since $N>0$, $Q_0>0$, $m_1>0$, $m_2>0$, we obtain $[\lambda m_1 m_2^2 L_{\theta_1\theta_1}(f_2 f_{12}-f_1 f_{22})+NQ_0(r_2 s_{2\theta_1} e_2 m_2)^2]<0$.

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THE MIGRATION FUNCTION AND THE TODARO PARADOX

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The purpose of this paper is to present a microeconomic foundation of the migration function and to discuss the impact of an increase in the job creation rate on migration and urban unemployment. Each rural worker must estimate his expected urban income on the basis of his own expected numbers of both newly created jobs and migrants during the coming period. Workers whose expected urban income is greater than the rural one decide to migrate, while those who estimate smaller urban income stay on.

1. Introduction

The problem of urban unemployment and rural–urban migration observed in many developing countries was first analyzed by Todaro (1969). The condition under which an increase in the rate of urban job creation results in an increase in urban unemployment has been a central subject in several papers, e.g., Todaro (1976), Blomqvist (1978) and Arellano (1981).

Their explanation of the so-called 'Todaro paradox' could be summarized as follows: Urban unemployment at time t, $U(t)$, is defined as urban unemployment at time $t-1$ plus rural–urban migration during the period $t-1$, $M(t-1)$, minus an increment of urban employment opportunities during the period $t-1$, i.e.,

$$U(t)=U(t-1)+M(t-1)-g(t-1)E(t-1), \tag{1}$$

where E and g stand for the number of urban employed workers and its growth rate, respectively. Differentiating partially with respect to g, we have

$$\frac{\partial U(t)}{\partial g(t-1)}=\frac{\partial M(t-1)}{\partial g(t-1)}-E(t-1). \tag{2}$$

An increase in the rate of job creation promotes not only urban employment but also rural–urban migration. If the latter effect is greater than the former,

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the Todaro paradox arises. They assume the migration function as

$$m(t-1)=\frac{M(t-1)}{R(t-1)}=m[w,P(t)], \tag{3}$$

where R and w denote the number of total rural workers and the constant ratio of urban manufacturing wage to rural agricultural income, respectively. P is the probability of getting an urban job and is defined as

$$P(t)=\frac{g(t-1)E(t-1)}{U(t-1)}. \tag{4}$$

Since

$$\frac{\partial M(t-1)}{\partial g(t-1)}=R(t-1)\frac{\partial m(t-1)}{\partial P(t)}\frac{\partial P(t)}{\partial g(t-1)}={}_m\eta_P\frac{ME}{UP}, \tag{5}$$

where ${}_m\eta_P$ denotes the elasticity of migration with respect to probability and is expressed by

$${}_m\eta_P=\frac{\partial m}{\partial P}\frac{P}{m};$$

the condition for the Todaro paradox is obtained by substituting (5) into (2),

$${}_m\eta_P>\frac{gE}{M}. \tag{6}$$

Eq. (4), however, implies that the migrants during the period $t-1$ cannot be candidates for getting newly created jobs open at time t. It also implies that the probability of getting an urban job at time t is known for the rural workers who try to decide at time $t-1$ whether they migrate or stay. At the beginning of time $t-1$, however, nobody knows such a probability, because nobody has the perfect information about employment plans of individual private firms (and the government) at time t nor about the number of migrants during the period $t-1$. An individual rural worker must estimate the probability by forecasting both the numbers of newly created jobs and migrants, i.e., instead of (4),

$$P^e(t)=\min\left[1,\frac{g^e(t-1)E(t-1)}{U(t-1)+M^e(t-1)}\right], \tag{7}$$

where superscript 'e' stands for the expected variables.

Moreover, the migration function (3) says that rural–urban migration is promoted if the wage differential becomes greater and/or if the probability of getting an urban job rises. It is not, however, clear on what criterion the decision making of rural workers is based when they try to decide whether they should migrate or not.

The purpose of this paper is to derive an aggregate migration function by introducing explicitly the criterion for the decision making, and then to discuss under what condition the Todaro paradox arises.

