domestic currency price of a unit of foreign currency. As usual, we assume that the foreign currency price of a unit of tradables is unity for analytical simplicity. The general price level of the economy (CPI) is constructed according to a geometric average of the prices of nontraded goods and traded goods with their expenditure shares,

$$P = P_N^\alpha e^{1-\alpha}, \quad (3)$$

where P_i denotes the domestic price of good i , and α and $1-\alpha$ represent the shares of the nontradables and the tradables in aggregate consumption expenditure, respectively.⁵

Constant returns to scale technology, coupled with a competitive market assumption, gives the following zero profit conditions, which link product prices and factor prices as

$$e = c_T(w, r_T) \quad (4)$$

$$P_N = c_N(w, r_N), \quad (5)$$

where $c_i(\bullet)$, r_i , and w denote the unit cost function, capital rental rate in sector i , and nominal wage rate, respectively. Following the two-gap specification, capital is assumed to be a composite good produced by combining a noncompetitive imported input such as machines, and a nontraded component such as construction services, in a fixed proportion. Denoting b_T and b_N as the input-output coefficients for the noncompetitive imported input and the nontraded components, respectively, the price of an aggregate capital good, P_K , and its percentage change are determined as⁶

$$P_K = b_T e + b_N P_N, \quad (6)$$

and therefore

$$\hat{P}_K = (1 - \beta)\hat{e} + \beta\hat{P}_N, \quad (7)$$

where $\beta (\equiv b_N P_N / P_K)$ is the cost share of nontradables in the production of an aggregate capital good, and a circumflex (^) denotes a percentage change of a variable.

⁵ That is, $\alpha = (P_N D_N) / E$ and $(1 - \alpha) = (e D_T) / E$, where D_i denotes the consumption demand for good i , and E denotes the nominal aggregate consumption expenditure on both goods.

⁶ Burstein, et al. (2004) find that investment has a very significant nontradable component in the form of construction services.

2.1.2. Factors and the nontradables markets

The labor market clears continuously via the flexible wage rate in both sectors so that full employment prevails at any given moment in the economy. Demand for labor in each sector can be obtained by the instantaneous profit maximization for the CES production functions as

$$L_T = a_1 (w / e)^{-\sigma_T} Q_T \quad (8)$$

$$L_N = a_3 (w / P_N)^{-\sigma_N} Q_N. \quad (9)$$

Labor supply is assumed to be fixed at \bar{L} . Therefore, the labor market equilibrium can be defined as

$$L_T + L_N = \bar{L}. \quad (10)$$

The nontradables market also clears continuously via a flexible P_N . Therefore, P_N should adjust instantaneously to satisfy the following nontradables market clearing condition:

$$D_N(e, P_N, E) + b_N [I_T + \Psi_T(I_T - \delta K_T) + I_N + \Psi_N(I_N - \delta K_N)] = Q_N(L_N, K_N), \quad (11)$$

where I_i and δ denote the gross investment in sector i and the constant depreciation rate of a capital good assumed to be common in both sectors, respectively. $\Psi_i(\bullet)$ is a strictly convex adjustment costs function of net investment in sector i so that $\Psi'_i(\bullet) \geq 0$ as $I \geq \delta K$, $\Psi''_i(\bullet) > 0$ and $\Psi(0) = \Psi'(0) = 0$.⁷

2.2. The representative agent's optimization problem

2.2.1. The optimization problem

Consumption and investment decisions are made by an infinitely-lived

⁷ A convex adjustment costs function is introduced to make the model consistent with the assumption of sector-specific capital as well as to reflect real world phenomena. Gould (1968) considers adjustment cost as a function of gross investment, while Lucas (1967) thinks of it as a function of net investment.

representative family firm having homothetic preferences. The family firm possesses perfect foresight, and selects the investment plans for both sectors and the consumption plans for both goods (expenditure) that maximize the additively separable utility function in which real money balances are included.⁸ Therefore, the representative family firm's maximization problem can be stated as

$$\max_{E, I_T, I_N} \int_0^{\infty} [V(e, P_N, E) + \Phi(M/P)] \exp(-\rho t) dt$$

subject to

$$\begin{aligned} \dot{M} = & R(e, P_N, K_T, K_N) - E - P_K [I_T + \Psi(I_T - \delta K_T)] \\ & - P_K [I_N + \Psi(I_N - \delta K_N)] \end{aligned} \quad (12)$$

$$\dot{K}_T = I_T - \delta K_T \quad (13)$$

$$\dot{K}_N = I_N - \delta K_N, \quad (14)$$

where ρ is the constant time discount rate and an overdot ($\dot{\cdot}$) denotes the time derivatives. $V(e, P_N, E)$ is the indirect utility function and retains all the properties of a usual indirect utility function such as $V_i = \partial V / \partial P_i < 0$, $V_E = \partial V / \partial E > 0$, and $V_{EE} < 0$. $\Phi(\bullet)$ also retains the usual properties of a utility function, such as $\Phi' > 0$, $\Phi'' < 0$. M denotes nominal money balance. Real money balances are included in the utility function for taking into account the nonpecuniary services yielded by money holding, such as the facilitation of transactions. On the right-hand side of (12), $R(\bullet)$ is the revenue function of the family firm and equals $eQ_T + P_N Q_N$. The revenue function also has the usual properties, such as

$$R_1(\bullet) = Q_T, \quad R_2(\bullet) = Q_N, \quad R_3(\bullet) = r_T, \quad R_4(\bullet) = r_N, \quad (15)$$

where the subscript j means the partial differentiation of the revenue function with respect to the j th argument.

⁸ This specification is convenient in that demand for each good depends only on prices and aggregate expenditure, but not on real money balances.

The budget constraint, (12), defines the evolution of domestic nominal money balances that accumulate as revenue exceeds the sum of consumption expenditure and investment spending in the two sectors. With the nontradables market cleared continuously, (12) can be interpreted as the domestic excess supply of tradables, and thus as the trade balance surplus, as in Dornbusch (1973). Equations (13) and (14) specify capital's law of motion in each sector as usual. The representative family firm now chooses the sequences of investment in each sector, and the expenditure, $\{I_T, I_N, E\}$, to maximize its utility based on the expectation on the evolutions of capital in each sector and money balance, $\{K_N, K_T, M\}$.

2.2.2. Solving the optimization problem: Solution Procedure

The present-value Hamiltonian function for this problem is specified as

$$\begin{aligned} H = \exp(-\rho t) [& V(e, P_N, E) + \Phi(M / P) + \lambda_1 [R(e, P_N, K_T, K_N) \\ & - E - P_K (I_T + \Psi_T(I_T - \delta K_T)) - P_K (I_N + \Psi_N(I_N - \delta K_N))] \\ & + \lambda_2 [I_T - \delta K_T] + \lambda_3 [I_N - \delta K_N]], \end{aligned}$$

where the co-state variables $\lambda_i (i=1,2,3)$ represent the current shadow prices of money, capital in the tradables sector, and capital in the nontradables sector, respectively.⁹

The first-order necessary conditions (FONCs)¹⁰ for the family firm's optimization problem are thus given as

$$V_E(e, P_N, E) = \lambda_1 \quad (16)$$

$$V_E P_K [1 + \Psi'_T(I_T - \delta K_T)] = \lambda_2 \quad (17)$$

$$V_E P_K [1 + \Psi'_N(I_N - \delta K_N)] = \lambda_3, \quad (18)$$

where these three conditions are obtained by maximizing H with respect to the three choice variables, $\{E, I_T, I_N\}$, respectively. Because they are intertemporal, no arbitrage conditions can be interpreted in a

⁹ Time subscripts attached to the variables are omitted for notational simplicity.

