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Entry and Exit Strategies in Migration Dynamics

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Entry and Exit Strategies in Migration Dynamics

Summary

This work is devoted to study the role of combined entry and exit strategies in the migration process. We develop a real option model in which the community of immigrants in the host country is described as a club and the immigrants benefits is a U-shaped function, depending on the dimension of the district. There exist two threshold levels: the first one triggers the migration choice, while the second triggers the return to the country of origin. The theoretical results show that the phenomenon of hysteresis is amplified by the existence of a community both in the entry case and in the exit case. Furthermore, the community can reduce the minimum wage level required to trigger both exit and entry: this fact could explain why in some cases we observe migration inflows with a low wage differential and also with underunemployment. We show also some possible further extensions of the model: in one case we introduce a possible way to select the entrants. skills and in another case we show some theoretical implementations to include possible policy shocks in the migrant's choice.

Keywords: Migration, Real Option, Theory of Clubs, Network Effect

JEL Classification: F22, H49, O15, R23

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1 Introduction

Generally, in economic literature, migration choice depends on the wealth difference between the country of origin and the host country, because mainly "people migrate in order to increase their welfare"[1]. The wage differential between the host country and the country of origin is assumed as the main variable affecting migration (Todaro, 1969; Langley, 1974; Hart, 1975; Borjas, 1990, 1994), even if it is not sufficient to totally explain migrant behaviour: evidence seems to stress the focal role of community networks in the migrant's choice (Boyd, 1989; Bauer and Zimmermann, 1997; Winters et al., 2001; Bauer et al., 2002; Coniglio, 2003; Munshi, 2001, 2003; Heitmueller, 2003). Moretti (1999), for example, with an alternative model to Todaro's, finds evidence that both the timing and the destination of migration could be explained by the presence of social networks in the host country. Another work (Bauer, Epstein and Gang, 2002) examines the relative importance and interaction of two alternative explanations of immigrant clustering: 1) network externalities and 2) herd behaviour. The same theme is studied in Epstein and Gang (2004), where the authors examine the roles "other people" play in influencing an individual's potential migration decision. In fact, the moment immigrants settle in a country, they have to acquire a place in that new society. This is true not only for physical needs such housing, but also in the social and cultural sense.

Integration is the process by which immigrants become accepted into society, both as individuals and as groups. Therefore, the process of integration is not only taking place - as is often supposed - at the level of the individual immigrant, but also at the collective level of the immigrant group. In fact, when a immigrant enters a new society, she begins to build a group of people (or she enters a group if is already exists), based on affinities, religions and the same way of life: this group is generally called "community". In addition, the process of integration is related to the level of institutions, which come in two broad types. The first are general public institutions of receiving societies or cities, such as the education system or institutional arrangements in the labour market or the dimension of the urban area in which the community develops. The second kind of institution belongs to specific types of immigrant group themselves, such as religious or cultural institutions. This aggregate of individuals that uses, like a family, the same goods, "deriving mutual benefit sharing [...] production costs, the members' characteristics, or a good characterised by excludable benefits", can be modelled by following economic theory of "club" (Sandler and Tschirhart, 1980; Buchanan, 1965; Berglas, 1976, Vergalli, 2006).

Furthermore, the fact that the migration decision is in many cases at least partially irreversible, is a third element that has been studied in economic theories. In this respect, Burda (1995), following a real option approach, implements Sjaastad's assumption (1962) that describes migration choice in terms of investment. Burda's results show that individuals prefer to wait before migrating, even if the present value of the wage differential is positive, because of the un-

[1] Khwaja, Y., "Should I Stay or Should I Go? Migration Under Uncertainty: A Real Option Approach", mimeo, March, 2002

certainty and the sunk costs associated with migration [2]. Subsequently Khwaja (2002) Anam et al., (2004), Moretto and Vergalli (2005), developed Burda's approach by describing the role of uncertainty in the migration decision. Another work that uses real option with respect to an argument that it is strictly related to migration is Feist's (1998) paper, in which the author analyses the option value of the low-skilled workers to escape to the unofficial sector if welfare benefits come too close to the net wage in the official sector. In a recent work, Vergalli (2006) studies migration choice by merging in a unified framework the real option approach of investment decision and the works on the classical theory of clubs.

So far, the theoretical approaches that use real option framework to study migration choice, assume that migration is an irreversible choice. Nevertheless, migration could also be thought as the combined effect of entry and exit strategies. By following this idea, this paper is devoted to develop Vergalli (2006)'s framework by studying a more general approach that includes the possibility that each migrant could go back to his country, following Dixit-Pindyck (1993) and Khwaja (2002). What does it change in the migration choice? What happen in the labour market?

