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Abstract

This paper develops a computational network model of migration. The importance of ties between family members and friends in migration has been long recognised by other social sciences and is increasingly confirmed by econometric studies. The paper presents a micro simulation of an economy in which the heterogeneous population moves between three locations, a rural and urban location of origin, and the destination. The key elements in (return) migration decisions are network feedback effects and income opportunities. The simulations generate stable patterns and detailed information on distributions, which reproduce available data for the geographical population distribution, wealth, and remittances. The model generates the clustering of migrants both at the origin and at the destination that is one of the most pervasive and resilient stylized facts of migration research.

JEL Classification: C63 Simulation Modelling, F22 International Migration, J61 Geographic Labour Mobility, Immigrant Workers

Keywords: migration, agent-based modeling, networks

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1 Literature Review

Income differences drive migration outcomes in standard models in the literature (see e.g. Borjas 1994). Both the macroeconomic (Hanson and Spilimbergo 1999: 1343, Mayda 2010) and microeconomic (Massey and Espinosa 1997: 962) empirical literature tends to corroborate this assumption by establishing a positive correlation between income and migration flows.[1]

A second important driver of migration outcomes, social networks, is well-established in the empirical literature. Analyses of networks typically find a significant effect of the stock of migrants at the destination on migration flows (Greenwood 1969: 191, Tomaske 1971: 849f, Levy and Wadycki 1973: 198, Hatton and Williamson 1998: 38). Data from the Mexico Migration Project confirms these results for migration stock on a community and family level (Massey, Goldring, and Durand 1994: 1495, Munshi 2003, Orrenius and Zavodny 2005: 228, Dolfin and Genicot 2010: 20, Woodruff and Zenteno 2007: 522).

The empirical work on networks thus documents the centrality of networks to migration fairly conclusively. While standard economic migration models (see e.g. Harris and Todaro 1970, Borjas 1994) capture networks indirectly through the reduction in migration costs, recent developments in modelling migration have made the network mechanism more explicit by allowing for endogenous feedback between network members.

Early work in this vein showed that positive feedback mechanisms easily lead to corner solutions (Spilimbergo and Ubeda 2002: 11), but that with s-shaped feedback mechanisms a low- and a high-migration scenario exist (Carrington, Detragiache, and Vishwanath 1996: 929). Furthermore, the explosive force of positive feedback loops can be balanced by negative feedback mechanisms, either through the effect on local wages (Chau 1997: 41f, Epstein 2008: 571) or through increasing productivity at the origin (McKenzie and Rapoport 2007).

The literature on agent-based models of migration is at a very early stage. Dean, Gumerman, Epstein, Axtell, Swedlund, Parker, and McCarroll 2000 calibrate Epstein and Axtell's (1996) 'Sugarscape' model to migration of prehistoric Native Americans to replicate archeological records on settlement patterns. Since the model does not reproduce the abandonment of the site, the authors suggest that non-environmental factors may have played a role in determining settlement. The model does not provide for interaction between agents or for the formation of networks. Klabunde (2011) develops an agent-based model of migration along small-world networks that replicates migrant clustering observed in real-world data. The model is calibrated with available data on Mexico-U.S. migration, even though the draft version available does not match aggregate

[1] Caveats from some notable exceptions (Piore 1979, Faini, Galli, Gennari, and Rossi 1997) and non linearities (Mallee 1995: 136f, Clark, Hatton, and Williamson 2007: 12f) notwithstanding.

flows.

The paper proceeds as follows. The next section summarises stylized facts of migration research; section 3 presents the model that incorporates the causal mechanisms identified in the literature and reproduces the stylized facts of the second section. Section 4 describes the results, and section 5 concludes.

2 Stylized Facts

Four stylized facts are presented next for the worldwide as well as for the Ecuadorian context. This list is intended to cover the main areas of development potential for migration models and is thus not exhaustive; in fact it is much more limited than, for instance, Ravenstein's (1885) famous eleven laws of migration.

First, the relative population stocks at the national rural-urban level and at the international level need to be accounted for simultaneously, as destination decisions can be made jointly. Typically, the share of migrants on the international level is relatively stable, and substantially below the number of internal migrants (UN 2011). Ecuadorian migrants in New York conform to this pattern. The population share is between 1% and 1.3% in 2010 (U.S. Census 2011).

Second, gross migration is usually a multiple of net migration (OECD 2013). Official data on migration and return migration for Ecuador points to a much higher flow than stock of migrants (UNFPA 2008: 16, INEC 2011).

Third, clustering at every level is a pervasive feature of migration. This finding is increasingly established in the empirical literature (Massey 1987, Massey and Espinosa 1997, Orrenius 1999, Munshi 2003, Hanson 2010). International migrants from Ecuador are highly clustered (Bertoli 2010). The top four states' share in the Ecuadorian population in the U.S. amounts to over 80%. New York in particular receives about 39% of Ecuadorian migrants, while its share in the U.S. population was about 6.2% in 2011 (see Table 1). Conversely, out-migration from Ecuador is concentrated in the Southern high planes and the hotspot around the capital Quito (Banco del Ecuador 2009).