¹⁰ It is assumed that the transversality conditions for three assets are met. See chapters 7 and 9 of Leonard and Long (1992) for detailed discussion on the transversality conditions.

standard way. (16) states that the shadow price of money is equal to the marginal utility of a one dollar increase in consumption expenditure. (17) and (18) imply that capital's shadow price in each sector is equal to a decrease in utility due to a unit increase in the capital good away from consumption expenditure.

The remaining FONCs are comprised of the following co-state equations that show the optimal changes in shadow prices over time, and thus must be satisfied along the optimal path of each variable of interest.¹¹

$$\dot{\lambda}_1 = \lambda_1 \rho - \frac{\Phi'(M/P)}{P} \quad (19)$$

$$\dot{\lambda}_2 = \lambda_1 [(\rho + \delta)P_K - r_T + \rho P_K \Psi'_T] \quad (20)$$

$$\dot{\lambda}_3 = \lambda_1 [(\rho + \delta)P_K - r_N + \rho P_N \Psi'_N] \quad (21)$$

The first task is to get rid of the unobservable shadow prices from the dynamic system, making use of the information on the FONCs. This can be done by differentiating (16) with respect to time and substituting for (19). Simple manipulations, making use of Roy's Identity, give

$$\tau^{-1} \frac{\dot{E}}{E} = \frac{\Phi'}{PV_E} - \rho + (\tau^{-1} - 1)\alpha \frac{\dot{P}_N}{P_N}, \quad (22)$$

where $\tau (\equiv -\frac{V_E}{V_{EE}E})$ is the intertemporal elasticity of substitution that is

the inverse of relative risk aversion. Similar manipulations involving (17) and (20), and then (18) and (21), yield

$$\begin{aligned} \Psi''_T \dot{I}_T &= (1 + \Psi'_T) \frac{\Phi'}{PV_E} + \delta \Psi''_T (I_T - \delta K_T) + \delta \\ &\quad - \frac{r_T}{P_K} - \beta (1 - \Psi'_T) \frac{\dot{P}_N}{P_N} \end{aligned} \quad (23)$$

¹¹ The argument of the adjustment cost function is omitted for notational simplicity.

$$\begin{aligned}\Psi_N'' \dot{I}_N &= (1 + \Psi_N') \frac{\Phi'}{PV_E} + \delta \Psi_N'' (I_N - \delta K_N) + \delta \\ &\quad - \frac{r_N}{P_K} - \beta(1 - \Psi_N') \frac{\dot{P}_N}{P_N},\end{aligned}\quad (24)$$

respectively.

Turning to the market clearing condition in the nontradables sector, we can obtain the expressions for \hat{P}_N and, subsequently, \dot{P}_N/P_N over the transitional period where $\dot{e} = 0$ as

$$\begin{aligned}\hat{P}_N &= (P_N Q_N J)^{-1} \{ \alpha dE + \beta P_K [(1 + \Psi_T') dI_T + (1 + \Psi_N') dI_N] \\ &\quad + \Theta_T dK_T + \Theta_N dK_N \}\end{aligned}\quad (25)$$

$$\begin{aligned}\frac{\dot{P}_N}{P_N} &= (P_N Q_N J)^{-1} \{ \alpha \dot{E} + \beta P_K [(1 + \Psi_T') \dot{I}_T + (1 + \Psi_N') \dot{I}_N] \\ &\quad + \Theta_T \dot{K}_T + \Theta_N \dot{K}_N \},\end{aligned}\quad (26)$$

where $\Theta_T \equiv (\frac{kr_N}{\theta_K^N})(\frac{\sigma_N \theta_L^N}{\theta_K^N})\omega_3 - \beta\delta\Psi_T'$, $\Theta_N \equiv (\frac{r_N}{\theta_K^N})[(\frac{\sigma_N \theta_L^N}{\theta_K^N})\omega_4 - 1] - \beta\delta\Psi_N'$, $k \equiv \frac{K_N}{K_T}$, $J \equiv \frac{D_N}{Q_N}(\varepsilon + \alpha) + \frac{\omega_1 \sigma_N \theta_L^N}{\theta_K^N}$ and ε is the compensated own price elasticity of demand. θ_j^i denotes the cost share of input j in sector i ($i = T, N, j = K, L$).

On the other hand, manipulations of the labor market clearing condition give a percentage change of the nominal equilibrium wage rate as¹²

$$\hat{w} = \omega_1 \hat{e} + \omega_2 \hat{P}_N + \omega_3 \hat{K}_T + \omega_4 \hat{K}_N, \quad (27)$$

where $\omega_1 = \Omega^{-1}(\frac{\sigma_T}{\theta_K^T})$, $\omega_2 = \Omega^{-1}(\frac{L_N}{L_T})(\frac{\sigma_N}{\theta_K^N})$, $\omega_3 = \Omega^{-1}$, $\omega_4 = \Omega^{-1}(\frac{L_N}{L_T})$

¹² In equation (27), the homogeneity property can be seen by noting that the sum of the coefficients of the nominal variables, e and P_N , equals 1.

and $\Omega = \frac{\sigma_T}{\theta_K^T} + (\frac{\sigma_N}{\theta_K^N})(\frac{L_T}{L_N})$.

Making use of (27) and (4) gives a percentage change of nominal return on capital in the tradables sector as

$$\hat{r}_T = s_1 \hat{e} - s_2 \hat{P}_N - s_3 \hat{K}_T - s_4 \hat{K}_N, \quad (28)$$

where $s_1 = (\frac{1}{\theta_K^T})(1 - \omega_1 \theta_L^T)$, $s_2 = \omega_2 (\frac{\theta_L^T}{\theta_K^T})$, $s_3 = \omega_3 (\frac{\theta_L^T}{\theta_K^T})$, $s_4 = \omega_4 (\frac{\theta_L^T}{\theta_K^T})$.

Likewise, combining (27) and (5) gives a percentage change of nominal return on capital in the nontradables sector as¹³

$$\hat{r}_N = v_1 \hat{e} - v_2 \hat{P}_N - v_3 \hat{K}_T - v_4 \hat{K}_N, \quad (29)$$

where $v_1 = (\frac{1}{\theta_K^N})(1 - \omega_2 \theta_L^N)$, $v_2 = \omega_1 (\frac{\theta_L^N}{\theta_K^N})$, $v_3 = \omega_3 (\frac{\theta_L^N}{\theta_K^N})$, $v_4 = \omega_4 (\frac{\theta_L^N}{\theta_K^N})$.