2. The model

At the beginning of time $t-1$, rural workers decide whether they should migrate to the urban area or not during the period $t-1$. It is assumed that the correct information they have at hand is the levels of constant rural agricultural and urban manufacturing wages, W_r and W, and the numbers of urban employed and unemployed, and total rural workers at time $t-1$, $E(t-1)$, $U(t-1)$ and $R(t-1)$. It is also assumed, as in Harris–Todaro (1970), that they migrate to the urban area as long as their expected urban income, $W_u^e(t)$, is greater than their expected rural income, $W_r^e(t)$, at time t. It is further assumed that the expected rural income is equal to W_r,

$$W_r^e(t)=W_r,$$

while the expected urban income is regarded as W multiplied by the expected probability formulated by (7),

$$W_u^e(t)=\min\left[W,W\frac{g^e(t-1)E(t-1)}{U(t-1)+M^e(t-1)}\right]. \tag{8}$$

If all rural workers have identical expectations of the growth rate, $g^e(t-1)$, and migrants, $M^e(t-1)$, they all decide to either stay or migrate depending on whether $W_u^e(t)$ is either smaller or greater than W_r. For instance, suppose that each individual is subject to static expectations like

$$g^e(t-1)=g(t-2)\quad\text{and}\quad M^e(t-1)=M(t-2),$$

then $W_u^e(t)$ has the unique value which is either smaller or greater than W_r.

In general, however, all rural workers would not have identical expectations. In the next section, the case in which they have different expectations of $M^e(t-1)$ but identical expectations of $g^e(t-1)$ is discussed, while the reverse case in which they have different $g^e(t-1)$ but identical $M^e(t-1)$ is described in section 4. Section 5 deals with the most general case in which they have different expectations of $M^e(t-1)$ and $g^e(t-1)$. In each section, the aggregate migration function is derived and the condition for the Todaro paradox is presented. Conclusions and some extensions are summarized in the final section.

3. Different expectations of the number of migrants

Fig. 1(a) shows the negative relationship (8) between the expected urban income and the expected number of migrants, given a common expected job creation rate. It is assumed that W is greater than W_r. There are two cases: In case 1 where $g^e E/U$ is so small that $Wg^e E/U$ is smaller than W_r, all rural workers want to stay in rural agriculture, because the expected urban income of every rural worker is smaller than the rural one. The other case is characterized by the inequality that $Wg^e E/U > W_r$.[1] Given the level of constant rural wage, there exists unique critical value of expected migrants, M^{e*}, such that the expected urban income is equated to the rural one. It is expressed by[2]

$$M^{e*} = wg^e E - U, \tag{9}$$

where w is the urban–rural wage differential, $w = W/W_r$. Rural workers whose expected number of migrants is smaller than M^{e*} migrate to the urban area, while those who forecast a greater number of migrants than M^{e*} stay in rural agriculture.

How many rural workers migrate depends on how many persons forecast the number of migrants smaller than M^{e*}. Let $f[M^e(t-1)]$ denote the frequency density distribution of this expectation as described in fig. 1(b), then the number of migrants during the period $t-1$ can be expressed by

$$M(t-1) = R(t-1) \int_0^{M^{e*}} f(M^e)\,\mathrm{d}M^e. \tag{10}$$

Rewriting (10) in the form often used in the discussion of the Todaro paradox,

$$m(t-1) = M/R = a(w, g^e), \tag{11}$$

where

$$a_1 = f(M^{e*})g^e E > 0 \quad \text{and} \quad a_2 = f(M^{e*})wE > 0.$$

Now, let us discuss whether an increase in the rate of urban job creation during the period $t-1$ increases urban unemployment at time t or not. If

[1] When the probability is unity, this relationship has a portion of flat horizontal line with the level of W before the portion of a negative sloping curve.

[2] For simplicity, hereafter we omit time dimension $(t-1)$ when it can be understood clearly.