Fourth, a more innovative aspect of migration research is the distribution generated by the migration process, even though data is sparser and not as well documented as for the first three stylized facts. For the case of Ecuador, the data on income indicates that the share of the top decile amounts to roughly 40%, which is more or less the income of the next 30 per cent's income, as well as that of the bottom 60% (World Bank 2011). There are also substantial differences in the remittances received by different groups of the population (Bendixen 2003, CIAME 2005, Ponce, Olivie, and Onofa 2008: 24).

The next section develops an agent-based model of migration that replicates these stylized facts. The model is calibrated to the data on Ecuador. Ecuador is an ideal case

Table 1: Share of Ecuadorian migrants by U.S. states* in 2011

State	Share of Ecuadorians (%)	Share of U.S. population (%)
New York	38.56	6.19
New Jersey	20.22	2.81
Florida	12.90	6.01
California	8.61	11.91
Illinois	3.30	4.10

* For states with a share of Ecuadorian migrants $> 5\%$.
Data Sources: IPUMS (Ruggles, Alexander, Genadek, Goeken, Schroeder, and Sobek 2010), U.S. Census 2011, ACS 2009

for economic migration research, because its migration flows are almost exclusively based on economic reasons, and Ecuadorians constitute a sizeable and fast-growing community in New York and even the U.S. Furthermore, as argued in this section, the Ecuadorian case mimics the stylized facts of international migration, so that the formulation of the 'middle-range' model presented in this paper is sufficiently general to apply to a wide range of migration patterns.

3 The Agent-Based Model

3.1 Regions

Three locations have been distinguished by development and migration economists as stylized places of interest: rural and urban areas in the country of origin, and the country of destination (Lewis 1954, Todaro 1969). In the model, there are three distinct locations: rural Ecuador, urban Ecuador, and New York. Upon initialization, agents live in rural Ecuador, and are then mobile between the three regions.

Labour markets form the backbone of this model of economic migration, and their regional differentiation is key to its equilibrium mechanism. There are unlimited employment opportunities in rural Ecuador and in New York. In rural Ecuador this is based on a notion of unlimited demand for rural labour in subsistence agriculture in the spirit of Lewis (1954), while the labour market for migrants in New York is large relative to the number of Ecuadorian migrants.

Employment opportunities in urban Ecuador, however, are limited, as the local urban labour market can be crowded by Ecuadorian migrants. Urban Ecuadorian labour market conditions generate important negative feedback effects of population size on the probability to migrate.

3.2 Agents and Networks

Agents in the model represent Ecuadorians, and at initialization agents and their family members are located in rural Ecuador. Both the mean and standard deviation of the number of family members are set exogenously[2] under the assumption of a normal distribution. Agents are embedded in family networks, within which all members are linked. These ties represent bonds of communication and trust, and in accordance with a network theory of migration, they are an important resource for migration in the model.

There are many possible mechanisms through which networks promote migration. While the nascent economic literature on network migration models focuses mainly on the reduction in migration costs (Carrington, Detragiache, and Vishwanath 1996, McKenzie and Rapoport 2007), economic historians have emphasized information flows (Nelson 1959: 49f, Baines 1994: 526f). Dolfin and Genicot (2010) distinguish three routes: credit provision, and information on border crossing or job opportunities. This model is agnostic to the precise mechanism by which network ties facilitate migration. It just incorporates the empirically established positive effect of network on the probability of migration.

In every time period of the model, each individual works for an income, consumes, makes a decision on migrating and, if applicable, remits (see Algorithm 1).

Algorithm 1 Behavioural Rules

```
ask agent each time period
→   earn income
→   consume
→   remit
→   migrate
```

The income of agents in the model is calibrated to empirical data and assumed to be normally distributed within each region. Current income from work is a flow that is added each period to the stock of wealth. The income that can be earned in each region as well as the number of available jobs is set exogenously, since economic dynamics, and hence growth and job creation are beyond the scope of this partial equilibrium model.

Agents consume and remit a fixed percentage of wealth.[3] Wealth thus accumulates over time and can be written as:

$$W_{it} = W_{i,t-1}(1-c)(1-r_i^s) + Y_i + r_i^r, \quad (1)$$

where c is the propensity to consume, r_i^s are propensity to send remittances, r_i^r, the

[2] For an overview of calibration and data sources, see Table 3.
[3] For the values of these parameters in the benchmark calibration of the model, see Table 3.

‘propensity’ to receive remittances, and Y_i, the income received at time t.[4]

Remittances can be sent from New York to Ecuador or from urban to rural Ecuador. Agents in rural Ecuador are thus receivers of remittances, while those in New York only send remittances. Agents in Urban Ecuador can be both senders and recipients of remittances. Remittance receivers are randomly selected among the network members with lower income than the remittance sender in the ‘eligible’ regions.