From now on, without loss of generality, units are chosen so that P_K equals 1. To trace the factor income changes, it is immediately clear that we need the information on dynamics of choice and state variables following devaluation.

The final task is, therefore, to obtain dynamic expressions for the three choice variables. Linearizing (22), (23), and (24), and evaluating them around the steady-state¹⁴, and then substituting (25), (28), and (29) into them yields a three-simultaneous-differential-equations system regarding \dot{I}_N , \dot{I}_T , and \dot{E} , as in Appendix 1.^{15, 16} In addition, linearizing (12), and

¹³ The basic homogeneity property appears again in (29) by $v_1 - v_2 = 1$, and in (28) by $s_1 - s_2 = 1$.

¹⁴ Note that $\Psi_T = \Psi_N = \Psi'_T = \Psi'_N = 0$, $I_i = \delta K_i$, $r_i = (\rho + \delta)P_K$, $[\Phi'(M/P)/PV_E] = \rho$ at the steady-state.

¹⁵ In order to get the complete solutions, we need to pin down the Ψ''_i terms. Log-differentiating (17) and evaluating it at the steady-state where $\Psi'_T(\bullet) = 0$, yields $\Psi''_T I_T \hat{I}_T = \hat{\lambda}_2 - \hat{\lambda}_1 - \hat{P}_K$. The RHS of the expression is, in fact, the percentage change in Tobin's q -ratio. Defining z to be the elasticity of investment with respect to q -ratio, and assuming that the q -elasticity of investment is the same in both sectors, we can get the expressions for Ψ''_i evaluated at a steady-state as $\Psi''_T = (1/z\delta K_T)$, $\Psi''_N = (1/z\delta K_N)$.

evaluating it around the steady-state, and substituting (26) into it yield the complete expression for \dot{M} as

$$\begin{aligned} \dot{M} = J^{-1} & \left[\left(\frac{D_N}{Q_N} \right) [\alpha dE + \beta (dI_T + dI_N) - \frac{(\rho + \delta)}{\theta_K^N} dK_N] \right. \\ & \left. + (\rho + \delta) dK_T - dE - dI_T - dI_N + (\rho + \delta) dK_N \right] \end{aligned} \quad (30)$$

(A.1), (A.2), (A.3) in Appendix 1. (13), (14), and (30) form the complete system of dynamic equations appropriate for the calibration as

$$\begin{bmatrix} \dot{M} \\ \dot{E} \\ \dot{I}_T \\ \dot{I}_N \\ \dot{K}_T \\ \dot{K}_N \end{bmatrix} = \begin{bmatrix} 0 & X_1 & X_2 & X_2 & X_{22} & X_3 \\ -X_4 & X_5 & X_6 & X_7 & X_8 & X_9 \\ -X_{10} & X_{11} & X_{12} & X_{13} & X_{14} & X_{15} \\ X_{16} & X_{17} & X_{18} & X_{19} & X_{20} & X_{21} \\ 0 & 0 & 1 & 0 & -\delta & 0 \\ 0 & 0 & 0 & 1 & 0 & -\delta \end{bmatrix} \begin{bmatrix} M - M^* \\ E - E^* \\ I_T - I_T^* \\ I_N - I_N^* \\ K_T - K_T^* \\ K_N - K_N^* \end{bmatrix}, \quad (31)$$

where an asterisk (*) denotes a new steady-state equilibrium, and X'_i s are the coefficients of the corresponding variables in each equation. Exact expressions for X'_i s are stated in Appendix 2.

III. CALIBRATION OF THE MODEL

In order to see whether the dynamic system in (31) has a unique convergent solution path, and to find the path if one exists, we need to obtain the eigenvalues of the coefficient matrix, X , and associated eigenvectors. Finding the eigenvalues of the 6×6 matrix involves solving a 6th-order polynomial equation, which is, as is well known, generally no way to get explicit solutions analytically. Therefore, we resort to a numerical method, using Mathematica, to get the eigenvalues and the associated eigenvectors.

¹⁶ In obtaining the solutions, we need to assume that the income elasticity of money demand, η ,

equals 1. That is, $\eta \equiv \frac{\hat{M}}{\hat{E}} = \frac{\Phi' V_{EE} E}{\Phi''(M/P) V_E} = \frac{\Phi'}{\Phi''(M/P) \tau} = 1$.

3.1. Determination of undetermined parameters

Before doing the calibrations, we should be able to assign the coefficient matrix, X , real number values. In fact, we can set plausible values for $\alpha, \beta, \sigma_i, \theta_j^i, \gamma, \rho, \tau, \mu$, and ε from the existing literature. However, we still have three parameters undetermined, (L_N / L_T) , k , and (D_N / Q_N) . These three parameters have to be set in an internally consistent way. This requires that we exploit the information in the budget constraint and the market clearing condition. Note first that when evaluated at the steady-state where $r_T = r_N$,

$$\frac{L_N}{L_T} = \left(\frac{\theta_L^N}{\theta_L^T} \right) \left(\frac{P_N Q_N}{e Q_T} \right) = \left(\frac{\theta_L^N}{\theta_L^T} \right) \left(\frac{VA_N}{1 - VA_N} \right), \quad (32)$$

$$k \left(\equiv \frac{K_N}{K_T} \right) = \frac{\theta_K^N}{\theta_K^T} \frac{VA_N}{1 - VA_N}, \quad (33)$$

where $VA_N \equiv (P_N Q_N / Y)$, $Y = e Q_T + P_N Q_N$.

From the nontradables market clearing condition and the budget constraint evaluated at a steady-state, we obtain

$$VA_N = \Gamma^{-1} \left[\alpha + \frac{\delta(\beta - \alpha)\theta_K^T}{(\rho + \delta)} \right] \quad (34)$$

$$\frac{D_N}{Q_N} = \frac{(P_N / E)(E / Y)}{(P_N Q_N / Y)} = \left(\frac{\alpha}{VA_N} \right) \left(\frac{E}{Y} \right) = \left(\frac{\alpha}{VA_N} \right) \left[1 - \delta \left(\frac{K}{Y} \right) \right], \quad (35)$$

where $\Gamma = 1 + \left[\frac{(\theta_K^T - \theta_K^N)\delta(\beta - \alpha)}{(\rho + \delta)} \right]$,

$$(K / Y) = (\rho + \delta)^{-1} [\theta_K^T + (\theta_K^N - \theta_K^T)VA_N].$$

Now, once we assign sensible values for the parameters, VA_N is determined by (34). The values for (L_N / L_T) , k , and (D_N / Q_N) are subsequently determined by (32), (33), and (35), respectively.

