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Return migration, uncertainty and precautionary savings

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Abstract

This paper presents a life-cycle model where migrants determine re-migration and consumption simultaneously in a stochastic environment. Whether precautionary savings of migrants are above or below those of natives is ambiguous in general—the sign depends on the risk in host- and home-country labor markets and on the correlation of labor market shocks. Furthermore, the effect of an uncertain environment on migration and re-migration plans cannot be unambiguously signed for the general case. It depends on the size of the wage differential as well as the relative risk the migrant exhibits in the two labor markets. © 1997 Published by Elsevier Science B.V.

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1. Introduction

A major form of migration into Europe and within Europe, but also in Asia as well as between Asia and countries of the Middle East, is *guest worker* or, more generally, *return* migration. The impact of this form of migration on the economies of both the labor-exporting and the labor-importing country differs in many aspects from that of permanent migration. In contrast to permanent migrants, temporary migrants either invest a large proportion of their earnings into savings in the host country, or they transfer it to their home country, where it is then saved

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or used to support family members. [1] Both the amounts of money that are transferred back home and that are saved in the host country have important implications for the economies involved. For the emigration country, transferred money is a major balance of payments support. For the immigration country, transfers have a strong negative effect on the balance of payments. Furthermore, savings of migrants provide a substantial part of domestic savings and, thereby, contribute to capital formation (Macmillen, 1982, p. 251). [2]

The motivation for remittances and savings has been explored in a number of contributions. Lucas and Stark (1985, 1988) show that remittances can be explained by pure altruism as well as by pure self-interest. They also provide some interesting empirical analysis which underlines their arguments. An explanation for the high savings rates of temporary migrants is provided by Djajic (1989) and Galor and Stark (1990): migrants condition their behavior in the host country on the future economic situation in the home country. As a consequence, if future economic conditions differ between home and host region, then saving rates of temporary migrants should differ from those of permanent migrants or natives. While Djajic (1989) emphasizes price levels as a distinguishing feature between home and host region, Galor and Stark (1990) stress differences in the future wage rate. [3] Merkle and Zimmermann (1992) explore the empirical implications of this model, using data for migrants to Germany. Karayalcin (1994) shows that in the absence of perfect capital mobility, temporary migrants will save more than natives since they face a higher rate of interest.

In these studies a return, or a return probability, are determined outside the model. However, in migration situations where workers may choose their return optimally, savings and re-migration decisions are likely to be met simultaneously. Djajic and Milbourne (1988) develop a model where an endogenous return is achieved by assuming that the marginal utility of consumption is higher in the home country than in the host country. A similar argument has been put forward by Hill (1987), who assumes that utility depends explicitly on a time path of the places of residence. Dustmann (1994b) adds a further motive for an interior return point, a high reward on host-country human capital in the home country, and

[1] In 1973, transfers from Turkish and Yugoslav workers in Germany into their home countries totaled to over twice the amount obtained through exports of goods from these countries to Germany (Hiemenz and Schatz, 1979, p. 1). Over the period from 1960 to 1984, transfers of Greek workers from Germany to Greece amounted to 16% of Greece's capital goods exports in the same period (Glytsos, 1988, p. 525). Transfers from Thai workers in the Middle East in 1981 were equivalent to about 6% of the total value of exports from Thailand in that year (Pitayanon, 1986, p. 273). Remittances of Pakistanis from the Middle East finance some 86% of Pakistan's trade deficit (Robinson, 1986).

[2] Jones and Smith (1970) report that the local savings rate (earnings that are invested into savings in the host country) of migrant workers in Great Britain in 1965 was about 2% above the UK average. For France, the average local savings of foreign workers in 1970 was 50% higher than those of a French person with the same income (Granier and Marciano, 1975).

[3] Galor and Stark (1991) use the same framework to explain higher work effort of migrants.

analyzes the savings behavior of migrants if return and consumption are jointly determined.

Both savings and return decisions depend crucially on future income streams in the home and host country, which are in turn strongly affected by uncertainty. The purpose of this paper is to extend the existing literature by analyzing the optimal length of migration and the savings behavior of migrant workers in a model where savings and migration durations are jointly determined and where there is uncertainty about income in both host and home country. To introduce uncertainty in migration models is no novelty. The aforementioned studies by Galor and Stark (1990, 1991) derive their results by assuming uncertainty about a future return. Stark and Levhari (1982) explain rural–urban migration as a device to diversify risk. Katz and Stark (1986) show that uncertainty about income in the immigration area can generate a situation where migration from a rural to an urban area is rational despite a higher mean income in the rural area. However, the effect of income uncertainty on migrants' savings and the desired length of migration in a model where both duration abroad and savings are jointly determined has not been investigated, and the analysis produces some new and interesting results.

The basic model draws on the work of Galor and Stark (1990, 1991) and Djajic and Milbourne (1988): wages are lower in the home region, and the marginal utility of consumption is lower in the host region. These two assumptions characterize not only international migrations, but also many internal migrations—for instance, rural–urban migration in many developing countries. The results of the analysis also apply therefore if the two regions are not separate countries. The analysis of the effect of uncertainty on savings draws on the work of Leland (1968) and Sandmo (1970). In this model, however, income in both periods may be affected by risk, and shocks in the two periods may be correlated. Additionally, the period length is made a further choice variable. This allows to analyze the effect of income uncertainty on the optimal return time along the lines of Levhari and Weiss (1974).

The model leads to a number of interesting and new results. It combines the motives of Galor and Stark (1990) and Djajic and Milbourne (1988): migrants save more than natives because lower future wages increase their marginal utility of wealth, and because the direct marginal utility of consumption is higher at home. The uncertainty adds a further important explanation for observed differences in savings behavior between migrants and natives: if the variance of income is higher in the emigration country, and/or if the migrant faces a higher income variance in the host country than the native, he will accumulate more wealth than the native worker while being abroad. However, this result is not unambiguous for the general case. While in Galor and Stark (1990) the probability of a return links savings decisions of the migrant in the host country to future economic conditions in the home country, here the temporary nature of migration links risk in the home-country labor market to risk in the host-country labor market. As a result, even if the income variance in both periods is higher for the migrant than for the native, a negative correlation between labor market shocks in the emigration and immigration country may allow the migrant to hedge against risk, and to reduce his lifetime income variance even below the level of the native worker.

The analysis of the effect of income uncertainty on the choice of the optimal length of the migration period identifies three effects of uncertainty: the first is a direct effect of risk aversion, the second and third effects are induced by the endogeneity of the return point. For the general case, the effect of uncertainty on the optimal length of the migration period cannot be unambiguously signed. However, more conclusive results are obtained for specific migration situations. For instance, if the wage differential between home and host country is large, and at the same time the home-country labor market is very risky, uncertainty should increase the migrant's stay abroad. On the other side, if the host-country labor market is perceived riskier than the home-country labor market, uncertainty is likely to reduce the migrant's stay abroad. The comparative statics are illustrated by simulations.

2. Saving and migration decisions

Consider a worker who is confronted with the problem of deciding whether he wants to migrate to a potential host country and for how long. An obvious motive for a migration is a higher rental rate on a unit of human capital stock in the potential immigration country. The worker would then migrate if the economic advantages of doing so outweigh the cost of migration, or following Sjaastad (1962), if the present value of the migration decision is positive. This, however, implies that the worker's objective is only to maximize lifetime income. Thus, his decision is solely influenced by monetary aspects. In this case, and after having decided to migrate, there is no reason for the worker to return to his home country. [4] In other words, only under certain assumptions is such a simple model capable of explaining *temporary* migration.