By trying to answer to these questions, this paper is organised as follows: section 2 presents the model and the basic assumptions; section 3 develops the theoretical framework that combines real option theory and the network effects, namely the optimal migration strategy in the presence of positive and negative externalities and show the main results; finally, section 4 summarises the conclusions.

2 The Model

This section presents a continuous-time model of migration where the differential benefits of migration, including the wage differential, evolves in a stochastic manner over time and there is ongoing uncertainty.

We can summarise our assumptions in the following manner:

1. There exist two countries: the country of origin where each potential migrant takes her decision and the host country.

2. At any time t each individual is free to decide to migrate to a new country. Individuals discount the future benefits at the interest rate ρ.

3. All immigrants are identical, are infinitely-lived, or choose vicariously for their descendants who will remain in the receiving country forever[3]. Their

[2] Investment is defined as the act of incurring an immediate cost in the expectation of future payoff. However, when the immediate cost is sunk (at least partially) and there is uncertainty over future rewards, the timing of the investment decision becomes crucial (Dixit and Pindyck, 1994, p.3).

[3] It is possible to show that the "sudden death" formulation is a very natural generalisation of the infinite-life case (Dixit and Pindyck, 1993, p.205).

size dn is infinitesimally small with respect to the total number of inhabitants.

4. Each individual enters a new country undertaking a single irreversible investment which requires an initial sunk cost K. if he wanted to return to his country he ought to cope with another sunk cost, called E.

5. The migrant faces some known constant variable costs of operation, called C[4].This latter cost might include legally required termination payments for houses, the buildings of the community he decided to sustain, the costs for buying a return ticket to his country and the loss of some businesses underway.

6. The wage differential for each migrant, called x, follows a geometric diffusion process:

$$dx = \alpha x dt + \sigma x dw \tag{1}$$

with $x_0 = x$ and $\alpha, \sigma > 0$. The component dw is a Weiner disturbance defined as $dw(t) = \varepsilon(t)\sqrt{dt}$, where $\varepsilon(t) \sim N(0,1)$ is a white noise stochastic process (see Cox and Miller, 1965). The Weiner component dw is therefore normally distributed with zero expected value and variance equal to: $dw \sim N(0, dt)$. From these assumptions and from the (1) we know that $E[dw] = 0$; $E[dx] = \alpha x dt$.

7. In the host country there is a community of ethnically homogeneous individuals. Each individual becomes a member (finding a job) instantaneously when she enters the host country.

8. The community net benefit function for each member is U-shaped with regards to the number of members and can be modelised by using "theory of clubs" as in Vergalli (2006). Formally, for a given level of common public good J (i.e. in the instant t), the migrant's utility function can be reduced to:

$$U(x, n) = x + \theta u(n) \tag{2}$$

where θ is a scale factor. The function $u(n)$ is twice continuously differentiable in n, and it is increasing over the interval $[0, \overline{n})$ and decreasing thereafter. Furthermore, if the initial level of the public good is not the optimal one, when J increases the maximum in $\overline{n}$ (i.e. u($\overline{n}$)) increases.
Proof. see Vergalli (2006). ■

[4] That could represent the costs of integration.

3 Results

As far as real option framework is concerned, we will observe two new threshold wages: an upper bound $\left(x^h\right)$ and a lower bound (x_l). If the shock crosses the upper bound, then the immigrant enters the host country, otherwise, if the shocks is below x_l then the migrant returns to his country of origin. We will also distinguish between the value of staying idle (V_0) and the value of belonging to the host country, (V_1).

Let us start with the idle entrant. The resulting equation is a differential equation for $V_0(x)$:

$$\frac{1}{2}\sigma^2 x^2 V_0''(x) + \alpha x V_0'(x) - \rho V_0(x) = 0 \tag{3}$$

This has the general solution:

$$V_0(x) = A_1 x^{\beta_1} \tag{4}$$

This value is valid over the interval $(0, x_h)$.

Now, let us consider the value of living in the host country for the migrant:

$$\frac{1}{2}\sigma^2 x^2 V_1''(x,n) + \alpha x V_1'(x,n) - \rho V_0(x,n) + x - C + \theta u(n) = 0 \tag{5}$$

The general solution of this equation is:

$$V_1(x,n) = B_1 x^{\beta_1} + B_2 x^{\beta_2} + \frac{x}{\rho - \alpha} + \frac{\theta u(n) - C}{\rho}$$

where the last three terms are the value of remaining in the country despite any losses and the first two terms are the value of the option to abandon the country. Because the value of the abandonement option should go to zero as x becomes very large, the coefficient B_1 corresponding to the positive root β_1 should be zero. This leaves:

$$V_1(x,n) = B_2 x^{\beta_2} + \frac{x}{\rho - \alpha} + \frac{\theta u(n) - C}{\rho} \tag{6}$$

this is valid for x in the range (x_L, ∞) [5].