3.2. Solution paths of the variables of interest

With all the parameters observable and determined consistently, we are now ready to solve the differential equations system, (31). The complete solutions for the convergent saddle paths of the variables of interest over time in the forms of elasticity with respect to devaluation are derived as

$$\begin{aligned}
\frac{\hat{M}}{\hat{e}} &= \frac{(M(t) - M^0) / M^0}{\hat{e}} = 1 + [v_{12}h'_2 \exp(\gamma_2 t) + v_{15}h'_5 \exp(\gamma_5 t) \\
&\quad + v_{16}h'_6 \exp(\gamma_6 t)], \\
\frac{\hat{E}}{\hat{e}} &= \frac{(E(t) - E^0) / E^0}{\hat{e}} = 1 + \mu[v_{22}h'_2 \exp(\gamma_2 t) + v_{25}h'_5 \exp(\gamma_5 t) \\
&\quad + v_{26}h'_6 \exp(\gamma_6 t)], \\
\frac{\hat{I}_T}{\hat{e}} &= \frac{(I_T(t) - I_T^0) / I_T^0}{\hat{e}} = \left(\frac{\mu}{\delta}\right) \left[\frac{k(\rho + \delta)}{\theta_K^N V A_N (Y / E)} \right] [v_{32}h'_2 \exp(\gamma_2 t) \\
&\quad + v_{35}h'_5 \exp(\gamma_5 t) + v_{36}h'_6 \exp(\gamma_6 t)], \\
\frac{\hat{I}_N}{\hat{e}} &= \frac{(I_N(t) - I_N^0) / I_N^0}{\hat{e}} = \left(\frac{\mu}{\delta}\right) \left[\frac{(\rho + \delta)}{k \theta_K^N (1 - V A_N)(Y / E)} \right] [v_{42}h'_2 \exp(\gamma_2 t) \\
&\quad + v_{45}h'_5 \exp(\gamma_5 t) + v_{46}h'_6 \exp(\gamma_6 t)], \\
\frac{\hat{K}_T}{\hat{e}} &= \frac{(K_T(t) - K_T^0) / K_T^0}{\hat{e}} = \mu \left[\frac{k(\rho + \delta)}{\theta_K^N V A_N (Y / E)} \right] [v_{52}h'_2 \exp(\gamma_2 t) \\
&\quad + v_{55}h'_5 \exp(\gamma_5 t) + v_{56}h'_6 \exp(\gamma_6 t)], \\
\frac{\hat{K}_N}{\hat{e}} &= \frac{(K_N(t) - K_N^0) / K_N^0}{\hat{e}} = \mu \left[\frac{(\rho + \delta)}{k \theta_K^N (1 - V A_N)(Y / E)} \right] [v_{62}h'_2 \exp(\gamma_2 t) \\
&\quad + v_{65}h'_5 \exp(\gamma_5 t) + v_{66}h'_6 \exp(\gamma_6 t)],
\end{aligned}$$

where γ_i and v_{ji} ($i, j = 1, \dots, 6$) are the corresponding i^{th} eigenvalues and eigenvectors, respectively. Here we assume that γ_2 , γ_5 , and γ_6 are negative eigenvalues. The h_i s associated with the negative eigenvalues are constants determined by the initial conditions of state variables,¹⁷ and $h'_i \equiv (h_i / M^0 \hat{e})$. Superscript "0" denotes the initial steady-state, or pre-

¹⁷ The h_i s associated with positive eigenvalues are set to be zero on the convergent saddle paths.

jump values.

3.3. Equilibrium paths of the real factor incomes

Changes in real factor incomes over time following devaluation can also be shown in the form of elasticity with respect to devaluation. First of all, subtracting the CPI inflation rate from (27) and dividing it by the percentage change in exchange rate gives the change of real wage rate in the form of its elasticity with respect to devaluation as

$$\frac{\left(\frac{\hat{w}}{P}\right)}{\hat{e}} = \frac{(\hat{w} - \hat{P})}{\hat{e}} = (\alpha - \omega_2)\left(1 - \frac{\hat{P}_N}{\hat{e}}\right) + \omega_3 \frac{\hat{K}_T}{\hat{e}} + \omega_4 \frac{\hat{K}_N}{\hat{e}}. \quad (36)$$

Similar manipulations of (28) and (29) make it possible to trace the change of real return on capital in each sector as

$$\frac{\left(\frac{\hat{r}_T}{P}\right)}{\hat{e}} = \frac{(\hat{r}_T - \hat{P})}{\hat{e}} = (\alpha + s_2)\left(1 - \frac{\hat{P}_N}{\hat{e}}\right) - s_3 \frac{\hat{K}_T}{\hat{e}} - s_4 \frac{\hat{K}_N}{\hat{e}}, \quad (37)$$

$$\frac{\left(\frac{\hat{r}_N}{P}\right)}{\hat{e}} = \frac{(\hat{r}_N - \hat{P})}{\hat{e}} = (\alpha - v_2)\left(1 - \frac{\hat{P}_N}{\hat{e}}\right) - v_3 \frac{\hat{K}_T}{\hat{e}} - v_4 \frac{\hat{K}_N}{\hat{e}}. \quad (38)$$

Manipulating (25) to get the elasticity of price of nontradables (\hat{P}_N) with respect to devaluation over time, and plugging it and the solution paths of the variables of interest into (36) - (38) yield the complete paths of real factor incomes over time.

3.4. Parameterization of the model

With the model ready for calibration, we finally should be able to assign plausible values for the parameters from the existing literature. The parameter values used to calibrate the model are summarized below in Table 1. Here we investigate the effects of devaluation with 36 different sets of parameter values that reflect different economic structures of

LDCs.¹⁸**[Table 1]** Parameter values used to calibrate the model

Parameters that vary in simulation	$\beta = .25, .50, .75$ $\tau = .20, 1.0$ $\theta_L^T = .30, .50, .70$ $z = .50, 1.5$
Parameters that are fixed in simulation	$\alpha = .50, \rho = .10, \delta = .06, \sigma_i = .50$ $\theta_L^N = .50, \theta_K^N = .50, \varepsilon = .20, \mu = .1$

The justification of particular choices of parameter values may be in order. For the cost share of the nontradables in the production of an aggregate capital good, β , Krueger (1978) gives a 40% share of construction in fixed capital formation as a normal case. Also, Burstein et al. (2004) find the share of domestic output in total investment generally to be on the order of .50-.75. Thus, we try three different values for β : 0.25 as the low end, 0.75 as the high end, and 0.5 as the in-between. For the compensated own price elasticity of demand for the nontradables, ε , we use .20, following Llunch, Powell, and Williams (1973) and Blundell (1988). For the intertemporal elasticity of substitution, τ , Summers (1984) puts it at about 1. According to Hansen and Singleton (1983), it would be on the order of 0-2.0. Hall (1988), criticizing the previous two papers, argues that it is close to 0, and that it is probably not above .20. Blundell (1988) also shows that it is small and probably less than .50. Attanasio and Weber (1989) obtain a slightly higher number. Here, we try .2 and 1.0 for the low and high ends. Regarding the q -elasticity of investment, z , we use .5 and 1.5. Abel (1980) shows that it is on the order of .50-1.1. Blanchard and Wyplosz (1981) estimates it as .43, while Hayashi (1982) puts it at about .67. Summers (1981) argues that it is about 1.5 in case of the USA. For the elasticity of factor substitution, σ_i , we fix it at .50 following White (1978), Khatkhate (1980), and Ahluwalia (1974). For the cost share of labor (capital) in the tradables sector, we try three different cases, $\theta_L^T = .30$ ($\theta_K^T = .70$) for the capital-intensive

¹⁸ In all 36 sets of parameter values tested, three negative and three positive distinctive real roots are obtained. Therefore, there exists a unique convergent saddle point solution for each set of parameter values.

tradables sector case, $\theta_L^T = .50$ ($\theta_K^T = .50$) for the neutral case, and $\theta_L^T = .70$ ($\theta_K^T = .30$) for the labor-intensive tradables sector case. For θ_L^N and θ_K^N , we consider a neutral case where they have the same shares, because we intend to focus on how different factor intensities in the tradables sector affect the outcome. The pure time preference rate, ρ , is assumed to be .10. The rate of depreciation, δ , and the consumption share of the nontradables, α , are set to be .06 and .50, respectively, to focus on the other important variables like θ_L^T , β , and τ . The ratio of money demand to income, μ , is set to be .10, as in Buffie (1992).