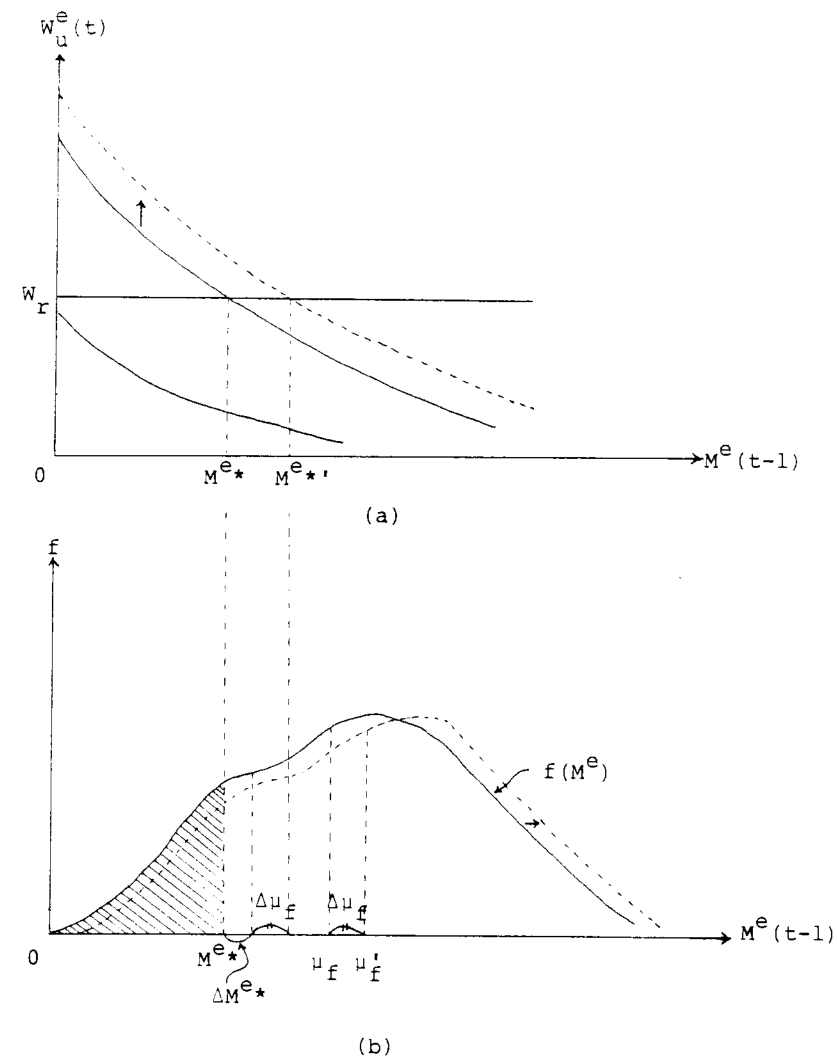

Fig. 1

rural workers have some information about an increase in the rate of job creation, they would forecast greater g^e and M^e than in the case of no information. Assuming that rural workers forecast greater g^e based on the new information, the negative sloping curve in fig. 1(a) shifts upwards so that the critical value of expected migrants is increased by

$$M^{e*\prime} - M^{e*} = wE\,\Delta g^e.$$

On the other hand, to forecast greater M^e means that the frequency density distribution changes and that the area below this distribution and under the critical value as shown in (10) becomes smaller. If we assume that a shift in distribution changes only the mean keeping other moments unchanged as illustrated in fig. 1(b), then such a rightward shift in distribution can be interpreted by a leftward shift of the critical value of expected migrants in the original distribution. Hence, the net increase in the critical value is expressed by

$$\Delta M^{e*} = wE\Delta g^e - \Delta\mu_f, \qquad (12)$$

where $\Delta\mu_f$ denotes an increment of the distrubition mean. Therefore, the number of migrants increases by

$$\Delta M = R\int_{M^{e*}}^{M^{e*}+\Delta M^{e*}} f(M^e)\,\mathrm{d}M^e = Rf(M^{e\prime\prime})(wE\,\Delta g^e - \Delta\mu_f), \qquad (13)$$

where $M^{e*} \leqq M^{e\prime\prime} \leqq M^{e*} + \Delta M^{e*}$. Since urban employment at time t is increased by $E\,\Delta g$, urban unemployment level at time time t increased if

$$Rf(M^{e\prime\prime})(wE\,\Delta g^e - \Delta\mu_f) > E\,\Delta g. \qquad (14)$$