3.3 Migration

At each time period, agents migrate stochastically based on each individual’s calculation of the probabilistic, individual ‘attractiveness’ of each region. Algorithm 2 gives an overview of this process.

Algorithm 2 Behavioural Rules for Migration

---

ask agent each time period
→ determine values of migration variables for each location based on
  relative income
  family
  jobs availability
  wealth
→ calculate migration probability for each region (multinomial logit)
→ stochastically select a region based on the cumulative migration probabilities
→ repeat the location selection τ times
↓ → move to region with the highest probability of being selected

---

The probabilities of migration thus depend on a range of factors found to be relevant in the empirical literature on migration, as described in section 1. They include network neighbours at origin and destination, income differences between the two locations, and availability of assets. The way in which the model captures these determinants is described next.

As discussed, the size of the social network with the destination is found by the empirical literature to be a key determinant of migration. In the model, the network is operationalised as the number of family at the destination, which is retrieved directly at any point in time. This number of family at destination enters the migration decision function normalized by the size of the entire family.

Economic incentives directly enter the migration decision in two aspects. First, income differences are the standard driver of migration decisions. The model therefore

[4] Analytically, the long-run solution of the above equation is $W^* = \frac{Y_i + r_i^r}{1-(1-c)(1-r_i^s)}$.

includes the ratio of income at origin to income at destination in calculating the probability of migrating. General equilibrium effects are captured in the Ecuadorian labour market, while income differences do not exhibit feedback effects but rather amount to a shift factor in the migration decision.

Second, the availability of funding is essential for the actual migratory process, especially in the case of clandestine migration. In the model, the required funding for migration is set exogenously, based on broad figures given in the literature (Pribilsky 2007). Even though funding is a *sine qua non* criterion for migration, an appropriately tuned parameter in the migration function can make the probability of migrating with insufficient funds almost equal to zero, and thus convert funding into a quasi-dummy variable. The variable in the model is migration costs normalized by wealth.

The most important stabilizing effect in the model is another economic factor, the labor market saturation in Ecuadorian cities. Constraints on the number of available jobs in urban Ecuador have feedback effects on the migration probabilities of agents. The labor market in Ecuadorian cities consists of an exogenous number of jobs, and if the number of job seekers exceeds the available jobs, the resulting unemployment deters further migrants to the labor market. The negative feedback effect of a large number of Ecuadorians in urban Ecuador for further migration to this region ensures that the model converges to an equilibrium[5], which in most cases is not a corner solution. That is, the negative feedback from this general equilibrium effect is strong enough to lead to an interior solution.

The four variables described above are weighted and integrated into mutually exclusive decisions to stay at the present location, or to move to either one of the other locations. In each location the options include rural or urban Ecuador and New York, so that each migrant faces three possible decision outcomes. We use a multinomial logistic function to generate the three probabilities for relocation, using the current location as the base case:

$$Prob(y_i = k) \quad = \quad \begin{cases} \frac{1}{1+\sum_{k=2}^{K} e^{v_{i,k}}}, & for\ k = 1 \\ \frac{e^{\rho v_{i,k}}}{1+\sum_{k=2}^{K} e^{v_{i,k}}}, & for\ k = 2,\ \ldots,\ K \end{cases} \tag{2}$$

where k is the location index. That is, $k = 1, 2, 3$ for rural Ecuador, urban Ecuador, and New York respectively. The exponential v is the matrix form of parameters and variables entering the probabilities for relocation:

[5]It should be noted that equilibria in agent-based modeling differ from those in mathematical models. They act as a center of gravity around which economic activity fluctuates, rather than as perfect equilibria with immediate adjustment. Prolonged deviations from these 'quasi-equilibria' are thus possible.

$$v_{i,k} = \alpha \cdot F_{ik} + \beta \cdot Y_{ik} + \gamma \cdot L_{ik} - \delta \cdot C_{ik}. \quad (3)$$

Four independent variables influence the migration decision of each agent i : F, the proportion of family at location k; Y, income at location k indexed by income at the current location; L, proportion of jobs available at location k; and C, the cost of migration to location k as a proportion of savings of agent i. That is, family networks and income differentials as well as job opportunities increase the probability of migrating, while the cost of migration decreases it.

Graphically, the multinomial logit generates migration probabilities in the form of an s-shaped sigmoid function, whose shape depends on the parameters. Parameters entering with a positive sign increase the probability, negative ones decrease it, and the larger a parameter, the stronger its effect.