IV. RESULTS

Under the parameterization of the economy given in the previous section, we trace the transitional dynamics of real factor incomes. Table 2 summarizes the part of simulation results concerning the impact effects of the devaluation on real factor incomes. In what follows, we present and interpret the simulation results, and take a closer look at three typical model economies.

4.1. General observations

Devaluation is neutral in the long run. Thus, all the real variables should remain unchanged in the long run after devaluation regardless of their transitional dynamics. Various simulation results show that real factor incomes return to their initial levels in the long run in all cases considered.

However, short-run dynamics differ strikingly among real factor incomes. Table 2 shows that capital owners in the tradables sector clearly benefit, while capital owners in the nontradables sector lose on impact following a devaluation in all cases considered. Workers, on the other hand, either benefit or lose depending mainly on parameter values. This result should be nothing strange to international economists, conforming with the conclusions of the famous specific factors model.

[Table 2] Impact effects of devaluation on real factor incomes $\tau = 0.2, z = 0.5$

β	Real wage rate	Real return on capital in T-sector	Real return on capital in N-sector	Factor Intensity
.25	-.030736	.159992	-.174811	$\theta_L^T = .30, \theta_K^T = .70$
	.007828	.159168	-.174824	$\theta_L^T = .50, \theta_K^T = .50$
	.032720	.160780	-.174959	$\theta_L^T = .70, \theta_K^T = .30$
.50	-.049215	.196862	-.196862	$\theta_L^T = .30, \theta_K^T = .70$
	0.	.193482	-.193482	$\theta_L^T = .50, \theta_K^T = .50$
	.031796	.190778	-.190778	$\theta_L^T = .70, \theta_K^T = .30$
.75	-.066247	.221990	-.204791	$\theta_L^T = .30, \theta_K^T = .70$
	-.009954	.222303	-.202395	$\theta_L^T = .50, \theta_K^T = .50$
	.028631	.219132	-.200194	$\theta_L^T = .70, \theta_K^T = .30$

 $\tau = 1.0, z = 0.5$

β	Real wage rate	Real return on capital in T-sector	Real return on capital in N-sector	Factor Intensity
.25	-.022753	.118437	-.129407	$\theta_L^T = .30, \theta_K^T = .70$
	.006068	.123379	-.135514	$\theta_L^T = .50, \theta_K^T = .50$
	.026329	.129328	-.140787	$\theta_L^T = .70, \theta_K^T = .30$
.50	-.032013	.128053	-.128053	$\theta_L^T = .30, \theta_K^T = .70$
	0.	.133389	-.133389	$\theta_L^T = .50, \theta_K^T = .50$
	.023160	.138961	-.138961	$\theta_L^T = .70, \theta_K^T = .30$
.75	-.039109	.131053	-.120899	$\theta_L^T = .30, \theta_K^T = .70$
	-.006249	.139566	-.127068	$\theta_L^T = .50, \theta_K^T = .50$
	.019153	.146586	-.133918	$\theta_L^T = .70, \theta_K^T = .30$

 $\tau = 0.2, z = 1.5$

β	Real wage rate	Real return on capital in T-sector	Real return on capital in N-sector	Factor Intensity
.25	-.033576	.174776	-.190964	$\theta_L^T = .30, \theta_K^T = .70$
	.008415	.171104	-.187934	$\theta_L^T = .50, \theta_K^T = .50$
	.034398	.168959	-.183930	$\theta_L^T = .70, \theta_K^T = .30$
.50	-.058823	.235291	-.235291	$\theta_L^T = .30, \theta_K^T = .70$
	0.	.232361	-.232361	$\theta_L^T = .50, \theta_K^T = .50$
	.037769	.226612	-.226612	$\theta_L^T = .70, \theta_K^T = .30$
.75	-.078721	.263790	-.243353	$\theta_L^T = .30, \theta_K^T = .70$
	-.012192	.272291	-.247907	$\theta_L^T = .50, \theta_K^T = .50$
	.035530	.271927	-.248427	$\theta_L^T = .70, \theta_K^T = .30$

$\tau = 1.0, z = 1.5,$

β	Real wage rate	Real return on capital in T-sector	Real return on capital in N-sector	Factor Intensity
.25	-.022574	.117503	-.128387	$\theta_L^T = .30, \theta_K^T = .70$
	.006031	.122639	-.134701	$\theta_L^T = .50, \theta_K^T = .50$
	.026156	.128473	-.139857	$\theta_L^T = .70, \theta_K^T = .30$
.50	-.033084	.132337	-.132337	$\theta_L^T = .30, \theta_K^T = .70$
	0.	.138295	-.138295	$\theta_L^T = .50, \theta_K^T = .50$
	.023998	.143988	-.143988	$\theta_L^T = .70, \theta_K^T = .30$
.75	-.039101	.131026	-.120874	$\theta_L^T = .30, \theta_K^T = .70$
	-.006394	.142788	-.130001	$\theta_L^T = .50, \theta_K^T = .50$
	.019884	.152184	-.139032	$\theta_L^T = .70, \theta_K^T = .30$

What is interesting is that the extent to which each factor of production benefits or loses depends on several key parameters that reflect an economy's peculiar structure. Real return on capital in the tradables sector (r_T / P) jumps up on impact following devaluation in all cases considered, and then approaches the new steady-state where the real return remains the same as its initial level. During the transitional period, real return on capital in the tradables sector always remains above its long-run equilibrium level. However, it generally increases more on impact as the cost share of the nontradables in the production of capital good β rises. Moreover, real return on capital in the tradables sector generally increases more on impact as the intertemporal elasticity of substitution, τ , gets smaller and the q -elasticity of investment demand, z , becomes bigger. With lower τ ($=.2$), its initial increase tends to be smaller as the tradables sector becomes more labor intensive. On the contrary, its initial increase tends to be bigger as the tradables sector becomes more labor intensive with higher τ ($=1.0$).