Namely, the condition for the Todaro paradox can be expressed by

$${}_{g^e}\eta_g - \frac{\mu_f}{wEg^e}\,{}_{M^e}\varepsilon_g > \frac{g}{Rf(M^{e\prime\prime})wg^e}, \qquad (15)$$

where

$${}_{g^e}\eta_g = \frac{\Delta g^e}{\Delta g}\frac{g}{g^e} \quad \text{and} \quad {}_{M^e}\varepsilon_g = \frac{\Delta\mu_f}{\Delta g}\frac{g}{\mu_f}.$$

When rural workers have some information about an increase in g, the higher the elasticity of expected growth rate and the lower the elasticity of expected migrants, the higher the probability that the Todaro paradox arises. If rural workers have no information, g^e and M^e remain unchanged so that urban unemployment at time t decreases by $E\Delta g$.

4. Different expectations of the rate of job creation

Fig. 2(a) shows the positive relationship (8) between the expected urban income and the expected rate of job creation, given a common expected number of migrants. Given the constant rural wage, there exists unique critical value of expected rate of job creation, g^{e*}, such that the expected

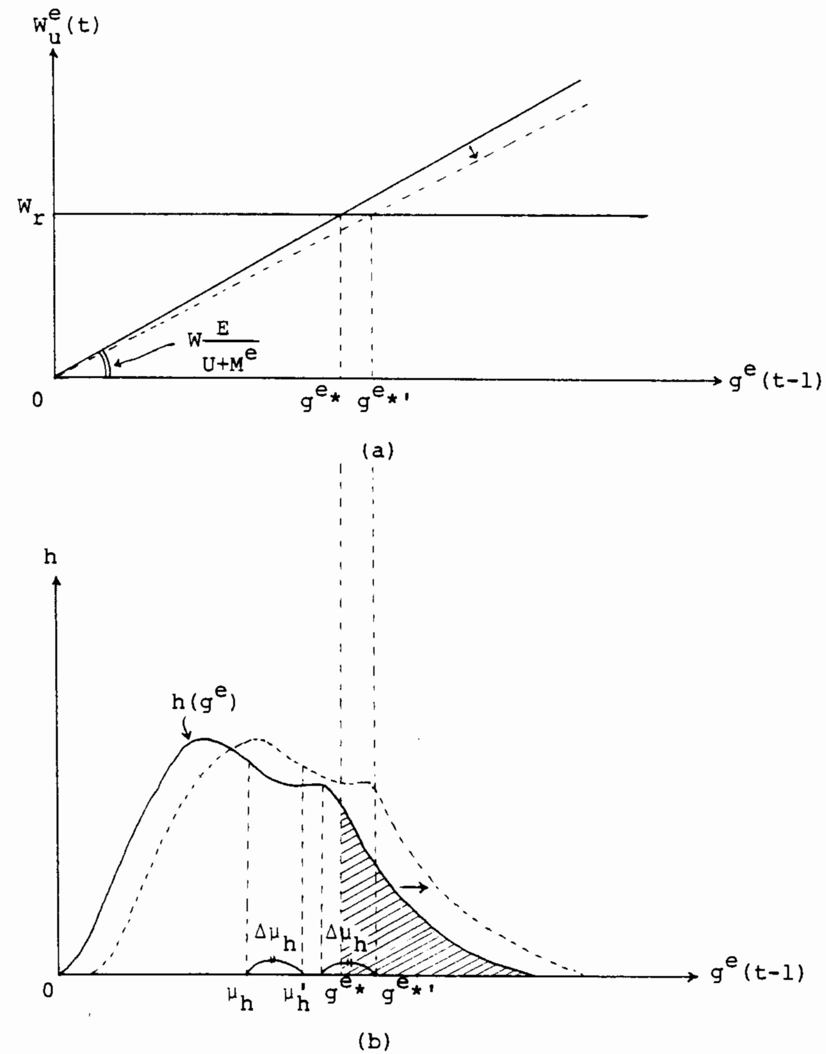

Fig. 2

urban income is equated to the rural one. It is expressed by

$$g^{e*}=\frac{U+M^e}{wE}. \tag{16}$$

Rural workers whose expected rate of job creation is greater than g^{e*} migrate to the urban area, while those who forecast the smaller rate of job creation than g^{e*} stay in rural agriculture.