A simple extension, which has been put forward by Djajic and Milbourne (1988), is to let the potential migrant maximize lifetime utility from consumption, given a lifetime budget constraint that depends on the migration decision. If the migrant prefers to consume at home rather than abroad (because of other arguments in the utility function that are complementary to consumption, such as being together with his family and friends, living in a familiar environment, enjoying the climate, etc.), his optimal decision may be to migrate only *temporarily*, although

[4] One possible explanation for a return which is compatible with the simple monetary model is that migrants improve their earnings position at home while being abroad by investment into home-country specific human capital. For a formal treatment, see Dustmann (1994a).

the value of his stock of human capital is higher abroad. [5] The reason for this is that, since lifetime is finite, each unit of time spent abroad increases his lifetime utility by raising his total consumption possibilities, but it decreases lifetime utility by reducing the time available for consumption at home.

More formally, let the lifetime horizon of the migrant be equal to $T = 1$ and assume, for simplicity, that the worker is productive over his entire life cycle. The migrant will have to choose the time t he wants to stay in the host country, thereby leaving the time $(1-t)$ to stay in his home country afterwards. The migrant's objective is to maximize utility from consumption. Let his lifetime utility function be additively separable with respect to home- and host-country consumption, with the subutility functions being increasing in consumption, strictly concave and continuously differentiable. Assume that the rate of time preference and the interest rate are both equal to zero. This does not change any qualitative results of the following analysis, but it implies that the flows of consumption in the host and home country are both constant. Technically, this allows to formalize the migrant's intertemporal optimization problem as a two-period model, with the period length as a further choice variable. The migrant's lifetime utility may be expressed in the following simple form:

$$V(c^{\mathrm{I}},c^{\mathrm{E}};t) = tu^{\mathrm{I}}(c^{\mathrm{I}}) + (1-t)u^{\mathrm{E}}(c^{\mathrm{E}}), \tag{1}$$

where u^{I} and u^{E} are the subutility functions in the immigration and the emigration country, and c^{I} and c^{E} are the respective constant flows of consumption. A higher preference for consumption at home corresponds to a higher utility from consuming an equal consumption flow k in the home country both in absolute as well as in marginal terms: $u^{\mathrm{E}}(k) > u^{\mathrm{I}}(k)$; $u'^{\mathrm{E}}(k) > u'^{\mathrm{I}}(k)$. [6] It will further be assumed that $u^{\mathrm{E}}(0) = u^{\mathrm{I}}(0) = 0$.

Total future earnings in the host and home country are given by $y^{\mathrm{I}}(t,x)$ and $y^{\mathrm{E}}(t,z)$, where x and z are random variables with the known joint-density function $f(x,z)$. These random variables can be interpreted as indices which reflect the impact of uncertainty on future incomes in the host and home country. [7] The variances of x and z will be denoted by σ_x^2 and σ_z^2, respectively, and the covariance between both by $\rho\sigma_x\sigma_z$. Furthermore, the following plausible assumptions are made, where subscripts denote partial derivatives:

$$y_t^{\mathrm{I}} > 0;\; y_t^{\mathrm{E}} < 0;\; y_x^{\mathrm{I}} > 0;\; y_z^{\mathrm{E}} > 0;\; y^{\mathrm{I}}(0,x) = y^{\mathrm{E}}(1,z) = 0. \tag{2}$$

The first two inequalities simply imply that total earnings accumulated in either

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[5] See also Hu (1978) who uses a similar formulation to analyze optimal retirement points.

[6] $u^{\mathrm{I}}(c^{\mathrm{I}})$ and $u^{\mathrm{E}}(c^{\mathrm{E}})$ could likewise be expressed as $u(c^{\mathrm{I}},G)$ and $u(c^{\mathrm{E}},F)$, where G and F are indices, representing environmental factors like family, friends, etc. When G and F are complementary to c^{I} and c^{E}, respectively, in the sense of Pareto and Edgeworth (see Hicks, 1979, p. 44), and if additionally $F > G$, then $u'^{\mathrm{E}}(k,G) > u'^{\mathrm{I}}(k,F)$. For simplicity, the indices G and F are suppressed here.

[7] For instance, when risk affects income in a multiplicative form, then $y^{\mathrm{I}} = \bar{y}^{\mathrm{I}}(t)x$ and $y^{\mathrm{E}} = \bar{y}^{\mathrm{E}}(t)z$, where $\bar{y}^{\mathrm{I}}$ and $\bar{y}^{\mathrm{E}}$ denote total incomes as functions of t in the home and host country.

country are the higher the longer the migrant will stay. [8] If x and z are interpreted as indices of labor market conditions, the next two inequalities are self-explanatory: the more favorable the state of the world, the higher will be total earnings, keeping t constant. Finally, the remaining equations state that total income accumulated in either country is equal to zero if the migrant does not stay in that country.

Unforeseeable future events that have an impact on labor markets and, therefore, on future income streams in the host and source country, could be due to unforeseeable changes in raw-material prices, such as in oil crises, wars, worldwide economic downturns, political unrest, etc. It seems appropriate to assume that, the longer the migrant intends to stay in either country, the stronger will be the impact of such a shock on the total income accumulated in that country. Formally, this can be expressed by assuming that $y^{\mathrm{I}}_{tx} > 0$ and $y^{\mathrm{E}}_{tz} < 0$. In other words, marginal total income at home and abroad, which are earnings per unit of time, increase in x and z respectively. [9] Levhari and Weiss (1974) call this *increasing risk* and it implies that the variability of total income, accumulated in either country, increases with the time spent in that country. Increasing risk would correspond to a multiplicative specification of the effect of uncertainty on earnings, as it is usually assumed in the literature on uncertainty and investment into human capital (see, for example, Eaton and Rosen, 1980, Kodde, 1986). Note that the same event may well have a positive impact on the economy of one country, while it has a negative impact on the economy of the other country. This would be the case if, for instance, the immigration country were a net importer for some raw material, like crude oil, and the emigration country a net exporter. An increase in world oil prices will affect both countries in opposite ways.

Another way to motivate uncertainty is imperfect labor market information. The migrant is uncertain about how the foreign labor market evaluates his abilities and human capital stock. This uncertainty is likely to play a minor role when there is an established and long-lasting migration relation between target and source region. But for the first wave of migrants it may be quite important. Migrants should accordingly exhibit a higher risk in the host-country labor market than native workers. Uncertainty about the host-country labor market, however, may decrease with the duration in the host country, while uncertainty about the home-country labor market may increase because the migrant loses information about his home economy. This type of uncertainty can in principle be addressed in the same type of model, but different assumptions would have to be made about y^{I} and y^{E}.

[8] Because lifetime is finite and t signifies the time being in the host country, an increase in t will increase $y^{\mathrm{I}}(.)$, but it will decrease $y^{\mathrm{E}}(.)$, since less time is available for the accumulation of earnings at home.

[9] This also allows for the possibility of unemployment. Marginal total income would then correspond to eventual unemployment benefits.