For each agent i at each point in time, this procedure thus generates probabilities for moving to, and staying in, each one of the three regions in the model. From this list, a cumulative probability vector is calculated which fully maps to the $[0, 1]$ domain. Stochasticity is introduced through a random number drawn between 0 and 1, which determines the selection of the location to move to. To avoid distortions from a small number of dice rolls, the agent rolls an odd-numbered τ trials and then takes the mode of the trial results.[6] The law of large numbers guarantees that this approach results in a proportion of migrants corresponding to the calculated probabilities for a sufficiently large number of cases. Finally, the multinomial logit generates migration probabilities in the form of an s-shaped sigmoid function, whose shape depends directly on the parameters. Parameters entering with a positive sign increase the probability, negative ones decrease it, and the larger a parameter, the stronger its effect.

3.4 Calibration

The model contains four variables, of which Table 2 gives an overview.

Table 2: Variables

Variable	Calculation
F	Family at destination/Family at current location
Y	Income at destination/Income at current location
L	Open jobs at destination/Total jobs at destination
W	Cost of migration to destination/Current wealth

[6] For a detailed description see Naqvi and Rehm (2012).

Table 3: Parameter Calibration

Parameter	Symbol	Value
Agent index	i	[1, n]
Location index (rural Ecuador, urban Ecuador, New York)	k	(1, 2, 3)
Parameter on family network	α	0.5
Parameter on income differentials	β	0.5
Parameter on labour market conditions	γ	0.5
Parameter on migration cost	δ	15
Propensity to consume	c	0.3
Propensity to remit	r^r	0.3
Propensity to receive remittances	r^s	-
Number of families at initialization	f_n	50,000
Number of trials	τ	3
Income rural Ecuador (mean)	$Y_{k=1}$	230
Income urban Ecuador (mean)	$Y_{k=2}$	450
Income New York (mean)	$Y_{k=3}$	1,100
Cost of migration to New York	M_{NY}	5,000
Family size	$N(\mu_f, \sigma_f)$	N(4, 1.8)
Proportion of jobs in rural Ecuador		45%

Sources: Income rural and urban Ecuador: ENEMDU (INEC 2011), Dec. 2004-Dec. 2009
Income New York: IPUMS (Ruggles, Alexander, Genadek, Goeken, Schroeder, and Sobek 2010)
Cost of migration: Pribilsky (2007)

The model is calibrated to economic data where possible. Income levels are set according to data from the Ecuadorian *Instituto nacional de estadistica y censos* (INEC) for rural and urban Ecuador.[7] In New York, the income data for the Ecuador-born population is taken from the Census and from the American Community Survey, both accessed through IPUMS (Ruggles, Alexander, Genadek, Goeken, Schroeder, and Sobek 2010). The cost of migrating is based on Pribilsky's (2007) estimation of the costs for illegal migrants to move to the U.S.

The model is initialized with f_n families with a normally distributed number of members ($f_n \sim N(\mu_f, \sigma_f)$) which translates into about 227,000 agents. This set-up is not varied over the sample runs.

Even though the model is set up and calibrated to reach a stationary state, the complex feedback effects in the model lead to an initial adjustment period. In the results presented in section 4, the early phase of a run during which the model exhibits extraordinary fluctuations is thus not reproduced.[8] Table 3 contains a list of exogenous parameters and, where applicable, their sources.

4 Results

This section describes the salient features of the model output under the benchmark calibration, and compares them to empirical data. The first subsection presents changes over time for the population distribution and the ratio of gross and net migration, the second shows the model findings with regard to distributions, and the third subsection highlights the effects of family size.

Summary statistics of model outputs are presented in Table 4.

Table 4: Summary statistics of model outputs

Variable	Rural Ecuador	Urban Ecuador	New York
Population (agents)	107,000	109,000	9,900
Income	230 (24)	450 (45)	13,100 (1,380)
Wealth	1,300 (2,130)	700 (1,150)	12,500 (1,890)
Remittances sent	-	225 (460)	5,100 (1,540)
Remittances received	530 (2,250)	175 (1,400)	-

Model results generated from 100 sample runs measured at step 400. Numbers $> 1,000$ rounded to the nearest 100 for readability. Standard deviations in brackets.

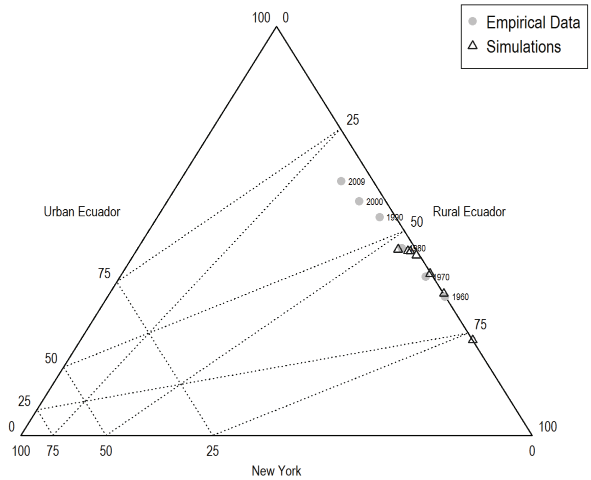
[7] See Table3 for detailed information on model calibration.