Meanwhile, real return on capital in the nontradables sector, (r_N / P), falls immediately after devaluation in all cases considered, and then approaches the new steady-state where the real return remains the same as its initial level. During the transitional period, real return on capital in the nontradables sector almost always remains below its long-run equilibrium level. It falls more on impact with lower intertemporal elasticity of

substitution, τ , and higher q -elasticity of investment demand, z . Unlike real return on capital in the tradables sector, we cannot find a consistent relationship between real return on capital in the sector and the cost share of the nontradables in the production of capital good β . With lower $\tau (=0.2)$, on the other hand, its initial drop tends to be smaller as the tradables sector becomes more labor intensive, except in two extreme cases ($\beta=0.25, z=0.5$ and $\beta=0.75, z=1.5$). On the contrary, its initial drop tends to be larger as the tradables sector becomes more labor intensive with higher $\tau (=1.0)$.

Of particular interest is the response of the real wage rate following devaluation. The real wage rate falls on impact after devaluation when the tradables sector is relatively capital intensive, while jumping up when the tradables sector becomes more labor intensive. Then, it moves toward the new steady-state where it is equal to its initial level. Its initial drop tends to be larger or initial jump-up, in general, tends to be smaller under a given factor intensity in the tradables sector as β decreases. It falls more on impact with lower intertemporal elasticity of substitution, τ , and higher q -elasticity of investment demand, z . With lower $\tau (=0.2)$, it drops or jumps up more as the q -elasticity of investment demand, τ , becomes larger. On the contrary, with higher $\tau (=1.0)$, such a consistent relationship between real wage and the q -elasticity of investment demand, z , is not detected.

Whether increasing or decreasing, changes to real wage rate are much smaller than those to real returns on capital in each sector, which seems contradictory to what is traditionally believed. When $\tau = 0.2$, $z = 0.5$, $\beta = 0.25$, $\theta_L^T = 0.30$, and $\theta_K^T = 0.70$, for example, a 100% devaluation brings a mere 3.1% decrease in real wage on impact, while real returns on capital in the tradables sector increase by 11.8%, and that in the nontradables sector falls by 12.8%. Therefore, it seems that devaluation may hit capitalists in the nontradables sector harder than workers, in the short run, when both are affected adversely.¹⁹

The responses of real returns on capital in each sectors following devaluation are self-evident and require no further explanation. Careful

¹⁹ In reality, however, workers may feel hit harder because they are less able to smooth their consumption facing adverse shocks.

attention, however, should be paid to the response of real wage. If the tradables sector is more labor intensive than the nontradables sector, devaluation causes excess demand for labor to occur on impact, ending up with a rising real wage. The more labor intensive the tradables sector is (compared to the nontradables sector), therefore, the higher the real wage is likely to rise. On the other hand, real wage jumps down immediately following devaluation when the tradables sector is relatively capital intensive. Other than the relative factor intensity, of course, parameters affecting price level, such as α , β , should play an important role on impact, making the responses of real wage more complicated. Equations (36) - (38), in fact, show the roles these parameters play in determining the responses of real factor incomes. As capital evolves over time, however, real factor incomes return to their initial steady-state levels, leaving devaluation neutral in the long run.

4.2. Model economies

In order to take a closer look at how real factor incomes in different economies respond to devaluation, we discuss three model economies, typical LDC economies with different cost share of nontradables in the production of a capital good, β , and different factor intensities in the tradables sector. Model economy I is the most labor-intensive in the tradables sector and is very dependent on imported machines in the production of an aggregate capital good ($\beta = .25$) while model economy III is the most capital-intensive in the tradables sector and the least dependent on imported machines in the production of an aggregate capital good ($\beta = .75$). Model economy II is in between and can be considered a neutral case for reference. Parameterization for the three economies is shown in Table 3. Impact effects of devaluation on real factor incomes and their transitional paths are shown below as in Figure 1-Figure 3.

Figure 1 shows that the real wage rate jumps up by .034% per percent devaluation immediately after devaluation in model economy I while it drops by .079% per percent after devaluation in model economy III. However, in the both cases, the real wage rate returns to its new steady state level in two to three years. No significant real wage rate change is

observed in model economy II.

[Table 3] Parameter values for the model economies

Model Economy	Common parameter values	Varying parameter values
I	$\alpha = .50, \rho = .10, \delta = .06,$	$\theta_L^T = .7, \theta_K^T = .3, \beta = .25$
II	$\sigma_i = .50, \theta_L^T = .50, \theta_K^T = .50, \beta = .20,$	$\theta_L^T = .5, \theta_K^T = .5, \beta = .5$
III	$\mu = .1, z = 1.5, \tau = .20$	$\theta_L^T = .3, \theta_K^T = .7, \beta = .75$

Figure 2 shows that real return on capital in the tradables sector increases immediately following devaluation by .169%, .232%, and .264% per percent devaluation in model economies I, II, and III, respectively. Since then, real return on capital in the tradables sector decreases sharply for 3-4 years toward the new steady-state where it is same as the initial level.

Figure 3 indicates that real return on capital in the nontradables sector drops sharply on impact following devaluation by .184%, .232%, and .243% per percent devaluation in model economies I, II and III respectively. Since then, real return on capital in the nontradables sector rebounds sharply for 3-4 years toward the new steady-state where it is same as the initial level.

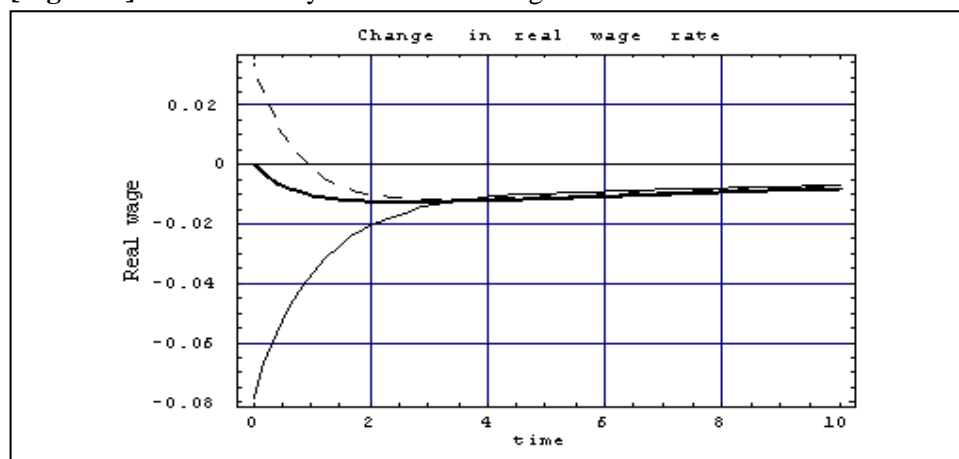
In sum, both workers and capitalists of the tradables sector gain in the short to medium run following devaluation in the economies similar to model economy I. On the contrary, workers lose while capitalists of the tradables sector gain in the economies similar to model economy III. In the economies like model economy II, workers are neutral. Capitalists of the nontradables sector always lose, while capitalists in the tradables sector invariably benefit in the short to medium run from devaluation.