The migrant's budget constraint is given by

$$tpc^{\mathrm{I}} + [1-t]c^{\mathrm{E}} + \eta = y^{\mathrm{I}}(t,x) + y^{\mathrm{E}}(t,z), \tag{3}$$

where p is the price level in the host country, relative to that in the home country, and η are fixed costs of migration. Rewriting Eq. (3) yields:

$$c^{\mathrm{E}} = \frac{1}{1-t}\left[y^{\mathrm{I}}(t,x) + y^{\mathrm{E}}(t,z) - \eta - tpc^{\mathrm{I}}\right]. \tag{4}$$

Inserting Eq. (4) into Eq. (1) and adopting the von Neumann–Morgenstern hypothesis of expected utility maximization, the individual will solve the following problem:

$$\phi = \max_{t,c^{\mathrm{I}}} E\left(V(c^{\mathrm{I}},c^{\mathrm{E}};t)\right). \tag{5}$$

Accordingly, the migrant will choose the level of consumption abroad, c^{I}, and the time t to stay in the host country so as to maximize expected lifetime utility.

Since any uncertainty is not resolved before t and c^{I} are chosen, the following restriction will be imposed on the migrant's total consumption in the host country:

$$tpc^{\mathrm{I}} \leq \left[y^{\mathrm{I}}(t,\underline{x}) + y^{\mathrm{E}}(t,\underline{z}) - \eta\right], \tag{6}$$

where $\underline{x}$ and $\underline{z}$ are the minimum levels of x and z. Eq. (6) simply states that total consumption in the host country has to be lower than total lifetime earnings if the most unfavorable state of the world should materialize.

The first-order conditions for an interior maximum are given by:

$$\phi_t = E\left[u^{\mathrm{I}}(c^{\mathrm{I}}) - u^{\mathrm{E}}(c^{\mathrm{E}})\right] + E\left[u'^{\mathrm{E}}(c^{\mathrm{E}})\frac{dc^{\mathrm{E}}}{dt}[1-t]\right] = 0, \tag{7a}$$

$$\phi_{c^{\mathrm{I}}} = E\left[u'^{\mathrm{I}}(c^{\mathrm{I}}) - pu'^{\mathrm{E}}(c^{\mathrm{E}})\right] = 0, \tag{7b}$$

where $dc^{\mathrm{E}}/dt = 1/(1-t)[y_t^{\mathrm{I}} + y_t^{\mathrm{E}} - pc^{\mathrm{I}} + c^{\mathrm{E}}]$. Eq. (7a) and Eq. (7b) together determine the optimal duration t and the level of consumption, c^{I}, in the host country. Consumption in the home country, c^{E}, follows then from Eq. (4). Eq. (7a) shows that the optimal t will be chosen such as to equalize the expected marginal loss in overall utility of staying one unit of time longer in the host country with the expected marginal gain of staying one unit longer abroad, both measured in units of utility. The migrant will decide to migrate when the expected increase in lifetime utility from staying the first unit of time abroad is at least as high as the decrease in lifetime utility by being deprived of the possibility to consume during this unit of time at home.

Before continuing, reconsider the migrant's optimization problem in a deterministic world. Let x and z be equal to their expected values, $x = E(x) = \tilde{x}$ and $z = E(z) = \tilde{z}$. It then follows for Eq. (7a) and Eq. (7b):

$$\left[u^{E}(c^{E}) - u^{I}(c^{I})\right] = \left[u'^{E}(c^{E})\frac{dc^{E}}{dt}[1-t]\right], \tag{8a}$$

$$u'^{I}(c^{I}) = pu'^{E}(c^{E}). \tag{8b}$$

Eq. (8a) and Eq. (8b) determine the optimal time to be spent abroad, t^0, and the optimal level of consumption in the host country, c^{I0}. For an equal price level in both countries ($p = 1$), and expressing a higher preference for consumption at home by a higher marginal utility of a constant flow of consumption k in the home country, $u'^{E}(k) > u'^{I}(k)$, it follows from Eq. (8b) that the optimal level of consumption at home is higher than the optimal level of consumption abroad: $c^{E0} > c^{I0}$. This effect will be re-enforced if the price level abroad is higher than the price level in the home country ($p > 1$). [10]

2.1. Precautionary savings of migrant workers

It follows from Eq. (8a) and Eq. (8b) that migrants save more than comparable natives during their stay in the host country if the economic situation in the home country is more unfavorable than in the host country, or if migrants have a preference for the home-country location, or if relative prices are higher in the host country than in the home country. The model therefore reproduces the results of Djajic (1989) and Galor and Stark (1990) (see Dustmann, 1994b for a detailed analysis of the deterministic model).

A further explanation of a divergent savings behavior of migrants and natives that has not been considered so far are differences in the accumulation of precautionary savings. This can be shown by comparing the response of savings with a small introduction of risk with a position of no risk along the lines of Leland (1968) and Sandmo (1970).

Let t^0 and c^{I0} be the optimal length of stay and the optimal level of consumption in the host country if x and z are known to be equal to their expected values $\tilde{x} = E(x)$ and $\tilde{z} = E(z)$. In other words, t^0 and c^{I0} solve Eq. (8a) and Eq. (8b). To compare the optimally chosen level of consumption in the deterministic case, c^{I0}, with that chosen under small uncertainty, expand Eq. (7b) around $x = \tilde{x}$ and $z = \tilde{z}$. Neglecting terms of order higher than two, and assuming that y^{E} and y^{I} are linear in x and z, respectively, this results in the following expression (for derivation see Appendix A):

$$E^0\left(u'^{I}(c^{I}) - u'^{E}(c^{E})\right) \approx -\frac{1}{2}\frac{1}{[1-t]^2}u'''^{E}(c^{E0})\left[\operatorname{Var}(y^{E} + y^{I})\right], \tag{9}$$

[10] Note that a higher price level abroad alone may induce the migrant to return before retirement age, although he is indifferent between consumption at home and abroad.

where $E^0(.) = E(.)$ if $z = \tilde{z}$ and $x = \tilde{x}$. It follows from the second-order conditions that $\phi_{c^I c^I} < 0$ (see Appendix A). Accordingly, $dE^0(u'^I(c^I) - u'^E(c^E))/dc^I < 0$. Therefore, the optimally chosen level of consumption in the host country under small uncertainty is smaller or larger than that chosen in the case of certainty, depending on whether the term on the right-hand side of Eq. (9) is negative or positive. Since $\text{Var}(y^E + y^I)$ will always be positive, the sign of the term on the right of Eq. (9) depends on the sign of $u'''^E(c^E)$, indicating the change in the attitude towards risk when c^E changes. If $u'''^E(c^E) = 0$, the optimal level of consumption is not affected by uncertainty. This is, for instance, the case for a quadratic utility function.

However, for $u'''^E(c^E) > 0$, it follows from Eq. (9) that $c^{I0} > \hat{c}^I$, where $\hat{c}^I$ is the optimal level of consumption when small uncertainty about income at home and abroad is present. It is easy to show that $u'''^E(c^E)$ has to be positive when absolute risk aversion is non-increasing and the utility function is additively separable (see Leland, 1968). Consequently, if the migrant's utility structure exhibited decreasing (or non-increasing) absolute risk aversion, he would, under small uncertainty, accumulate precautionary savings. The migrant would wish to have a higher level of consumption at home than abroad, even if he were indifferent between consumption in both countries.

The interesting question that arises now is whether precautionary savings of migrant workers differ from those of comparable natives. Consider, therefore, an identical native reference individual whose lifetime is divided into two periods, where period 1 corresponds to t and period 2 to $(1 - t)$. Comparisons of savings of migrant workers with those of natives refer then to the first period.