Now, to analyse the effect of the community on the decision to migrate and to return home, we define the following function:

$$\begin{aligned} G(x,n) &= V_1(x,n) - V_0(x) = \\ &= -A_1 x^{\beta_1} + B_2 x^{\beta_2} + \frac{x}{\rho - \alpha} + \frac{\theta u(n) - C}{\rho} \end{aligned} \tag{7}$$

[5] In Appendix A, we explain how it is possible to find the value of the parameters of these equations, following the methodology of Dixit and Pindyck.

where $G(x)$ represents on the interval (w_L, w_H) the migrant's incremental value of migrating. If the same function without the presence of the community is:

$$G(x) = V_1(x) - V_0(x) =$$
$$= -A_1 x^{\beta_1} + B_2 x^{\beta_2} + \frac{x}{\rho - \alpha} - \frac{C}{\rho} \tag{8}$$

It is easy to demonstrate the role of the community in the definition of the trigger value for entering or for returning to the country of origin. Let us observe the following figure obtained by (7) - blue and black line - and (8) - red line.

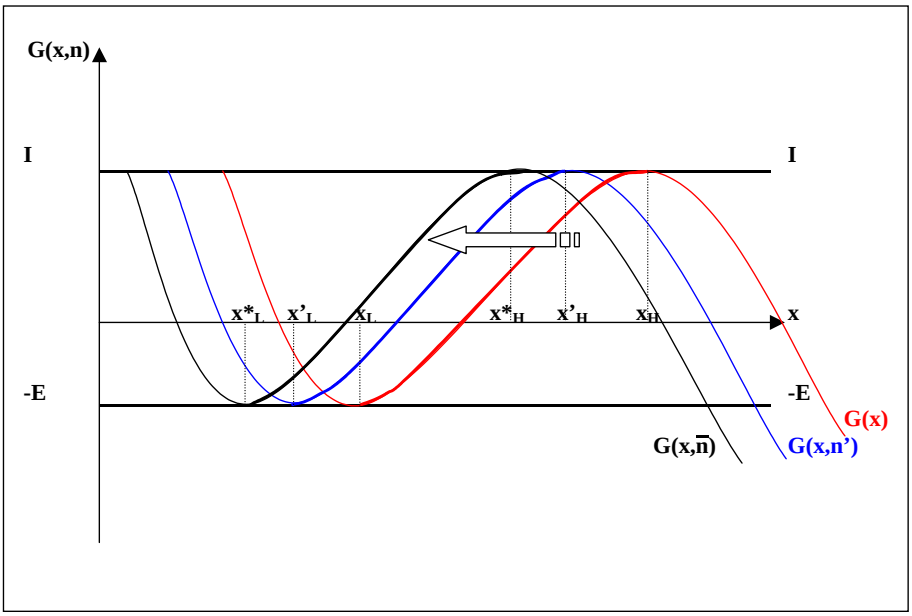

Figure 1: Entry and exit strategies.

The following comments are obtained by comparing the entry-exit strategy without community (8) with respect the same strategy with community (7) The role of the community for the entry-exit migrant's choice has the following effects:

1. the greater the number of members of the community for a given dimension of J, the lower the trigger value x_H at which each individual decides to migrate (for $n < \overline{n}$). This fact implies that the higher the number of members for $n \in (0, \overline{n})$, the earlier the migration starts;

2. the greater the number of members of the community, for a given dimension J, the lower the trigger value of exit x_L This fact magnifies the phenomenon of hysteresis to remain in the host country even if the level

of the migrant's wage is low. And the greater the benefit coming from the community, the lower the level of wage that each member needs to remain, because of a high network effect. Therefore, if the value of the U function is sufficiently high, the individual will remain for low level of wage. These two insights could explain why we sometimes observe migration inflows in countries with high unemployment rates and low average wages.

3. by appendix B we show that the migration thresholds x_H rises and x_L falls with the investment cost K. This important interaction between the costs and thresholds should also be intuitive upon reflection. The individual abandons the community with some reluctance because of his option value. By staying in the community, he avoids incurring the investment cost once again should the wage process become sufficiently favorable in the future. Therefore, the larger the investment cost, the larger is this option value and the greater is the reluctance to abandon. The mirror image result, namely, that the migration threshold x_H rises and x_L falls as the abandonment cost E increases, is perhaps even clearer. The individual is more reluctant to undertake the project if he might have to incur a greater cost of shutting it down in the future. The role of the community consists in modifying the effect of a change in K: if the migration cost increases, the entry threshold x_H raises lower than in the case of community's absence and the exit's threshold falls more than in the case of no community.