How many rural workers migrate depends on how many persons forecast the rate of job creation greater than g^{e*}. Let $h(g^e)$ denote the frequency density distribution of this expectation as described in fig. 2(b), then the number of migrants during the period $t-1$ can be expressed by

$$M(t-1)=R\int_{g^{e*}}^{\bar{g}^e} h(g^e)\,\mathrm{d}g^e, \tag{17}$$

where $\bar{g}^e$ is a sufficiently great number such that $h(\bar{g}^e)=0$. Rewriting (17) in the popular form,

$$m(t-1)=M/R=b(w,M^e), \tag{18}$$

where

$$b_1=h(g^{e*})g^{e*}/w>0 \quad \text{and} \quad b_2=-h(g^{e*})/(wE)<0.$$

The impact of an increase in g on M^e can be explained by a clockwise rotation of the straight line through the origin as shown in fig. 2(a). The critical value of expected growth rate is raised by

$$g^{e*\prime}-g^{e*}=\Delta M^e/(wE).$$

On the other hand, the new information about an increase in g changes the frequency density distribution. Similarly assuming that a shift in distribution changes only the mean, a rightward shift in distribution can be dealt with by a leftward shift of the critical value of expected growth rate in the original distribution. Hence, the net increase in the critical value is expressed by

$$\Delta g^{e*}=\frac{\Delta M^e}{wE}-\Delta\mu_h, \tag{19}$$

where $\Delta\mu_h$ denotes an increment of the distribution mean. The number of migrants, therefore, increases by

$$\Delta M=R\int_{g^{e*}+\Delta g^{e*}}^{g^{e*}} h(g^e)\,\mathrm{d}g^e=Rh(g^{e''})\left(\Delta\mu_h-\frac{\Delta M^e}{wE}\right), \tag{20}$$

where $g^{e''}$ takes a value between g^{e*} and $g^{e*}+\Delta g^{e*}$; $g^{e*}\leqq g^{e''}\leqq g^{e*}+\Delta g^{e*}$. If this ΔM is greater than $E\Delta g$, then urban unemployment increases at time t. Namely, the condition for the Todaro paradox is expressed by

$${}_{g^e}\varepsilon_g-\frac{M^e}{wE\mu_h}\,{}_{M^e}\eta_g>\frac{gE}{Rh(g^{e''})\mu_h}, \tag{21}$$

where

$${}_{g^e}\varepsilon_g=\frac{\Delta\mu_h}{\Delta g}\frac{g}{\mu_h} \quad \text{and} \quad {}_{M^e}\eta_g=\frac{\Delta M^e}{\Delta g}\frac{g}{M^e}.$$

5. Different expectations of both $M^e(t-1)$ and $g^e(t-1)$

Fig. 3 shows the positive relationship (8) between the expected rate of job creation and expected number of migrants on which the expected urban income is equal to the rural one. Above the line, the expected urban income is smaller than the rural one, while below the line it is greater. Hence, rural workers whose combination of expected values of g^e and M^e is in the region below this line migrate to the urban area, while those who forecast any combination in the region above the line stay in rural agriculture.