It is obvious from Eq. (9) that the effect of uncertainty on the savings decision depends on the size of $\text{Var}(y^E + y^I)$, the variance of lifetime income:

$$\begin{aligned}\text{Var}(y^E + y^I) &= \text{Var}(y^E) + \text{Var}(y^I) + 2\text{Cov}(y^E + y^I)\\ &= \left[y_x^{I2}\sigma_x^2 + y_z^{E2}\sigma_z^2 + 2\rho y_x^I y_z^E \sigma_x \sigma_z \right]. \qquad (10)\end{aligned}$$

The variance of the migrant's lifetime income consists of the variance of total incomes in the host and in the source country, both depending positively on the time spent in either location, and on the covariance between both. The degree of risk exhibited by the respective labor market may be measured by σ_i^2, $i = x, z$. Assume first that the random variables x and z are uncorrelated. For the native reference individual, this corresponds to the assumption that random shocks affecting the labor market of the immigration country in the first and the second period are uncorrelated. The variance of lifetime income of a migrant worker, and, accordingly, his precautionary savings, may then be higher than that of a comparable native worker for the following reasons: the variance of income accumulated in the host country ($\text{Var}(y^I)$) is higher than that of the native worker in his first period, or the variance of income accumulated at home ($\text{Var}(y^E)$) is higher than that of the native worker in his second period, or both.

First consider $\text{Var}(y^I)$, the variance of total income accumulated abroad.

Evaluated for the same t, $\mathrm{Var}(y^{\mathrm{I}})$ is higher for migrant workers than for comparable natives if migrants perceive the host-country labor market as riskier than do native workers. It is likely that this is frequently the case. For instance, in many immigration countries migrant workers do not have the same labor-market rights and benefit entitlements than native workers. Discrimination may prevent migrant workers from having the same opportunities to stay in the job, or to find a new job. For illegal migrants, the variance of total income to be accumulated in the host country should be particularly high. Besides being confined to those jobs which usually exhibit a high degree of job uncertainty, illegal migrants do usually not have the right to claim any benefit support in the host country. Their illegal status prevents them further from appealing to any labor-market law that concerns minimal wages or job security. Accordingly, in many migration situations (and especially if migration is illegal) the variance of total income of a migrant in the host country should be higher than that of a comparable native worker over the same period.

Secondly, higher precautionary savings of migrants may be induced by the temporary nature of migration. If the migrant stays only temporarily in the host country and, after returning, enters the labor market of the home country, the variance of his lifetime income depends likewise on the riskiness of the home-country labor market. Emigration countries are often characterized by poorly developed benefit systems. They frequently exhibit fairly high rates of unemployment and low stability, and are highly sensitive to economic shocks. This would render the variance of the migrant's income to be accumulated after his return ($\mathrm{Var}(y^{\mathrm{E}})$) to be higher than that of a comparable native worker.

Accordingly, in migration situations where the migrant's subjectively perceived income uncertainty in the first and/or second period is higher than that facing a comparable native worker, one should expect that precautionary motives contribute to some extent to higher observed savings of migrants.

So far, a possible correlation between the effects of labor-market shocks in emigration and immigration countries (or in the first and second period) has been excluded. However, if such a correlation is present, not only the variances of y^{E} and y^{I}, but also the covariance between y^{E} and y^{I}, determine the size of $\mathrm{Var}(y^{\mathrm{E}} + y^{\mathrm{I}})$. A positive correlation ($\rho > 0$) between total incomes accumulated at home and abroad signifies that some event has the same qualitative effect on both labor markets, while a negative correlation ($\rho < 0$) implies opposite effects. Assume, for instance, that the emigration country is a net importer of raw materials, such as crude oil, while the immigration country is a net exporter. A rise in oil prices would then have a positive effect on the economy of the immigration country and a negative effect on the economy of the emigration country. On the contrary, if both economies were net importers of crude oil, a rise or fall in oil prices would affect both economies similarly. Accordingly, any correlation between the effects of some random shocks on the labor markets of the countries involved may respectively weaken or reinforce the size of precautionary savings the migrant wishes to accumulate.

Consider a situation where random shocks affecting labor markets in the first and the second period are positively correlated in the immigration country, but negatively correlated (or uncorrelated) between immigration country and emigration country. In this case, the migrant may hedge against risk (or diversify risk), while the native will necessarily accumulate risk. [11] It is now possible that the variance of lifetime income is smaller for the migrant than for the native, although the variances of migrant's income in the two periods separately are higher than for the native worker. In this case, precautionary savings accumulated by the migrant are *smaller* than those accumulated by the native. This is an interesting result: under certain assumptions about the correlation of the effect of shocks on the two economies, migrants may reduce lifetime income risk below the level of native workers, although they perceive a higher income risk in each of the two periods separately. Therefore, if investigating savings of temporary migrants due to precautionary motives, one should not only consider income risks of migrants and native reference individuals in the two periods separately, but also take account of a possible correlation of the effect of shocks on labor markets in the two locations.

2.2. Uncertainty and migration decisions

Uncertainty not only influences the migrant's savings in the host country, as shown above, but also his desired length of stay abroad and, when analyzed around $t^0 = 0$, his migration decision itself. To investigate the effect of income uncertainty on the optimal choice of t, denote again t^0 and c^{I0} as those realizations of t and c^I which solve the migrant's decision problem when x and z are known to be equal to their expected values. Expanding Eq. (7a) around $x = \tilde{x}$ and $z = \tilde{z}$, and assuming that y^I and y^E are linear in x and z respectively, results in the following expression (for the derivation see Appendix A):

$$\begin{aligned} &E^0\left[u^I(c^I) - u^E(c^E)\right] + E^0\left[u'^E(c^E)\left[\frac{dc^E}{dt}[1-t]\right]\right] \approx \Delta^1 + \Delta^2 = \Delta; \\ &\Delta^1 = \Delta^{11} + \Delta^{12}; \\ &\Delta^{11} = \frac{1}{2}\frac{1}{[1-t]^2}\left[u''^E(c^E)\right]\left[\mathrm{Var}(y^E + y^I)\right]; \\ &\Delta^{12} = \frac{1}{2}\frac{1}{[1-t]^2}\left[\frac{du''^E(c^E)}{dt}\right]\left[\mathrm{Var}(y^E + y^I)\right]; \\ &\Delta^2 = \frac{1}{2}\frac{1}{[1-t]}u''^E(c^E)\left[\frac{d}{dt}\mathrm{Var}(y^E + y^I)\right], \end{aligned} \tag{11}$$

[11] A similar argument has been put forward by Stark (1991, chapter 4) in the context of rural-to-urban migration, where families diversify risk by placing members in the urban sector, which is independent of agricultural production.

where E^0 indicates that the expectations are evaluated at $x=\tilde{x}$ and $z=\tilde{z}$. For $\phi_{tt}<0$ (see Appendix A), the term on the left decreases in t. Therefore, depending on whether Δ is smaller or larger than zero, the desired length of stay abroad under small uncertainty, $\hat{t}$, is smaller or larger than that chosen in the deterministic case, t^0:

$$\hat{t}\begin{Bmatrix} > \\ = \\ < \end{Bmatrix} t^0 \text{ if } \Delta \begin{Bmatrix} > \\ = \\ < \end{Bmatrix} 0.$$

There are three effects of uncertainty on the optimal choice of t, one direct effect and two indirect effects. Uncertainty affects the optimal choice of t directly because the migrant is risk averse (Δ^{11}), and indirectly because a change in t changes the variance of total lifetime income (Δ^2) and, by way of altering c^{E}, the attitude towards risk (Δ^{12}). It will be shown that the sign of Δ^1 is crucially determined by the wage differential between home and host country, while the sign of Δ^2 depends on the riskiness of the two labor markets and the correlation coefficient ρ.