   In conclusion,

   Proposition 1 "the existence of a community of immigrants in the host country magnifies the hysteresis' phenomenon. This fact explains migration inflows in presence of high unemployment rates and low wages".

4. By Dixit and Pindyck: "a project with higher operating cost is undertaken more reluctantly and abandoned sooner". For the previous conclusions, the community reduces the first and increases the second effect.

3.1 Harris_Todaro paradox

In two seminal papers, Todaro (1969) and Harris and Todaro (1970) have developed a canonical model of rural-urban migration. The main idea is quite simple since it says that migration will occurs as long as the urban expected income (i.e. income times the probability to find an urban job) is higher than the rural one. These papers have been so influential that they are referred in the literature to as the Harris-Todaro model. One of the main issues raised in these papers was that creating urban jobs may increase rather than decrease urban unemployment because of the induced negative effect on rural migration, which may outweight the positive effect of creating jobs (Todaro, 1976). This is referred to as the Todaro paradox.

The paradox is due to the assumptions that in choosing between labour markets, risk-neutral agents consider expected wages; that the probability of

obtaining urban employment is approximated by the ratio of urban jobs to the urban labor force; and that the urban wage rate is considerably and consistently higher than the rural wage rate. Under these assumptions, inter-labour market (rural-urban) equilibrium mandates urban unemployment. This unemployment ensures that the expected urban wage is equal to the rural wage (which is assumed constant throughout). The repercussion of this simple set of assumptions is that contrary to received wisdom, once the migration response is factored in, several policies aimed at reducing urban unemployment will raise urban unemployment rather than reduce it. In the Harris-Todaro model migration is regarded as the adjustement mechanism by which workers allocate themselves between different labor markets, some of which are located in urban areas and some in rural areas, while attempting to maximize their expected incomes. The effects of the model described above, change the magnitudo and the sign of the Harris-Todaro (1970) paradox: by reducing the threshold level to migrate (i.e. the minimum wage) with respect to a labour market without community, the unemployment rate is not so efficient to counterbalance the migration inflows. In this case the Todaro paradox is diluted. This effect is similar to a reduction of "unemployment benefit" imposed by the goverment as descirbed in Zenou (2005). In their framework, a Todaro paradox exists if a reduction in the urban unemployment benefit (exogenous variable and policy instrument) leads to an increase of both urban employment and unemployment. This is a paradox since a reduction in the unemployment benefit has the natural effect to increase urban employment but the counterintuitive effect to also increase urban unemployment.

In the case of a search-matching model where wages are bargained, a Todaro paradox may exist if a condition on parameters is satisfied. Indeed, the benefit of community has a direct positive effect on bargained wages. As a result, because it is cheaper and thus more profitable to hire a worker, more firms enter the urban labor market and more jobs are created, and thus rural-urban migration increases. However, when the community benefit decreases, there is also a direct negative effect on migration since urban wages are lower and thus less rural workers migrate. The net effect is thus ambiguous. A condition that guarantees that the indirect positive effect on migration is larger than the direct negative effect leads to a Todaro paradox since a reduction in community benefit increases in this case both urban employment and unemployment.

3.2 Effects of community in countries with centralised wage-setting and no labour mobility

Another insight rises with respect to a two-countries centralised wage-setting framework (Boeri and Brücker, 2005).

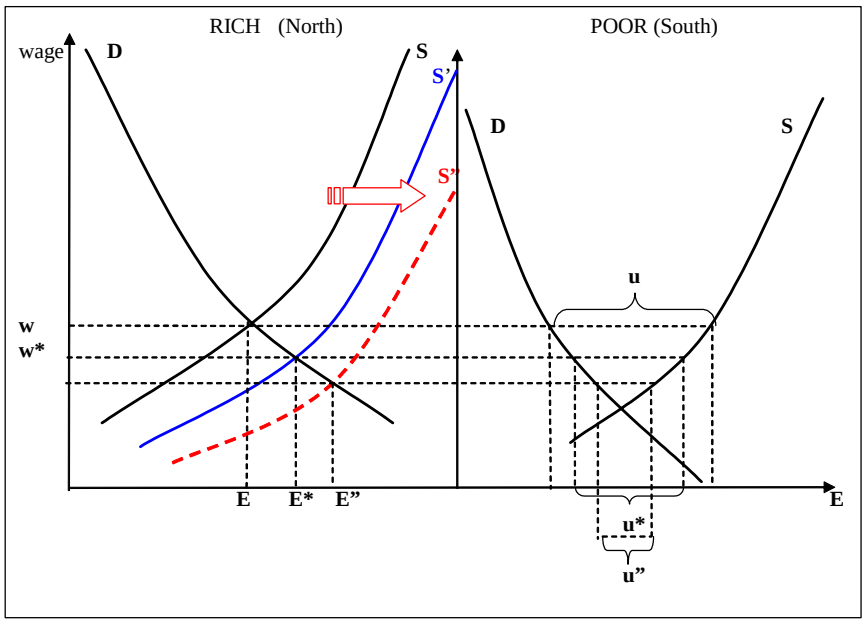

Figure 2: Effects of community in countries with centralised wage-setting and no labour mobility.