V. CONCLUDING REMARKS

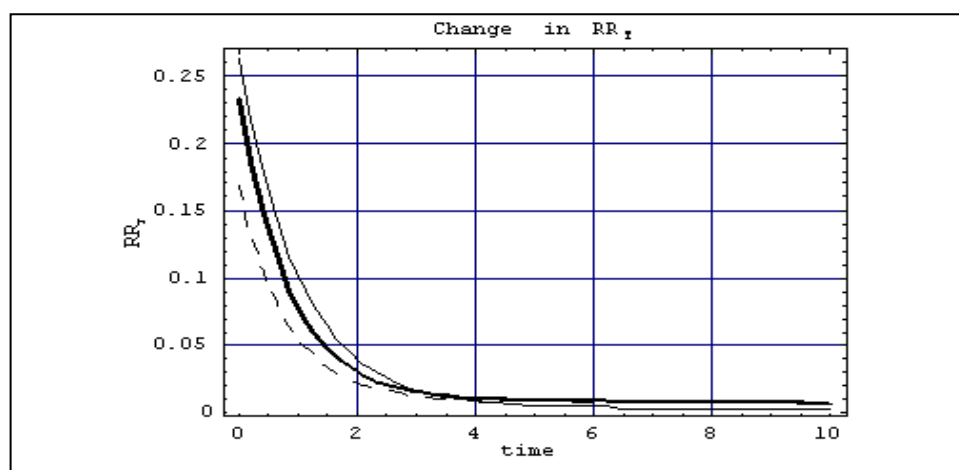
This paper has vividly shown that, using a general equilibrium dynamic optimization model, devaluation adversely affects capitalists in the nontradables sector in the short run, while benefiting capitalists in the tradables sector. More importantly, the paper has demonstrated that workers may or may not benefit from devaluation in the short to medium

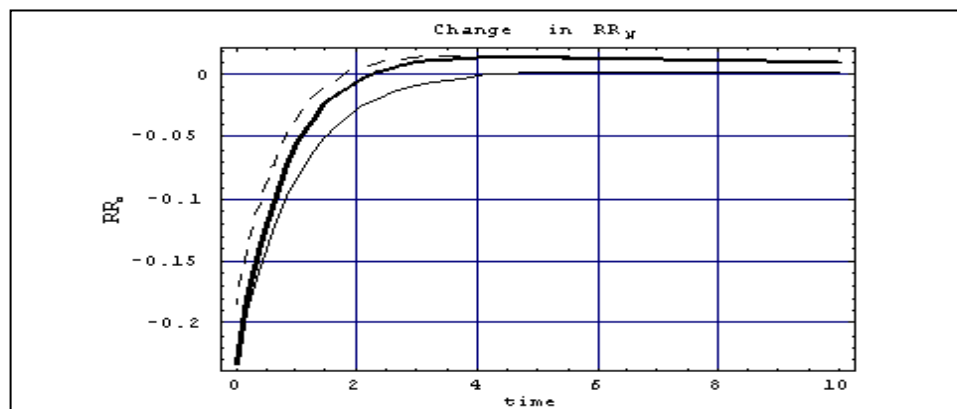
run depending mainly on factor intensities in the production sectors and the share of imported machines in the production of capital goods. With neutral assumption on factor intensity in the nontradables sector, workers benefit more from devaluation in the short run as the tradables sector becomes more labor intensive while losing more as the tradables sector gets more capital intensive. These results can be reconciled with recent simulation studies by Minot (1998), Friedman and Levinsohn (2002), and Haughton and Hoang (2003) by showing that devaluations may bring different distributive consequences for the countries with different economic structures.

[Figure 1] Transitional dynamics of real wage rate



[Figure 2] Transitional dynamics of real return on capital in T-sector



[Figure 3] Transitional dynamics of real return on capital in N-sector

Note: Model economies I, II, and III are depicted by dotted, thick, and thin lines, respectively.

The findings of this paper clearly do have some important policy implications. First of all, the government should pay careful attention to different effects on income distribution when implementing devaluation. While devaluation is expected to work smoothly facing less political pressure from workers in some cases, it is not in the other cases. Secondly, the stabilization program should include necessary measures to mitigate workers' misfortune when it is anticipated. Depending on an economy's peculiar structure, devaluation turns out to be a harsh experience to workers, at least in the short run. In particular, as the tradables sector becomes more capital intensive compared to the nontradables sector, workers are expected to suffer more severely in the short run. In this case, the government should be able to prepare an emergency fund to compensate for workers' deficient income in advance.

That being said, it may be called for to suggest some future research directions that are closely related to the limitations of the model. First, it would be desirable to extend the simple representative agent model to a more plausible heterogeneous agents model, as emphasized by Kirman (1992) and Stadler (1994). Second, it would be more realistic to construct a model that allows private agents to hold foreign assets. Finally, it would be much rewarding to collect and analyze factor income data in developing countries before and after devaluation to check if the theoretical simulation results obtained in the paper are empirically supported or not.

<Appendix 1> Solutions for \dot{I}_T, \dot{I}_N , and \dot{E}

$$\begin{aligned}
G\dot{I}_T = & A_1 \left\{ B_4(dI_T - \delta dK_T) + \rho B_3(dE - \frac{dM}{\mu}) + B_6[\alpha dE \right. \\
& + \beta(dI_T + dI_N) + \Theta_T dK_T + \Theta_N dK_N] + s_3(\rho + \delta)dK_T \\
& + \frac{s_4(\rho + \delta)}{k}dK_N - A_4\Theta_N(dI_N - \delta dK_N) \} \\
& + B_7 \left\{ [(dI_T - \delta dK_T) + \frac{1}{k}(dI_N - \delta dK_N)] + A_2[\alpha dE + \beta(dI_T + dI_N) \right. \\
& + \Theta_T dK_T + \Theta_N dK_N] + z\delta(s_3 - v_3)dK_T + \frac{z\delta(s_4 - v_4)}{k}dK_N \} \\
& + A_3 \left\{ \rho(dE - \frac{dM}{\mu}) + \frac{H}{\alpha}[\Theta_T(dI_N - \delta dK_N) + \Theta_N(dI_N - \delta dK_N)] \right\}
\end{aligned} \tag{A.1}$$

$$\begin{aligned}
G\dot{I}_N = & A_1 \left\{ B_5(dI_N - \delta dK_N) + \rho B_3k(dE - \frac{dM}{\mu}) + B_8[\alpha dE \right. \\
& + \beta(dI_T + dI_N) + \Theta_T dK_T + \Theta_N dK_N] + k(\rho + \delta)v_3dK_T \\
& + (\rho + \delta)v_4dK_N - kA_4\Theta_T(dI_T - \delta dK_T) \} \\
& + B_7 \left\{ [(dI_T - \delta dK_T) + \frac{1}{k}(dI_N - \delta dK_N)] + A_2[\alpha dE + \beta(dI_T + dI_N) \right. \\
& + \Theta_T dK_T + \Theta_N dK_N] + z\delta(s_3 - v_3)dK_T + \frac{z\delta(s_4 - v_4)}{k}dK_N \} \\
& + kA_3 \left\{ \rho(dE - \frac{dM}{\mu}) + \frac{H}{\alpha}[\Theta_T(dI_N - \delta dK_N) + \Theta_N(dI_N - \delta dK_N)] \right\}
\end{aligned} \tag{A.2}$$