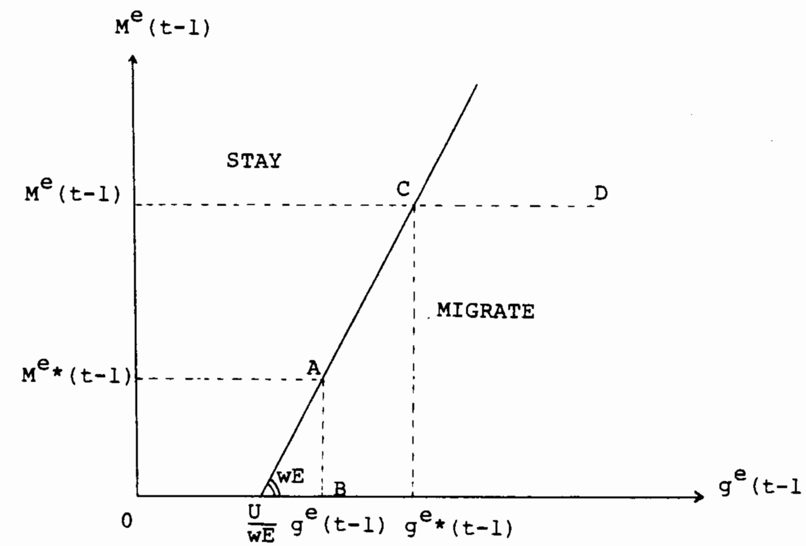

Fig. 3

If all rural workers have the identical expected rate of job creation which is greater than $U/(wE)$, there exists unique critical value M^{e*} such that rural workers whose expected number of migrants is smaller than M^{e*} migrate.

This is the case discussed in section 3 before, and is shown as, for instance, AB in this figure. On the contrary, if all rural workers have an identical expected number of migrants, there exists unique critical value g^{e*} such that rural workers whose expected rate of job creation is greater than g^{e*} migrate. This is the case examined in section 4, and is shown as, for instance, CD in this figure.

The joint frequency density distribution being denoted by $q[M^e, g^e]$, the number of migrants in the form of the ratio to the total rural workers can be expressed by

$$m(t-1) = M/R = \int_{U/wE}^{\bar{g}^e} \int_{0}^{wg^eE-U} q[M^e, g^e]\,\mathrm{d}M^e\,\mathrm{d}g^e. \tag{22}$$

The migration function derived above is a function of w. The number of migrants increases as w rises, because an increase in w broadens the migration region in fig. 3 through not only shifting the straight line leftwards but also making its slope steeper.

If rural workers have some information about an increase in g, their expectations based on this information shift the joint distribution toward the north-east. Making a similar assumption about a shift in distribution, a shift toward the north-east is decomposed into a rightward and upward shift. Furthermore, a rightward shift in the joint distribution can be dealt with by a leftward shift in the straight line in fig. 3 by the amount of $\Delta\mu_g$, and an upward shift can be understood by a downward shift in the straight line by the amount of $\Delta\mu_M$, where μ_g and μ_M stand for the means of respective variables g^e and M^e. Hence, the number of migrants increases by

$$\begin{aligned} \Delta M &= R \int_{U/wE}^{\bar{g}^e} \int_{wg^eE-U+\Delta\mu_g wE-\Delta\mu_M}^{wg^eE-U} q(M^e, g^e)\,\mathrm{d}M^e\,\mathrm{d}g^e \\ &= \left(\bar{g}^e - \frac{U}{wE}\right)(wE\,\Delta\mu_g - \Delta\mu_M)\,q(\tilde{M}^e, \tilde{g}^e), \end{aligned} \tag{23}$$

where

$$U/(wE) \leqq \tilde{g}^e \leqq \bar{g}^e, \quad \text{and}$$

$$w\tilde{g}^eE - U + wE\,\Delta\mu_g - \Delta\mu_M \leqq \tilde{M}^e \leqq wg^eE - U.$$

The condition for the Todaro paradox, therefore, can be expressed by

$$_{g^e}\hat{\lambda}_g - \frac{\mu_M}{wE\mu_g}\,{}_{M^e}\hat{\lambda}_g > \frac{gE}{\mu_g wER\left(\bar{g}^e - \frac{U}{wE}\right)q(\tilde{M}^e, \tilde{g}^e)}, \tag{24}$$

where

$$_{g^e}\hat{\lambda}_g = \frac{\Delta\mu_g}{\Delta g}\frac{g}{\mu_g} \quad \text{and} \quad {}_{M^e}\hat{\lambda}_g = \frac{\Delta\mu_M}{\Delta g}\frac{g}{\mu_M}.$$

6. Conclusions and further remarks

If the probability of getting an urban job is known as in (4), each rural worker forecasts the same level of expected urban income. Hence, if the same criterion for the decision making is introduced, all rural workers either stay or migrate depending on whether the identical expected urban income is either smaller or greater than the rural one. Such an outcome is quite far from the phenomenon observed in many developing countries. It is, therefore, clear that some other different criterion must be presupposed in order that the migration function (3) be meaningful.