In presence of wage compressing institutions, international migration can reduce unemployment also in the low-productivity (high-unemployment) regions. This additional "greasing the wheels" effect of migration is visually characterised in the above diagram. The panel on the left-hand side shows the market-clearing wage prevailing in the dynamic regions (called here the Rich or North) which is also paid – due to the imposition of the same contractual minima throughout the country – in the Poor or South. At the initial equilibrium, the South experiences unemployment as the Northern wage acts as a binding minimum wage. Migration has two useful functions in this context. On the one hand, it increases employment and reduces wages in the North by shifting to the right labour supply (as shown by the blue line, S'). On the other hand, migration, by acting on Northern wages, reduces labour costs also in the South (from w to w*) allowing partially to absorb its unemployment pool there (which shrinks from u to u*). As observed above, the community reduces the entry-exit threshold, that is, the centralised minimum wage. Therefore, the effect is an increase in the supply to the red dotted line, by increasing the number of immigrants. The consequence is a rise of the employment (E") in the rich region and a reduction of the unemployment rate in the poor region (u").

4 Some extensions

So far, we have studied the role of the community in the entry and exit of a migrant, developing a model quite similar to Burda and implementing an extension taken from the theory of club. We have observed that a homogeneous community of individuals reduces the trigger level at which the individual decides to migrate and also reduces wage level at which each migrant wants to go back. We have assumed that all the individuals are homogeneous and we haven't take into account any policy choice. Now we would like to generalise the model in a simple manner, considering two possible implementations.

Taking into account the possibility of different skills among the migrants, we could assume that they are able to gain higher wages, the higher their levels of skill. That is, in a simple manner we could assume that the value of migrating in the host country is:

$$V(x,n) = E_0 \left[\int_0^\infty (\Psi_i x + \theta u(n)) e^{-\rho t} \left| n_0 = n, \theta_0 = \theta, x_0 = x \right| \right]$$

with $\Psi_i > \Psi_j$, if the skill level i is greater than j.

By this function and following the previous method, it is possible to demonstrate that the first inflow would be composed of high skills, because of a greater benefit for the same shock x. Furthermore, for the same reason they would remain more time than the others. Nevertheless, increasing the number of the community's members, the benefit should increase, ceteris paribus. This fact should mean a reduction of the threshold level and the entry also of low-skill immigrants. A possible policy for selecting the migrants'skills, could consist in increasing entry costs, as Urrutia (2001) suggests. However, as we have seen, this policy option would increase the hysteresis phenomenon of remaining in the community. Furthermore, the policy makers generally help the integration of new groups because of their lower possibilities. Although this policy choice is right for ethic reasons, it would not only stimulate migration, increasing the phenomenon of hysteresis but also reduce the average level of migrants' skills.

Governments can not only deploy measures to reduce the uncertainty facing potential investors, they can also create uncertainty through the prospect of policy change. This feature of the policy process is relevant in migration analysis because a new law could increase or reduce the costs of integration of all immigrants. It is commonly believed that expectations of shifts in policy can have powerful effects on decisions to invest. We show a possible analytical implementation in appendix C.

5 Conclusions

In this work we study the role of combined entry and exit strategies in the migration process. We develop a real option model in which the community of immigrants in the host country is described as a club and the immigrant's benefits is a U-shaped function, depending on the dimension of the district. This framework is in line with Vergalli(2006). In particular, in the present paper, we apply some extensions taken from Dixit and Pindyck (1993, pp. 217-222) regarding the combined entry and exit strategies of migrants: there exists a threshold that triggers the entry and a second that triggers the return to the country of origin. The theoretical results show that the phenomenon of hysteresis is amplified by the existence of a community both in the entry case and in the exit case. Furthermore, the community can reduce the minimum wage level required to trigger both exit and entry: this fact could explain why in some cases we observe migration inflows with a low wage differential and also with underunemployment as previously shown by Todaro (1970). This important result shows some theoretical implications: in a framework with centralised wage-setting and no labour mobility (Boeri and Brücker, 2005), the consequence is a rise of the employment in the rich region and a reduction of the unemployment rate in the poor region, because of a reduction minimum wage and an increase in the labour supply. We show also some possible further extensions of the model: in one case we introduce a possible way to select the entrants' skills and in another case we show some theoretical implementations to include possible policy shocks in the migrant's choice.