$$\begin{aligned}
GE = & F \left\{ \rho(dE - \frac{dM}{\mu}) + \frac{H}{\alpha}[\Theta_T(dI_T - \delta dK_T) + \Theta_N(dI_N - \delta dK_N)] \right\} \tag{A.3} \\
& + A_6 \left\{ [(\rho + \delta) - (\frac{A_3}{\alpha})\Theta_T](dI_T - \delta dK_T) + z\delta\rho(1 + k)B_3(dE + \frac{dM}{\mu}) \right. \\
& + B_1[\alpha dE + \beta(dI_T + dI_N) + \Theta_T dK_T + \Theta_N dK_N] \\
& + z\delta(\rho + \delta)s_3dK_T + \frac{z\delta(\rho + \delta)s_4}{k}dK_N - \frac{A_3}{\alpha}\Theta_N(dI_N - \delta dK_N) \\
& + [(\rho + \delta) - (\frac{kA_3}{\alpha})\Theta_N](dI_N - \delta dK_N) + B_4[\alpha dE + \beta(dI_T + dI_N) \\
& + \Theta_T dK_T + \Theta_N dK_N] + z\delta k(\rho + \delta)v_3dK_T
\end{aligned}$$

$$+z\delta(\rho+\delta)v_4dK_N - k(\frac{A_3}{\alpha})\Theta_T(dI_T - \delta dK_T)\}$$

<Appendix 2> Expressions for X_i' s

$$X_1 = \alpha A_5 - 1, X_2 = \beta A_5 - 1, X_{22} = \Theta_T A_5 + (\rho + \delta), X_3 = \Theta_N A_5 + (\rho + \delta),$$

$$X_4 = (\frac{\rho}{\mu G})[F + A_6 B_3 z \delta (1 + k)],$$

$$X_5 = (\frac{1}{G})[\rho F + A_6 B_3 z \delta \rho (1 + k) + (B_1 + B_2)\alpha],$$

$$X_6 = (\frac{1}{G})[F(\frac{H}{\alpha})\Theta_T + A_6[(\rho + \delta) - (\frac{A_3}{\alpha})\Theta_T - A_3(\frac{k}{\alpha})\Theta_T] + (B_1 + B_2)\beta],$$

$$X_7 = (\frac{1}{G})[F(\frac{H}{\alpha})\Theta_N + A_6[(\rho + \delta) - (\frac{A_3}{\alpha})\Theta_N - A_3(\frac{k}{\alpha})\Theta_N] + (B_1 + B_2)\beta],$$

$$X_8 = (\frac{1}{G})[(B_1 + B_2)\Theta_T + A_6[(\rho + \delta)\delta[z(s_3 + kv_3) - 1]$$

$$+ A_6(\frac{A_3}{\alpha})\delta\Theta_T(1 + k) - F(\frac{H}{\alpha})\Theta_T\delta],$$

$$X_9 = (\frac{1}{G})[(B_1 + B_2)\Theta_N + A_6[(\rho + \delta)\delta[z(\frac{s_4}{k} + v_4) - 1]$$

$$+ A_6(\frac{A_3}{\alpha})\delta\Theta_N(1 + k) - F(\frac{H}{\alpha})\Theta_N\delta],$$

$$X_{10} = (\frac{\rho}{\mu G})[A_1 B_3 - A_3], X_{11} = (\frac{1}{G})[A_1(\rho B_3 + \alpha B_6) + \alpha A_2 B_7 - \rho A_3],$$

$$X_{12} = (\frac{1}{G})[A_1(B_4 + \beta B_6) + B_7(1 + \beta A_2) - A_3(\frac{H}{\alpha})\Theta_T],$$

$$X_{13} = (\frac{1}{G})[A_1(\beta B_6 - A_4\Theta_N) + B_7(\beta A_2 - \frac{1}{k}) - A_3(\frac{H}{\alpha})\Theta_N],$$

$$X_{14} = (\frac{1}{G})[A_1(B_6\Theta_T + s_3(\rho + \delta) - B_4\delta) + B_7[A_2\Theta_T$$

$$+ z\delta(s_3 - v_3) - \delta] + A_3(\frac{H}{\alpha})\Theta_T\delta],$$

$$X_{15} = (\frac{1}{G})[A_1(B_6\Theta_N + \frac{s_4(\rho + \delta)}{k} - A_4\Theta_N\delta) + B_7[\frac{\delta}{k} + A_2\Theta_N$$

$$+ \frac{z\delta(s_4 - v_4)}{k} - \delta] + A_3(\frac{H}{\alpha})\Theta_N\delta],$$

$$X_{16} = (\frac{\rho k}{\mu G})[A_3 - A_1 B_3], \quad X_{17} = (\frac{1}{G})[A_1(\rho B_6 k + \alpha B_8) - \alpha B_7 A_2 - \rho A_3 k],$$

$$X_{18} = (\frac{1}{G})[A_1(\beta B_6 - A_4 k \Theta_T) - B_7(1 - \beta A_2) - A_3(\frac{H}{\alpha})k \Theta_T],$$

$$X_{19} = (\frac{1}{G})[A_1(B_5 + \beta B_8) - B_7(\beta A_2 \frac{1}{k}) - A_3(\frac{H}{\alpha})k \Theta_N],$$

$$X_{20} = (\frac{1}{G})[A_1(B_6 \Theta_T + k(\rho + \delta)v_3 + A_4 \Theta_N k \delta) - B_7[A_2 \Theta_T + z\delta(s_3 - v_3) - \delta] + kA_3(\frac{H}{\alpha})\Theta_T \delta],$$

$$X_{21} = (\frac{1}{G})[A_1(B_8 \Theta_N + (\rho + \delta)v_4 - B_5 \delta) - B_7[\frac{\delta}{k} + A_2 \Theta_N + \frac{z\delta(s_4 - v_4)}{k}] + kA_3(\frac{H}{\alpha})\Theta_N \delta],$$

$$\text{where } A_1 = z\delta(1 + H)A_5, \quad A_2 = \frac{z\delta\theta_K^N(v_1 + s_2)}{J(\rho + \delta)k}, \quad A_3 = z\delta\alpha A_4,$$

$$A_4 = \frac{\beta\theta_K^N}{J(\rho + \delta)k}, \quad A_5 = \frac{(D_N / Q_N)}{J}, \quad A_6 = \beta(1 - \tau)A_5, \quad B_1 = z\delta A_6 B_6,$$

$$B_2 = z\delta A_6 B_6, \quad B_3 = \frac{\alpha\theta_K^N}{\tau k(\rho + \delta)(D_N / Q_N)}, \quad B_4 = [\frac{(\rho + \delta)}{z\delta} - A_4 \Theta_T],$$

$$B_5 = [\frac{(\rho + \delta)}{z\delta} - kA_4 \Theta_N], \quad B_6 = \frac{(\beta + s_2)\theta_L^N}{Jk}, \quad B_7 = \frac{z\delta\beta^2\theta_K^N}{J},$$

$$B_8 = \frac{(\beta - v_1)\theta_L^N}{J}, \quad F = 1 + z\delta(1 + k)\beta A_4, \quad H = \alpha(\tau - 1)A_5,$$

$$G = F + H.$$

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