Consider first Δ^1: since $\mathrm{Var}(y^{\mathrm{I}}+y^{\mathrm{E}})>0$, the sign of $\Delta^1=\Delta^{11}+\Delta^{12}$ depends on the sign and magnitude of $du''^{\mathrm{E}}/dt=u'''^{\mathrm{E}}(c^{\mathrm{E}})[dc^{\mathrm{E}}/dt]$ and $u''^{\mathrm{E}}(c^{\mathrm{E}})$. For a given variance of total lifetime income, $u''^{\mathrm{E}}(c^{\mathrm{E}})$ captures the direct effect of uncertainty on the choice of t. The term $du''^{\mathrm{E}}/dt=u'''^{\mathrm{E}}(c^{\mathrm{E}})[dc^{\mathrm{E}}/dt]$ represents the indirect effect by a change in the attitude towards risk, caused by a change in desired consumption at home, c^{E}, that again results from a change in t. Non-increasing absolute risk aversion would imply that $u'''^{\mathrm{E}}(c^{\mathrm{E}})>0$. Accordingly, since $dc^{\mathrm{E}}/dt=1/(1-t)[y_t^{\mathrm{I}}+y_t^{\mathrm{E}}-c^{\mathrm{I}}+c^{\mathrm{E}}]>0$, [12] an increase in t would, by way of increasing the flow of consumption in the home country, increase the willingness to accept some given risk and influence the length of migration positively. Since the direct effect is negative ($u''^{\mathrm{E}}(c^{\mathrm{E}})<0$), the sign of Δ^1 is ambiguous for the general case. However, the indirect effect Δ^{12} can be made arbitrarily large by increasing the wage differential between home and host country, since this would induce dc^{E}/dt to be large. [13] Therefore, if absolute risk aversion is non-increasing, the positive indirect effect Δ^{12} should overcompensate the negative direct effect Δ^{11} (and consequently, induces Δ^1 to be positive) in migration situations which are characterized by high wage differentials between the sending country and the receiving country.

The second indirect effect is induced by the impact of a change in t on the

[12] This follows from the first-order conditions and the assumption that marginal utility of a constant flow of consumption is higher in the home country than in the host country.

[13] Notice that, for $u^{\mathrm{E}\prime}(k)>u^{\mathrm{I}\prime}(k)$, $c^{\mathrm{E}}>c^{\mathrm{I}}$. Therefore, $u^{\mathrm{E}\prime\prime}(c^{\mathrm{E}})>u^{\mathrm{I}\prime\prime}(c^{\mathrm{I}})$ iff $u'''>0$. From Eq. (8b), it follows then that $dc^{\mathrm{I}}/dc^{\mathrm{E}}=u^{\mathrm{E}\prime\prime}/u^{\mathrm{I}\prime\prime}<1$. Since an increase in the host-country wage will increase both c^{I} and c^{E}, but $dc^{\mathrm{E}}>dc^{\mathrm{I}}$, it follows that dc^{E}/dt is an increasing function of the host-country wage rate.

Table 1
Effect of a change in t on the variance of lifetime income

CORR	$(0 < t^0 < 1)$	$t^0 = 0$
$\rho = -1$	$\underbrace{\underbrace{[y_x^I\sigma_x - y_z^E\sigma_z]}_{\gtreqless 0}\,\underbrace{[y_{xt}^I\sigma_x - y_{zt}^E\sigma_z]}_{>0}}_{\gtreqless 0}$	$\underbrace{\sigma_z y_z^E[y_{zt}^E\sigma_z - y_{xt}^I\sigma_x]}_{<0}$
$\rho = 0$	$\underbrace{[\underbrace{y_x^I y_{xt}^I\sigma_x^2}_{>0} + \underbrace{y_z^E y_{zt}^E\sigma_z^2}_{<0}]}_{\gtreqless 0}$	$\underbrace{y_z^E y_{zt}^E\sigma_z^2}_{<0}$
$\rho = 1$	$\underbrace{\underbrace{[y_x^I\sigma_x + y_z^E\sigma_z]}_{>0} + \underbrace{[y_{xt}^I\sigma_x + y_{zt}^E\sigma_z]}_{\gtreqless 0}}_{\gtreqless 0}$	$\underbrace{\sigma_z y_z^E[y_{xt}^I\sigma_x + y_{zt}^E\sigma_z]}_{\gtreqless 0}$

variance of total lifetime income. This effect is captured by the term Δ^2. Since $u''^{\mathrm{E}}(c^{\mathrm{E}}) < 0$, the sign of Δ^2 depends on the sign of $d\mathrm{Var}(y^{\mathrm{E}} + y^{\mathrm{I}})/dt$. If, for some t^0, $d\mathrm{Var}(y^{\mathrm{E}} + y^{\mathrm{I}})/dt < 0$, an increase of the time being in the host country will reduce the variance of total lifetime income. This would be the case if, for instance, the labor market of the home country was very risky, relative to that of the host country. Consequently, risk aversion would then tend to induce the migrant to increase the length of stay abroad. This can directly be seen from Eq. (11): for $d\mathrm{Var}(y^{\mathrm{E}} + y^{\mathrm{I}})/dt < 0$, and $u''^{\mathrm{E}}(c^{\mathrm{E}}) < 0$, $\Delta^2 > 0$.

Generally, the sign of $d\mathrm{Var}(y^{\mathrm{E}} + y^{\mathrm{I}})/dt$ (and therefore, of Δ^2) depends on the degree of risk in the respective labor markets, as represented by σ_x and σ_z, on the correlation between the random variables x and z, on the wage differential and on the optimal length of the time abroad the migrant would choose under certainty. For $\rho = -1$, $\rho = 0$ and $\rho = 1$, the first column in Table 1 presents $[1/2]d\mathrm{Var}(y^{\mathrm{E}} + y^{\mathrm{I}})/dt$ if the solution of the deterministic problem is an interior one $(0 < t^0 < 1)$. Without further specification of y^{I}, y^{E}, and the distribution of x and z, as well as the migrant's utility function and the income functions in both countries, it is ambiguous whether Δ^2 will tend to have an increasing or a decreasing effect on the time spent abroad, compared with the duration chosen under certainty. However, it follows from the expressions in Table 1 that, if the labor market of the home country becomes sufficiently riskier than the labor market of the host country ($\sigma_x < \sigma_z$), Δ^2 tends to become positive (and vice versa).

To conclude, although the effect of uncertainty on the desired length of migration is ambiguous for the general case, uncertainty is likely to have an *increasing* effect on the desired time in the host country if the migration situation is characterized by large wage differentials between home and host country and a highly risky home-country labor market, relative to that of the host country. These features may characterize, for instance, legal temporary migrations from former Eastern countries to industrialized Western countries, or guest-worker migrations from eastern Turkey and Southern Europe to Northern Europe during the 1960s and 1970s.

On the other hand, uncertainty is likely to *reduce* the time abroad if the wage differential is small and/or the host-country labor market is perceived as considerably riskier than the home-country labor market. Some illegal migrations may fit this scenario.