[8] The choice of a particular value for the initialization phase is somewhat arbitrary. It is set here to 400 based on visual inspection of trends in model results.

4.1 Migration Stocks and Flows

The distribution of the population in the model tracks the geographical distribution of the Ecuadorian population. Figure 1[9] shows the actual and simulated population distributions. In the model, less than 1% of agents are located in New York, which closely tracks the share of the Ecuadorian population living in the U.S.

Figure 1: Population distribution



Data Sources: U.S. Census 2001, World Bank 2011

The rest of the population is divided between the two Ecuadorian regions, rural and urban Ecuador, with a somewhat larger share being located in rural Ecuador. To capture the process of urbanization, this graph uses the first seven periods (excluding the period of initialization). The values are averaged over 100 runs. The model successfully tracks the urbanization of Ecuador between 1960 and 1980, but misses the subsequent continuing trend to urbanization.

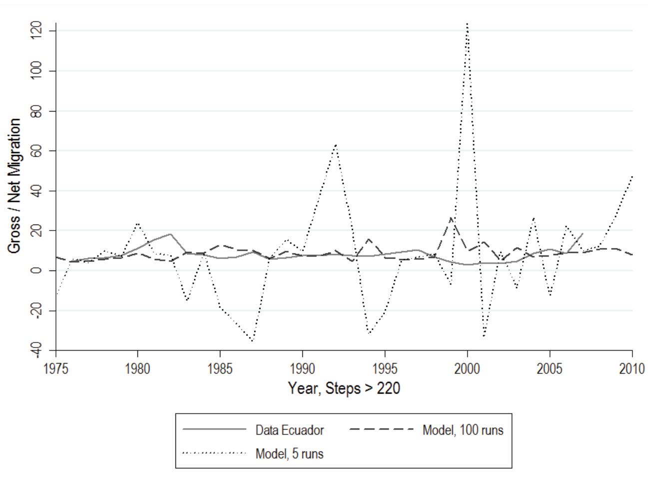
Figure 2 shows that the model replicates the pervasive stylized fact that gross migration is a multiple of net migration. The average in the model at about 8.7 is very close to the empirical data of about 8.1. Averaging over a large number of model runs (the dashed line in Figure 2) produces a relation whose stability is comparable to the

[9]Triplots reproduce data for three variables which sum to a constant, often 100%. Since there are only two independent sources of information, the three variables can be plotted as a triangle in two dimensions. Values on the left axis (EC in Figure 1) are read across to the right axis along the dotted lines. Actual population shares for EC thus vary from around 34% in 1960 to about 65% in 2009. Values on the right axis (ER) are read off towards the bottom axis, and in Figure 1 thus range from 66% to 33% in 2009. Values for the bottom axis (NY) are read towards the left axis, so that the population share in New York rises from under 1% to 1.3%.

Ecuadorian gross-net migration data, while a smaller number of runs (dotted line) generates one that is substantially more volatile than the data. Since net migration need not be positive, a small number of runs can also indicate out-migration.

The model is capable of capturing networks as the primary cause of migrant clustering. While the modeling of network migration constitutes a significant advance over traditional modeling of migration, it should be noted that clustering as an outcome is not an emergent property of the model. The model generates clustering both of migrants and of the population of Ecuador due to the built-in behavioral rules of network migration, according to which migrants tend to move where their kin is located both upon migration and return migration.

Figure 2: Gross/Net migration



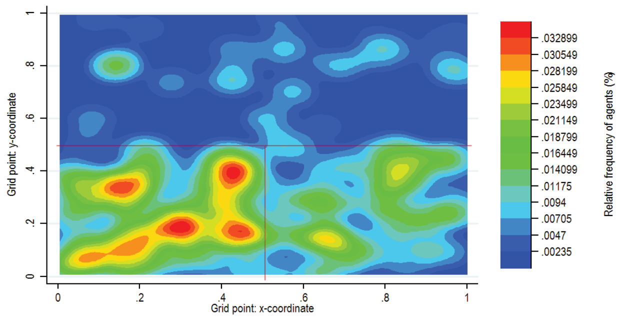
Model results measured at steps 220-400.
Data Sources: UNFPA 2008: 16 (1976-1992), INEC 2011 (1993-2011).

However, individual migration is still a possibility in the model when no family members are migrated. Network migration only becomes dominant when the inflection point of aggregate migration is passed, that is, when a sufficient number of migrating Ecuadorians have a family member located at the location of destination. It is then that migration along network and links rather than individual migration becomes the norm and very strong clustering is observed.

The heat map in Figure 3 depicts a typical output of the model after the initialization period. It provides a visual indication of the uneven density of the geographical population distribution. The darker-colored areas indicate higher population concentration, suggesting that there is clustering present in the data produced by the model.

Non-uniformity in population distribution satisfies a weak requirement of clustering.