A Combined entry and exit strategies

Let us start with the idle entrant. The resulting equation is a differential equation for $V_0(x)$:

$$\frac{1}{2}\sigma^2 x^2 V_0''(x) + \alpha x V_0'(x) - \rho V_0(x) = 0 \tag{9}$$

This has the general solution:

$$V_0(x) = A_1 x^{\beta_1} + A_2 x^{\beta_2}$$

where A_1 and A_2 are constants to be determined, β_1 and β_2 are the roots:

$$\beta_1 = \frac{1}{2} - \frac{(\rho-\delta)}{\sigma^2} + \sqrt{\left[\frac{(\rho-\delta)}{\sigma^2} - \frac{1}{2}\right]^2 + 2\frac{\rho}{\sigma^2}} > 1$$

$$\beta_2 = \frac{1}{2} - \frac{(\rho-\delta)}{\sigma^2} - \sqrt{\left[\frac{(\rho-\delta)}{\sigma^2} - \frac{1}{2}\right]^2 + 2\frac{\rho}{\sigma^2}} < 0$$

We know that the coefficient A_2, corresponding to the negative root β_2, must be zero. This fact leaves:

$$V_0(x) = A_1 x^{\beta_1} \tag{10}$$

This value is valid over the interval $(0, x_h)$.

Let us consider the value of living in the host country for the migrant:

$$\frac{1}{2}\sigma^2 x^2 V_1''(x,n) + \alpha x V_1'(x,n) - \rho V_0(x,n) + x - C + \theta u(n) = 0$$

The general solution of this equation is:

$$V_1(x,n) = B_1 x^{\beta_1} + B_2 x^{\beta_2} + \frac{x}{\rho-\alpha} + \frac{\theta u(n) - C}{\rho}$$

where the last three terms are the value of remaining in the country despite any losses and the first two terms are the value of the option to abandon the country. Because the value of the abandonement option should go to zero as x becomes very large, the coefficient B_1 corresponding to the positive root β_1 should be zero. This leaves:

$$V_1(x,n) = B_2 x^{\beta_2} + \frac{x}{\rho-\alpha} + \frac{\theta u(n) - C}{\rho} \tag{11}$$

this is valid for x in the range (x_L, ∞).

In Appendix A, we explain how it is possible to find the value of the parameters of these equations, following the methodology of Dixit and Pindyck. Now,

to analyse the effect of the community on the decision to migrate and to return home, we define the following function:

$$\begin{aligned} G(x,n) &= V_1(x,n) - V_0(x) = \\ &= -A_1 x^{\beta_1} + B_2 x^{\beta_2} + \frac{x}{\rho-\alpha} + \frac{\theta u(n) - C}{\rho} \end{aligned} \tag{12}$$

where $G(x)$ represents on the interval (w_L, w_H) the migrant's incremental value of migrating. If the same function without the presence of the community is:

$$\begin{aligned} G(x) &= V_1(x) - V_0(x) = \\ &= -A_1 x^{\beta_1} + B_2 x^{\beta_2} + \frac{x}{\rho-\alpha} - \frac{C}{\rho} \end{aligned} \tag{13}$$

So, following the methodology of Dixit and Pindyck, we could solve (4) and (6) using the conditions of value matching and smooth pasting:

$$\begin{aligned} F_0(x_H) &= F_1(x_H) - K \\ F_0'(x_H) &= F_1'(x_H) \\ F_1(x_L) &= F_0(x_L) - E \\ F_1'(x_L) &= F_0'(x_L) \end{aligned}$$

and substituting (4) and (6), we have:

$$-A_1 x_H^{\beta_1} + B_2 x_H^{\beta_2} + \frac{x_H}{\rho-\alpha} + \frac{\theta u(n) - C}{\rho} = K \tag{14}$$

$$-\beta_1 A_1 x_H^{\beta_1 - 1} + B_2 \beta_2 x_H^{\beta_2 - 1} + \frac{1}{\rho-\alpha} = 0 \tag{15}$$

$$-A_1 x_L^{\beta_1} + B_2 x_L^{\beta_2} + \frac{x_L}{\rho-\alpha} + \frac{\theta u(n) - C}{\rho} = -E \tag{16}$$

$$-\beta_1 A_1 x_L^{\beta_1 - 1} + B_2 \beta_2 x_L^{\beta_2 - 1} + \frac{1}{\rho-\alpha} = 0 \tag{17}$$

The four equations determine the four unknow values.

B Comparative statics

Although the equations defining the thresholds are highly nonlinear and do not have closed-form solutions, the total differentials corresponding to small

changes in exogenous parameters are, as usual, linear. This makes it relatively straightforward to obtain qualitative comparative statics results for at least some parameters. We show the effects of the investment cost K in detail and the effects of E and C are similar.