Moreover, the non-existence of the number of migrants in the denominator of the probability (4) entails a large difference in the condition for the Todaro paradox, because any information about an increase in g would in most cases increase M^e and hence decrease the expected probability which in turn has the impact of discouraging partly rural–urban migration. In our analysis, this effect is expressed by the second term of the left-hand side of the condition for the Todaro paradox in each section.

So far, our explanation was confined to the decision making of rural workers. The decision of urban unemployed workers, however, can be also described in our framework. They decide to migrate to the rural area when their expected urban income is smaller than the rural one. $M^e(t-1)$ now expresses net rural–urban migration. Hence, it may be negative. Nobody would, however, forecast negative M^e which entails $(U+M^e)<0$, because the probability of getting an urban job becomes unity as long as g^e is positive. In the phase where g^e is negative, (7) does not mean the probability. In this case, the probability must be zero.

In our model, the expected urban income at time t is compared with the rural one. Our analytical framework can be extended to the more reasonable case in which workers compare the discounted present value of the expected urban income with that of the rural one. Let i denote the discount rate, the present value of rural income is expressed by

$$W_r \sum_{n=0}^{T} \frac{1}{(1+i)^n},$$

where T stands for the time horizon, while that of expected urban income is formulated by

$$W \sum_{n=0}^{T} \frac{P^e(t+n)}{(1+i)^n}.$$

If $M^e(t+j)$ and $g^e(t+j)$ are determined uniquely by $M^e(t+j-1)$ and $g^e(t+j-1)$, respectively, and if the present value of expected urban income is the positive function of $M^e(t-1)$ and $g^e(t-1)$, then similar analysis would be possible. It would also be possible to say that young people tend to migrate relative to old people because the former could enjoy a higher wage of urban manufacturing for a much longer period than the latter. If we take into account the long lifetime expected income, the once-for-all migration cost (which we assumed away for simplicity) would become a negligibly small amount relative to the discounted present value over the time horizon.

In our model, why some persons decide to migrate when others want to stay depends primarily on the assumption that each individual makes a different expectation. The difference of taste for risk-taking would give an explanation for justifying this assumption. Risk lovers would tend to estimate higher g^e and smaller M^e than risk averters.

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CALIBRATING LONGITUDINAL MODELS OF RESIDENTIAL MOBILITY AND MIGRATION

An Assessment of a Non-Parametric Marginal Likelihood Approach

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This paper discusses the problems of controlling for omitted variables in estimating the structural parameters of longitudinal models and focuses upon an assessment of a non-parametric marginal maximum likelihood approach suggested by the results of Laird (1978). The approach is shown to be statistically valid for a plausible discrete-time model of the incidence of residential or migration moves, at least for data in which no household moves in every time period. Empirical evaluation with two large datasets on residential mobility indicates that the approach is also computationally feasible and provides a promising alternative to more conventional methods for controlling for omitted variables.

1. Introduction

Micro-level research into residential mobility and migration has been increasingly dominated by analyses of longitudinal data, mostly from panel studies [see, for example, the review by Clark (1982)]. However, the identification of the characteristics and determinants of move behaviour has been hindered by the serious statistical problems posed by omitted variables. These problems are not unique to mobility research but arise in most areas of social science endeavour in which interest may focus upon temporal or sequential processes. For example, in studying employment [Heckman and Willis (1977)] and unemployment [Lancaster (1979)], shopping behaviour [Massy et al. (1970)], modal choice [Johnson and Hensher (1982)], responses to intelligence tests [Bock and Aitkin (1981)], and duration of stay in hospital [Eaton and Whitmore (1977)]. When the longitudinal data consists of single durations for each sampled individual, it is impossible to distinguish

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