Figure 3: Spatial distribution of agents



Model results measured at step 400.

4.2 Distributions

After the initialization period the model produces aggregate time series of total and average assets, debt and remittances in Ecuador and in New York which are stationary. On the individual level, the model generates distributions of wealth, debt and remittances. Empirical data on aggregate or per capita wealth, debt and remittances that is disaggregated by location is sparse, and distributions on the individual level are even more difficult to come by. Since most models are not able to handle real agent heterogeneity and thus distributions effectively, there are no model results to compare the findings presented here to, either.

Figures 4a and 4b show the wealth distribution generated by the model. The ability to accumulate savings is substantially lower in Ecuador than in New York, in accordance with the differential income generating possibilities in these regions.

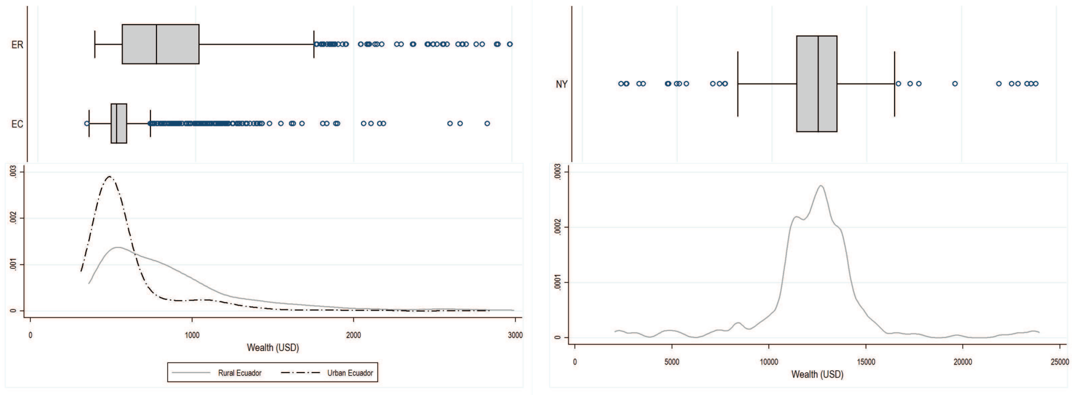
There is, however, a statistically significant difference in incomes between wealth held in rural and urban Ecuador, with the former showing both a higher mean and a wider spread of incomes. The model thus generates wealth levels in urban Ecuador that are below those in rural Ecuador. This is an important emergent property of the model, since the income earned in urban Ecuador is somewhat higher than in rural Ecuador.

This finding fits well with Pribilsky's (2007) observation that migrants from the Ecuadorian countryside can find it difficult to settle and engage in income-generating activities in urban Ecuador. In the model, the result is most likely the result of a combination of lower remittance receipts and job rationing in urban Ecuador, which leads to rotating incomes and thus to lower average assets.

High-wealth outliers in rural and in urban Ecuador reach and even exceed wealth

Figure 4: Wealth distribution

(a) Ecuador (b) New York



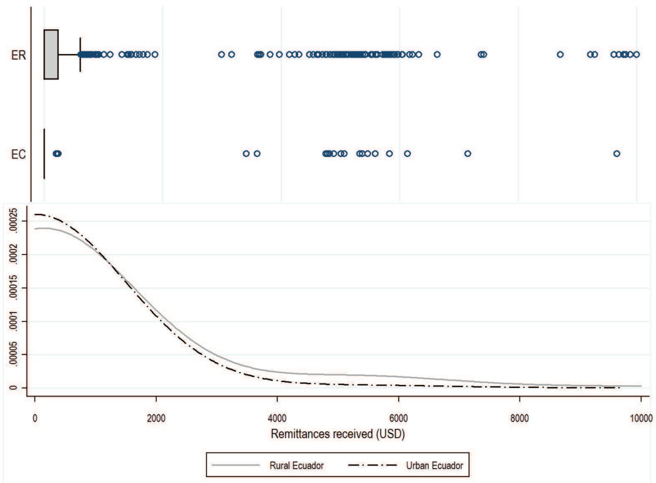
levels observed in New York. These are probably return migrants who accumulated a large amount of wealth while migrated. The kernel density plot for New York shows that the wealth is unevenly distributed. While Ecuadorians in New York possess higher wealth than the vast majority of residents of Ecuador, a significant share of international migrants owns three to four times the assets of those in Ecuador.

Remittances received by Ecuadorians in the model differ by the region of sender. While more people send remittances to rural Ecuador, for the majority of residents in urban Ecuador, the amount of remittances that they receive is higher (see Figure 5). This is because rural Ecuadorians receive remittances both from urban Ecuador and from New York, while urban Ecuadorians receive remittances only from New York residents with their higher average savings.