Working with the function G remains useful, and it helps to show its dependence on the option value coefficients. Thus we write $G(x, A_1, B_2)$. The value-matching and smooth-pasting conditions are:

$$G(x_H, A_1, B_2) = K, \qquad G(x_L, A_1, B_2) = -E \tag{18}$$

$$G_P(x_H, A_1, B_2) = 0, \qquad G_P(x_L, A_1, B_2) = 0 \tag{19}$$

Now suppose that I changes by dI, and consider how the four endogenous variables A_1, B_2, x_L and x_H respond. Begin by differentiating the value-matching conditions (18) totally. Denote the partial derivatives of G by subscripts as usual, and write $G_A(x_H, A_1, B_2) = G_A(H)$, etc., for brevity. We obtain:

$$\begin{aligned} G_A(H)\, dA_1 + G_B(H)\, dB_2 &= dK \\ G_A(L)\, dA_1 + G_B(L)\, dB_2 &= 0 \end{aligned}$$

Note that the terms $G_P(H)dx_H$ and $G_P(L)dx_L$ have vanished because of the smooth-pasting conditions (19). Therefore the general comparative static system in the four endogenous changes dA_1, dB_2, dx_L, and dx_H in fact separates in a simpler manner. First we solve the above two equations for the changes in the option value coefficients dA_1, dB_2. Then we can totally differentiate the smooth-pasting conditions to obtain the changes in the thresholds dx_H, dx_L.

Noting that $G_A(H) = x_H^{\beta_1}$, etc., the solution is

$$dA_1 = \frac{x_L^{\beta_2} dK}{\Delta}, \qquad dB_1 = \frac{x_L^{\beta_1} dK}{\Delta}$$

where

$$\Delta = x_H^{\beta_1} x_L^{\beta_2} - x_H^{\beta_2} x_L^{\beta_1}$$

which is positive because $x_H > x_L$ and $\beta_1 > 0 > \beta_2$.

Now differentiate the smooth-pasting condition at x_H in (19) to write

$$G_{xx}(H)\, dx_H + G_{xA}(H)\, dA_1 + G_{xB} dB_2 = 0$$

which yields

$$G_{xx}(H)\, dx_H = -\frac{\left[\beta_1 x_H^{\beta_1 - 1} x_L^{\beta_2} - \beta_2 x_H^{\beta_2 - 1} x_L^{\beta_1}\right] dK}{\Delta}$$

Since $G(x)$ is concave at x_H, $G_{xx}(H)$ is negative and then $dx_H > 0$ when $dK > 0$. The investment threshold rises with the investment cost, as we should expect. Similarly, x_L falls as E rises.

Similarly, the lower smooth-pasting condition gives:

$$G_{xx}(L)\, dx_L = -\frac{(\beta_1 - \beta_2)\, x_L^{\beta_1+\beta_2-1} dK}{\Delta}$$

Since $G_{xx}(L) > 0$, we have $dPL < 0$ when $dK > 0$.

C Policy Uncertainty

Dixit and Pindyck (1993) affirm that "policy uncertainty is not likely to be well captured by a Brownian motion process; it is more likely to be a Poisson jump". Therefore our model changes in the following manner:

if θ follows a jump process, we write this compactly by analogy with the notation for Brownian motion as:

$$d\theta = \gamma\theta dt + \theta dq \tag{20}$$

where dq is the increment of a Poisson process with mean arrival rate γ, and dq is independent from dw. [so that $E(dzdq) = 0$]. We will assume that if an "event" occurs, q falls by some fixed percentage with probability 1. By the brownian motion study in (1), we know that

$$E(dw)^2 = dt$$
$$(dx)^2 = \sigma^2 x^2 dt$$

Let us denote (Dixit and Pindyck , 1993, p.85) a Poisson process by analogy with the weiner process. In other words, let dq be equal to 0 with probability $1 - \varpi dt$ and equal to $-\phi$ with probability ϖdt, so that

$$E(d\theta) = \gamma\theta dt - \theta\phi\varpi dt$$

If the two variables x and θ follow respectively a geometric brownian motion and a jump process we can use Itô's Lemma to calculate dV, writing (Dixit and Pindyck, 1993, p.209):

$$dV(x, \theta, n) = \frac{\partial V}{\partial t} dt + \frac{\partial V}{\partial x} dx + \frac{\partial V}{\partial \theta} d\theta + \frac{1}{2}\frac{\partial^2 V}{\partial x^2}(dx)^2 \tag{21}$$