2.3. The migration decision

The second column of Table 1 reports $d\mathrm{Var}(y^{\mathrm{E}}+y^{\mathrm{I}})/dt$ if the solution of the deterministic problem were $t^0=0$, i.e. if the objective function reaches its maximum for $t^0=0$. In this case, the migrant would decide not to migrate in a deterministic world. The effect of Δ^2 is now more definite. Neglecting the effect of Δ^1, column 2 of Table 1 shows that uncertainty with respect to future income would induce migration for $\rho=0$ and $\rho=-1$. This is due to the tendency of the migrant to hedge against risk or to diversify risk, respectively. If x and z are positively correlated, the effect of Δ^2 on the migration decision is again ambiguous. If σ_x is small relative to σ_z, however, uncertainty may favor the decision to migrate in this situation, also.

2.4. An example

Some simple simulations may help to illustrate the above arguments. Assume the migrant's utility structure to be of the following simple form:

$$u(c^{\mathrm{I}})=Gc^{\mathrm{I}\,0.5};\ u(c^{\mathrm{E}})=Fc^{\mathrm{E}\,0.5},$$

where F and G are indices which capture environmental arguments, like family, friends, etc. The utility function has the property that $u'''>0$. Let $F>G$, with $G=1$ and $F=2$.

Assume that total earnings in host and home country, y^{I} and y^{E}, are linear in x and z, as well as in t and $[1-t]$:

$$y^{\mathrm{I}}=w^{\mathrm{I}}tx;\ y^{\mathrm{E}}=w^{\mathrm{E}}[1-t]z.$$

Again, w^{I} and w^{E} denote earnings per unit of time in immigration and emigration country. Let the price levels in host and home country be equal ($p=1$), and set the fixed costs of migration to zero ($\eta=0$). Let the random variables x and z have means of unity, variances σ_x^2 and σ_z^2 and covariance $\sigma_x\sigma_z\rho$.

First consider the impact of the wage differential on Δ. As outlined above, if the wage differential increases, Δ^{12} should eventually overcompensate Δ^{11} and

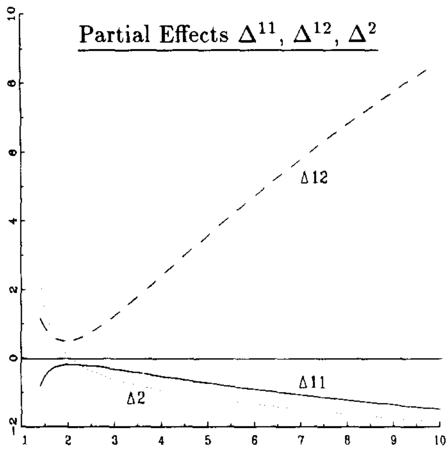

Fig. 1. Wage differential and uncertainty: $\rho = 0; \omega^E = 1$.

induce Δ^1 to become positive. For simulation purposes, w^E is set equal to 1 and w^I is varied between 1 and 10. [14] These numbers are quite realistic—many immigration countries pay wages which are at least by factor 10 higher than wages in emigration countries (consider, for instance, European East–West migration). Fig. 1 illustrates the effects of an increasing wage differential on the various Δ^i, for $\rho = 0$, where the horizontal axis measures w^I.

The term Δ^{11} is negative throughout; it decreases slightly since an increase in w^I (and the induced increase in t) will raise the variance of lifetime income. The term Δ^2 is first positive, but it becomes negative for a wage differential larger than 2.3. This is directly obvious from the expressions in Table 1: for an increasing wage in the host country, an increase in the time abroad ($\hat{t}^0$) will necessarily increase lifetime income variance. Finally, the term Δ^{12} first slightly decreases, but grows large if the wage differential increases. It is this effect which will eventually overcompensate the other two effects.

Fig. 2 illustrates total effects Δ for $\rho = (-1,0,1)$. In all cases, Δ tends to become positive for large wage differentials. For small wage differentials, however, the effect of uncertainty on the optimal time abroad may well be negative.

Fig. 3 and Fig. 4 illustrate the effect of risk differentials on Δ. For simulation purposes, w^I and w^E are chosen to be equal to 2 and 1, respectively. The term σ_z is set to 1, while σ_x is varied between 0 and 2. In other words, risk in the host-country labor market is varied from being considerably lower than that in the home country to being considerably higher. [15]

[14] The optimal t varies between 0.04 and 0.61.

[15] The optimal $\hat{t}^0$ for this parameter constellation is equal to 0.16.

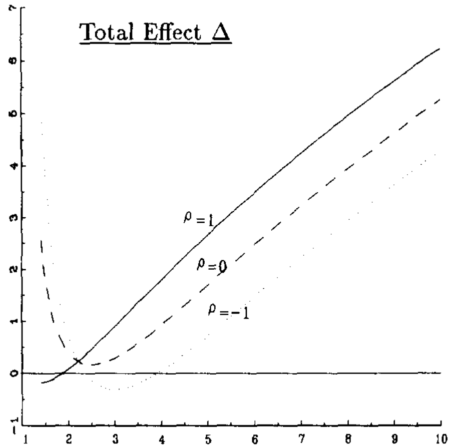

Fig. 2. Wage differential and uncertainty: $\omega^E = 1; \rho = (-1,0,1)$.

Fig. 3 illustrates the effect on the Δ^i, again for $\rho = 0$, where the horizontal axis measures σ_x. As expected, an increase in σ_x affects strongly Δ_2, while Δ^{11} and Δ^{12} vary only slightly. In Fig. 4, the total effects Δ are displayed, again for $\rho = (-1,0,1)$. As long as the host-country labor market is less risky than the home-country labor market ($\sigma_x < \sigma_z = 1$), the impact of uncertainty on the optimal time abroad is positive for all cases. As the host-country labor market grows more risky, relative to the home-country labor market, the effect of uncertainty tends to become negative.

These simple simulations illustrate the results derived above. Income uncer-

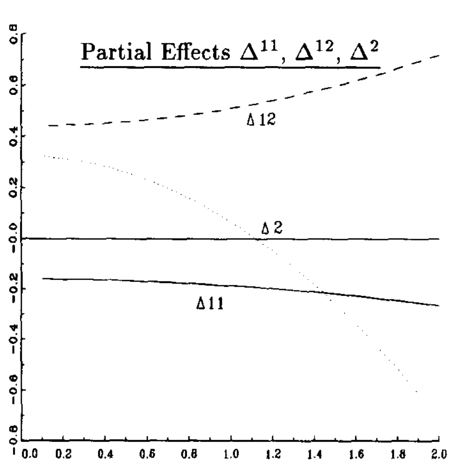

Fig. 3. Risk differential and uncertainty, $\rho = 0$.

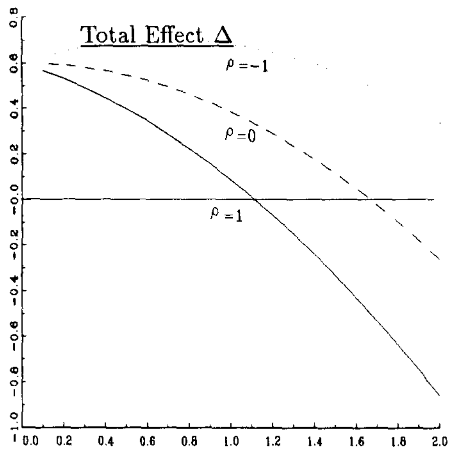

Fig. 4. Risk differential and uncertainty, different $\rho = 0$s.

tainty affects the migrant's desired length of stay, but cannot be unambiguously signed for the general case. Still, the analysis shows that the analyst may have some strong beliefs about the effect of uncertainty on the desired length of stay for specific migration situations.