This is corroborated by the distribution of remittances sent; those sent from New York are substantially higher than remittances sent from urban Ecuador (see Figure 6). Again, this is because average savings of migrants in New York are higher than those of migrants in urban Ecuador, and remittances are a proportion of assets. However, outliers in urban Ecuador remit as much as most international migrants and, more importantly, a larger number of people remits from urban Ecuador in the model.

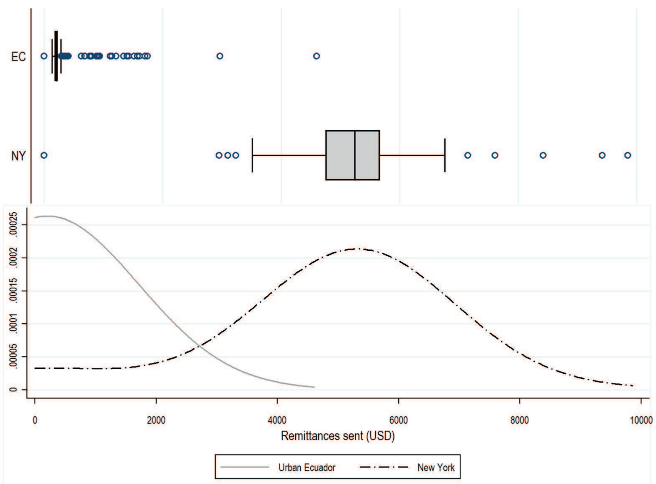
The model results thus strongly suggest that disaggregating remittance receipts by the location of the sender will substantially alter results. A much larger share of the population receives remittances if money transferred between urban and rural areas is included in the definition of remittances, and the per capita amount of remittances increases.

Figure 5: Remittances Received



Model results generated from 100 sample runs measured at step 400.

Figure 6: Remittances Sent



Model results generated from 100 sample runs measured at step 400.

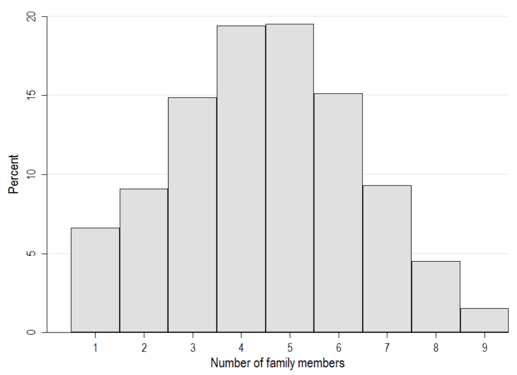
4.3 Wealth by household size

This subsection looks at distributions dependent on the family size, which determines network effects in this model. Since this paper argues that networks play an important role in migration, the expectation is to find discontinuities in distributions when networks are taken into account.

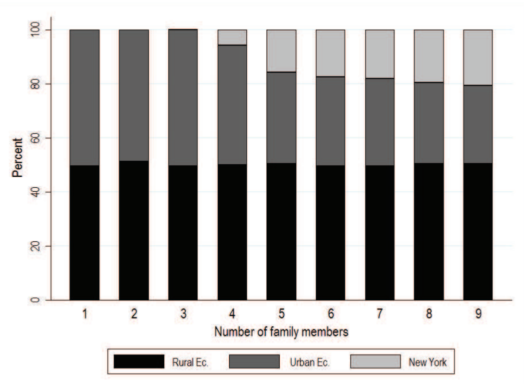
Figure 7a shows the family distribution generated by the normal distribution function. As Figure 7b demonstrates, the probability of a family member migrating to New York increases non-linearly beyond a family size of four.

Figure 7: Households

(a) Distribution of family size



(b) Distribution of family size by region

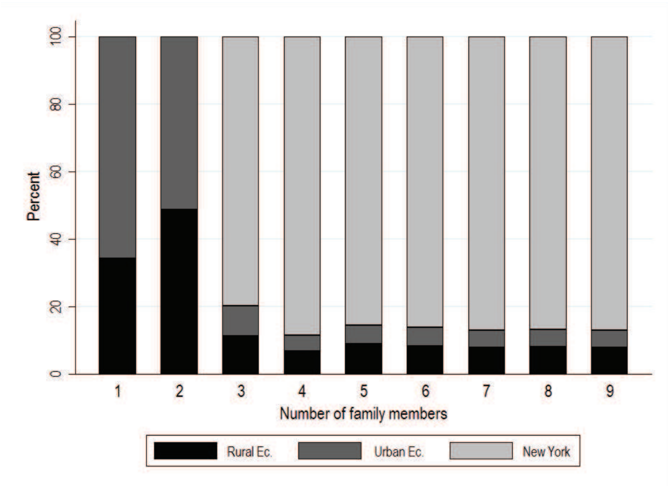


Results from 100 sample runs.

Figure 8 illustrates the importance of international migration for family wealth. Here the discontinuity occurs at even earlier stages in Figure 7b. That is, at a family size of three persons a significant amount of family wealth is located in New York. This discrepancy to the family distribution in Figure 7b is explained by the fact that even though only a small number of persons in families of three have migrated to New York, these already dominate the distribution of wealth.