And substituting (1), (20), into (21), dividing all by dt and rearranging we can obtain the expected value of dV:

$$E(dV) = \frac{\partial V}{\partial x}\alpha x + \frac{\partial V}{\partial \theta}\theta\gamma + \frac{1}{2}\frac{\partial^2 V}{\partial x^2}\sigma^2 x^2 + \varpi\left\{V\left[(1-\phi)x\right] - V(x)\right\} \tag{22}$$

And now substituting (22) into Bellman equation (**??**) we have:

$$\rho V = \frac{1}{2}\frac{\partial^2 V}{\partial x^2}\sigma^2 x^2 + \frac{\partial V}{\partial x}\alpha x + \frac{\partial V}{\partial \theta}\theta\gamma + \varpi\left\{V\left[(1-\phi)x\right] - V(x)\right\} + \left[x + \theta u(n)\right]$$
$$\frac{1}{2}\frac{\partial^2 V}{\partial x^2}\sigma^2 x^2 + \frac{\partial V}{\partial x}\alpha x + \frac{\partial V}{\partial \theta}\theta\gamma - (\rho+\varpi)V + \varpi V\left[(1-\phi)x\right] + \left[x + \theta u(n)\right] \tag{23}$$

To solve (23) we can use a simplification as advisable from Dixit and Pindyck (p. 210):

$$\begin{aligned} V(x,\theta,n) &= \theta u f\left(\frac{x}{\theta u(n)}\right) = \theta u f(s) \\ \frac{\partial V}{\partial x} &= f'(s) \\ \frac{\partial^2 V}{\partial x^2} &= \frac{f"(s)}{\theta u} \\ \frac{\partial V}{\partial \theta} &= uf(s) - usf'(s) \end{aligned} \tag{24}$$

Substituting (24) into (23) we obtain:

$$\frac{1}{2}\frac{f"(s)}{\theta u}\sigma^2 x^2 + f'(s)\alpha x + \left[uf(s) - usf'(s)\right]\theta\gamma - (\rho+\varpi)\theta u f(s) + \tag{25}$$
$$+\varpi\theta u f\left[(1-\phi)s\right] + \left[x + \theta u(n)\right] \tag{26}$$

rearranging and dividing all by θu

$$\frac{1}{2}f"(s)\sigma^2 s^2 + f'(s)s\left[\alpha-\gamma\right] - f(s)\left[\varpi+\rho-\gamma\right] + \varpi f\left[(1-\phi)s\right] + s + 1 \tag{27}$$

Now we can search for the general solution as the sum of a solution of the homogeneous equation plus a particular solution of the inhomogeneous equation. The first step is the analysis of the homogeneous equation:

$$\frac{1}{2}f"(s)\sigma^2 s^2 + f'(s)s\left[\alpha-\gamma\right] - f(s)\left[\varpi+\rho-\gamma\right] + \varpi f\left[(1-\phi)s\right] \tag{28}$$

The solution of (28) is again of the form $f(s) = As^{\beta_1}$, but now is the positive solution to a slightly more complicated non-linear equation:

$$\frac{1}{2}\beta(\beta-1)\sigma^2 + \beta\left[\alpha-\gamma\right] - \left[\varpi+\rho-\gamma\right] + \varpi(1-\phi)^{\beta} = 0 \tag{29}$$

The value of β that satisfies (29) and $f(0) = 0$ can be found numerically. The general solution of (27) appears to be the following:

$$f(s) = As^{\beta_1} + \pi(s) \tag{30}$$

where $\pi(s)$ is a particular solution of (27).

It is possible to demonstrate that the study done until now, could be simplified by reducing our analysis of the sum of two variables following stochastic processes to the analysis of a combined brownian motion and a jump process as shown in Dixit and Pindyck (pp. 167-173). In the same way the drift of the jump process can be included in the drift of the brownian motion or erased. In the following analysis let us for simplicity set $\gamma = 0$ and considering that:

$$f_1 = \frac{(1-\phi)\, s}{\rho - \alpha}$$

the solution of (27) is:

$$\pi(s) = \frac{\varpi\,(1-\phi)\, s}{(\rho-\alpha)\,(\rho-\alpha+\varpi)} + \frac{s}{(\rho-\alpha+\lambda)} + \frac{1}{(\rho+\varpi)} \tag{31}$$

$$= \frac{s}{(\rho-\alpha+\varpi)} \cdot \left[\frac{\varpi\,(1-\phi)}{(\rho-\alpha)} + 1\right] + \frac{1}{(\rho+\varpi)} \tag{32}$$

Thus the general solution is:

$$f(s) = As^{\beta_1} + \frac{s}{(\rho-\alpha+\varpi)}\left[\frac{\varpi\,(1-\phi)}{(\rho-\alpha)} + 1\right] + \frac{1}{(\rho+\varpi)} \tag{33}$$

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