3. Conclusion

This paper presents a simple life-cycle model where the migrant determines simultaneously consumption and the desired length of stay abroad. The focus of the analysis is to compare decisions under certainty with those under income uncertainty in host and home country. Savings of migrant workers due to precautionary motives are compared with those of native workers and the impact of uncertainty on migration and re-migration decisions is analyzed.

If their utility functions exhibit non-increasing absolute risk aversion, migrant workers accumulate precautionary savings while being abroad. The magnitude of these savings depends on the perceived variance of future income in home and host country. If random shocks affecting labor markets in the first and second period are uncorrelated, the variance of lifetime income may be larger for migrants than for native workers if migrants perceive either the host-country labor market as riskier than natives, or if the respective home-country labor market is riskier for migrants than for natives, or both. Migrants are then likely to accumulate higher precautionary savings than comparable native workers while being abroad. This is possibly the case for migration situations where migrant workers cannot claim the same rights in the labor market of the immigration country as native workers (illegal migration) and when the labor market of the host country discriminates against foreign workers; further, when the labor market of the home country exhibits a high degree of risk and instability.

If, however, random shocks affecting the labor market of the host country in period 1 and period 2 are positively correlated, while the period 1 shock in the host country is negatively correlated (or uncorrelated) with the period 2 shock in the migrant's home country, migration may *reduce* the migrant's lifetime income variance. While the native worker accumulates risk in the two periods, the temporary nature of migration allows the migrant to hedge against risk (or to diversify risk). In this case, precautionary savings of migrants may be *lower* than those of natives, even if the migrant experiences a higher income risk in the two periods separately.

The analysis isolates three effects of uncertainty on the optimal choice of the return point t—one direct effect and two indirect effects. The indirect effects arise because of the endogeneity of t—an induced change in t affects lifetime income variance on the one side and the degree of risk aversion on the other side. Although the effect of an uncertain future income on the length of the migration period is ambiguous for the general case, some conclusions about the sign of the effect may be drawn for specific migration situations. For instance, uncertainty is likely to have a positive effect on the migration duration in situations where the wage differential between home and host country is large and the perceived risk of the home-country labor market is large relative to the host-country labor market. This characterizes, for example, the latest East–West migration in Europe.

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Appendix A

A.1. The sufficiency conditions

Let $\psi(c^{\mathrm{E}},c^{\mathrm{I}},t;x,z) = tu^{\mathrm{I}}(c^{\mathrm{I}}) + [1-t]u^{\mathrm{E}}(c^{\mathrm{E}})$ for any x, z defined over the range $(\underline{x},\bar{x})$ and $(\underline{z},\bar{z})$, where $\underline{x}$, $\underline{z}$ and $\bar{x}$, $\bar{z}$ are the lower and upper limits of the distributions of x and z, respectively. Then it follows for $\psi_{c^{\mathrm{I}}c^{\mathrm{I}}}$:

$$\psi_{c^{\mathrm{I}}c^{\mathrm{I}}} = tu''^{\mathrm{I}}(c^{\mathrm{I}}) + \frac{t^2}{[1-t]}p^2 u''^{\mathrm{E}}(c^{\mathrm{E}}), \tag{A.1}$$

and for ψ_{tt}

$$\psi_{tt} = [1-t]u''^{\mathrm{E}}(c^{\mathrm{E}})\left[\frac{dc^{\mathrm{E}}}{dt}\right]^2 - u'^{\mathrm{E}}(c^{\mathrm{E}})\frac{dc^{\mathrm{E}}}{dt} + u'^{\mathrm{E}}(c^{\mathrm{E}})\left[y_{tt}^{\mathrm{I}} + y_{tt}^{\mathrm{E}}\right]. \quad \text{(A.2)}$$

$\psi_{c^{\mathrm{I}}c^{\mathrm{I}}}$ is definitely negative. ψ_{tt} is smaller than zero for y^{I} and y^{E} being concave in t. However, if $y_{tt}^{\mathrm{I}} > 0$ and $y_{tt}^{\mathrm{E}} > 0$, as it would be the case if human capital accumulation is allowed for, then $\psi_{tt} < 0$ iff $\|[1-t]u''^{\mathrm{E}}(c^{\mathrm{E}})[dc^{\mathrm{E}}/dt]^2 - u'^{\mathrm{E}}(c^{\mathrm{E}})[dc^{\mathrm{E}}/dt]\| > |u'(c^{\mathrm{E}})[y_{tt}^{\mathrm{I}} + y_{tt}^{\mathrm{E}}]|$. That this is the case will be assumed throughout the analysis. Furthermore, $\psi_{tc^{\mathrm{I}}} = -ptu''^{\mathrm{E}}(c^{\mathrm{E}})[dc^{\mathrm{E}}/dt]$. It follows that $\psi_{c^{\mathrm{I}}c^{\mathrm{I}}}\psi_{tt} > \psi_{tc^{\mathrm{I}}}^2$. Since ψ is concave in c^{I}, t for all x, z the same must be true for $\phi = E(V(c^{\mathrm{E}}, c^{\mathrm{I}}; t))$.

A.2. Derivation of Eq. (9) and Eq. (11)

A second order expansion of Eq. (8a) around $x = E(x) = \tilde{x}$ and $z = E(z) = \tilde{z}$, and neglecting higher order terms, yields:

$$\begin{aligned}
&E\left[u'^{\mathrm{I}}(c^{\mathrm{I}}) - u'^{\mathrm{E}}(c^{\mathrm{E}})\right] \\
&\approx u'^{\mathrm{I}0}(c^{\mathrm{I}}) - u'^{\mathrm{E}}(c^{\mathrm{E}0}) - \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\left\{\frac{\delta}{\delta x}u'^{\mathrm{E}}(c^{\mathrm{E}0})[x-\tilde{x}]\right. \\
&\quad + \frac{\delta}{\delta z}u'^{\mathrm{E}}(c^{\mathrm{E}0})[z-\tilde{z}] + \frac{1}{2}\frac{\delta^2}{\delta x^2}u'^{\mathrm{E}}(c^{\mathrm{E}0})[x-\tilde{x}]^2 \\
&\quad \left. + \frac{1}{2}\frac{\delta^2}{\delta z^2}u'^{\mathrm{E}}(c^{\mathrm{E}})[z-\tilde{z}]^2 + \frac{\delta^2}{\delta x \delta z}u'^{\mathrm{E}}(c^{\mathrm{E}})[x-\tilde{x}][z-\tilde{z}]\right\} \\
&\quad \times f(x,z)\mathrm{d}x\mathrm{d}z. \qquad \text{(A.3)}
\end{aligned}$$

where all derivatives are evaluated at $x = \tilde{x}$ and $z = \tilde{z}$. When assuming that y^{I} and y^{E} are linear in x and z, respectively, Eq. (A.3) simplifies to:

$$\begin{aligned}
E^0\left[u'^{\mathrm{I}}(c^{\mathrm{I}}) - u'^{\mathrm{E}}(c^{\mathrm{E}})\right] &\approx u'^{\mathrm{I}}(c^{\mathrm{I}0}) - u'^{\mathrm{E}}(c^{\mathrm{E}0}) - \frac{1}{2}\frac{1}{[1-t]^2}u'''^{\mathrm{E}}(c^{\mathrm{E}0}) \\
&\quad \times \left[y_x^{\mathrm{I}2}\sigma_x^2 + y_z^{\mathrm{E}2}\sigma_z^2 + 2\rho y_x^{\mathrm{I}} y_z^{\mathrm{E}}\sigma_x\sigma_z\right]. \qquad \text{(A.4)}
\end{aligned}$$