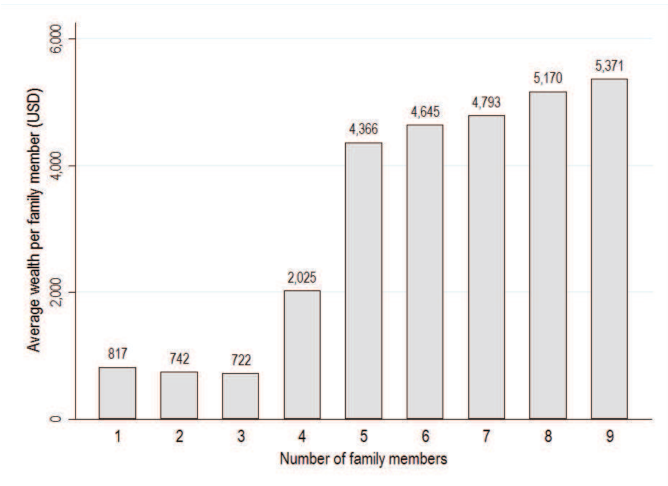
This effect is further elucidated by Figure 9. Even though a large share of family wealth is located in New York, the fact that the share of persons living in New York at these network sizes is still small leads to a still relatively low level of wealth per person. The inflection point of the average wealth distribution curve over family sizes appears to lie at around 4 family members.

Figure 8: Wealth distribution by Region



Results from 100 sample runs.

Figure 9: Average Household member wealth by family size



Results from 100 sample runs.

5 Conclusion

This paper developed an agent-based model of migration that explicitly incorporates network ties at its core. Networks are essential to the migration process on the microeconomic level – links to family and friends are at the heart of the decision to migrate, and the choice of destination, the ability to find employment, the choice of sector and the decision to send remittances are all informed by the ties to other migrants and family members in the country of origin. While other social sciences have made substantial progress in describing the individual experiences of the migration process and understanding the networks that lead to migration, economists have only recently begun incorporating network dynamics in migration research. The methodology used in this paper, agent-based modelling, is a further step in this direction. It provides a new approach to the analysis of migration, and addresses the still under-researched area of networks in economic migration.

The model represents migration from Ecuador to the U.S., benefitting from the body of anthropological literature which describes the prevalent migration from the Andean region to New York. This literature provides guidance for the behavioural rules implemented in the model. Furthermore, Ecuador is an ideal case for economic migration research, because its migration flows are almost exclusively based on economic reasons, and Ecuadorians constitute a sizeable and fast-growing community in New York and even the U.S. Finally, as argued in this paper, the Ecuadorian case mimics the stylized facts of international migration, so that the formulation of the 'middle-range' model presented in this paper is sufficiently general to apply to a wide range of migration patterns.

The agent-based model of migration outlined in this paper draws on several well-established economic concepts, including development economics and economic theories of migration. Agents move between three locations, rural Ecuador, urban Ecuador and New York as they work, migrate, remit, and return migrate, while embedded in a family network.

In some respects, however, the model departs from received modelling practices to incorporate insights gained by anthropologists and sociologists. Most notably, migration decisions hinge upon network effects, mediated through a multinomial logit framework. Migration decisions are based on the positive feedback effects of income differences and family living in the place of destination and the negative feedback effect of labour market crowding in urban Ecuador and the cost of migration. Since migration is an out-of-equilibrium phenomenon, the methodology of agent-based modeling is well suited for its study as it allows for tracking flows of people and money in real time.

The paper presented model results both for 'standard' stylized facts as well as for 'newer' venues for migration research. The model broadly reproduces the geographical distribution of Ecuadorians and the ratio of gross to net migration. More innovatively, the model generates the clustering of migrants both at the origin and at the destination that is one of the most resilient stylized facts of recent empirical migration research.

Notable inter-regional differences in the distribution of wealth result from agent heterogeneity in terms of network structure and migration history. An emergent property of the model, the higher wealth of Ecuadorians living in rural areas as compared to urban migrants, is in concord with anthropological research. Savings are substantially higher for migrants in New York, an effect that translates to family wealth. The number of network members impacts the geographical distribution of family members, the geographical distribution of family wealth, and the average wealth of family members non-linearly. The inflection points lie between 3 and 4 family members.

Remittances sent from New York are higher than those from urban Ecuador; however, the large number of people remitting from urban Ecuador more than balances the lower remittances per person. Consequently, most residents of rural Ecuador receive less in absolute amounts, yet a much higher share of them receives some income from remittances.

In our view, the ultimate goal of economic research is policy advice. In further developing this line of research, the potential insights gained from the model outcomes can be applied to policy suggestions, for instance regarding the effects of border policies on migration flows, or issues around the volatility of migrants' income, wealth and remittances.

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