Expanding $\mathrm{Var}(y^{\mathrm{I}} + y^{\mathrm{E}})$ around the mean values of x and z yields (for linear risk):

$$\begin{aligned}
\mathrm{Var}(y^{\mathrm{I}} + y^{\mathrm{E}}) &= \mathrm{Var}(y^{\mathrm{I}}) + \mathrm{Var}(y^{\mathrm{E}}) + 2\mathrm{Cov}(y^{I}, y^{\mathrm{E}}) \\
&= \left[y_x^{\mathrm{I}2}\sigma_x^2 + y_z^{\mathrm{E}2}\sigma_z^2 + 2\rho y_x^{\mathrm{I}} y_z^{\mathrm{E}}\sigma_x\sigma_z\right]. \qquad \text{(A.5)}
\end{aligned}$$

Substituting into Eq. (A.4):

$$E^0\big(u'^{\mathrm{I}}(c^{\mathrm{I}}) - u'^{\mathrm{E}}(c^{\mathrm{E}})\big) \approx u'^{\mathrm{I}}(c^{\mathrm{I0}}) - u'^{\mathrm{E}}(c^{\mathrm{E0}}) - \frac{1}{2}\frac{1}{[1-t]^2}u'''^{\mathrm{E}}(c^{\mathrm{E0}}) \times \big[\mathrm{Var}(y^{\mathrm{E}} + y^{\mathrm{I}})\big]. \tag{A.6}$$

Since the first-order condition of the deterministic problem requires that $u'^{\mathrm{I}}(c^{\mathrm{I0}}) - u'^{\mathrm{E}}(c^{\mathrm{E0}}) = 0$, Eq. (9) follows directly from Eq. (A.6).

The derivation of Eq. (10) follows the same lines:

$$\begin{aligned}
&E^0\big[u^{\mathrm{I}}(c^{\mathrm{I}}) - u^{\mathrm{E}}(c^{\mathrm{E}})\big] + E^0\left[u'^{\mathrm{E}}(c^{\mathrm{E}})\frac{dc^{\mathrm{E}}}{dt}[1-t]\right]\\
&\approx u^{\mathrm{I}}(c^{\mathrm{I0}}) - u^{\mathrm{E}}(c^{\mathrm{E0}}) + u'^{\mathrm{E}}(c^{\mathrm{E0}})\left[\frac{dc^{\mathrm{E}}}{dt}\right]^0[1-t]\\
&+\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\left\{\frac{\delta}{\delta x}\left[u'^{\mathrm{E}}(c^{\mathrm{E}})\frac{dc^{\mathrm{E}}}{dt}[1-t] - u^{\mathrm{E}}(c^{\mathrm{E}})\right][x-\tilde{x}]\right.\\
&+\frac{\delta}{\delta z}\left[u'^{\mathrm{E}}(c^{\mathrm{E}})\frac{dc^{\mathrm{E}}}{dt}[1-t] - u^{\mathrm{E}}(c^{\mathrm{E}})\right][z-\tilde{z}]\\
&+\frac{1}{2}\frac{\delta^2}{\delta x^2}\left[u'^{\mathrm{E}}(c^{\mathrm{E}})\frac{dc^{\mathrm{E}}}{dt}[1-t] - u^{\mathrm{E}}(c^{\mathrm{E}})\right][x-\tilde{x}]^2\\
&+\frac{1}{2}\frac{\delta^2}{\delta z^2}\left[u'^{\mathrm{E}}(c^{\mathrm{E}})\frac{dc^{\mathrm{E}}}{dt}[1-t] - u^{\mathrm{E}}(c^{\mathrm{E}})\right][z-\tilde{z}]^2\\
&\left.+\frac{\delta^2}{\delta x \delta z}\left[u'^{\mathrm{E}}(c^{\mathrm{E}})\frac{dc^{\mathrm{E}}}{dt}[1-t] - u^{\mathrm{E}}(c^{\mathrm{E}})\right][x-\tilde{x}][z-\tilde{z}]\right\}\\
&\times f(x,z)\,\mathrm{d}x\,\mathrm{d}z,
\end{aligned} \tag{A.7}$$

where

$$c^{\mathrm{E}} = \frac{1}{1-t}\left[y^{\mathrm{I}} + y^{\mathrm{E}} - tc^{\mathrm{I}} - \eta\right]$$

and

$$\frac{dc^{\mathrm{E}}}{dt} = \frac{1}{1-t}\left[y_t^{\mathrm{I}} + y_t^{\mathrm{E}} - c^{\mathrm{I}} + c^{\mathrm{E}}\right].$$

After some tedious calculations, Eq. (A.7) simplifies to:

$$E^0\left[u^{\mathrm{I}}(c^{\mathrm{I}}) - u^{\mathrm{E}}(c^{\mathrm{E}})\right] + E^0\left[u'^{\mathrm{E}}(c^{\mathrm{E}})\frac{dc^{\mathrm{E}}}{dt}[1-t]\right]$$

$$\approx u^{\mathrm{I}}(c^{\mathrm{I}0}) - u^{\mathrm{E}}(c^{\mathrm{E}0}) + u'^{\mathrm{E}}(c^{\mathrm{E}0})\left[\frac{dc^{\mathrm{E}}}{dt}\right]^0[1-t] + \frac{1}{2}\frac{1}{[1-t]^2}$$

$$\times\left[u'''^{\mathrm{E}}(c^{\mathrm{E}})\frac{dc^{\mathrm{E}}}{dt} + u''^{\mathrm{E}}(c^{\mathrm{E}})\right]\left[y_x^{\mathrm{I}2}\sigma_x^2 + y_z^{\mathrm{E}2}\sigma_z^2 + 2y_x^{\mathrm{I}}y_z^{\mathrm{E}}\sigma_{xz}\right]$$

$$+\frac{1}{[1-t]}u''(c)\left[y_x^{\mathrm{I}}y_{xt}^{\mathrm{I}}\sigma_x^2 + y_z^{\mathrm{E}}y_{zt}^{\mathrm{E}}\sigma_z^2 + \left[y_{xt}^{\mathrm{I}}y_z^{\mathrm{E}} + y_{zt}^{\mathrm{E}}y_x^{\mathrm{I}}\right]\right.$$

$$\left.\times\sigma_{xz}\right]. \tag{A.8}$$

It follows from Eq. (A.5):

$$\frac{d}{dt}\mathrm{Var}(y^{\mathrm{E}} + y^{\mathrm{I}}) = 2\left[y_x^{\mathrm{I}}y_{xt}^{\mathrm{I}}\sigma_x^2 + y_z^{\mathrm{E}}y_{zt}^{\mathrm{E}}\sigma_z^2 + \left[y_{xt}^{\mathrm{I}}y_z^{\mathrm{E}} + y_{zt}^{\mathrm{E}}y_x^{\mathrm{I}}\right]\sigma_{xz}\right] \tag{A.9}$$

Again, it follows from the first-order conditions of the deterministic problem that $u^{\mathrm{I}}(c^{\mathrm{I}0}) - u^{\mathrm{E}}(c^{E0}) + u'^{\mathrm{E}}(c^{\mathrm{E}0})[dc^{\mathrm{E}}/dt]^0[1-t] = 0$. Consequently, substituting Eq. (A.6) and Eq. (A.9) into Eq. (A.8) yields Eq. (11).

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