Quantifying Global International Migration Flows

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Supplementary Materials

www.sciencemag.org/content/343/6178/1516/suppl/DC1
Materials and Methods
Figs. S1 to S11
Tables S1 to S7
References (*20*–*36*)

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Quantifying Global International Migration Flows

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Widely available data on the number of people living outside of their country of birth do not adequately capture contemporary intensities and patterns of global migration flows. We present data on bilateral flows between 196 countries from 1990 through 2010 that provide a comprehensive view of international migration flows. Our data suggest a stable intensity of global 5-year migration flows at ~0.6% of world population since 1995. In addition, the results aid the interpretation of trends and patterns of migration flows to and from individual countries by placing them in a regional or global context. We estimate the largest movements to occur between South and West Asia, from Latin to North America, and within Africa.

Existing data on global bilateral migration flows are incomplete and incomparable because of national statistical agencies not measuring migration or variation in the way migration flows are defined (*1*–*3*). Stock data, measured at a given point in time as the number of people living in a country other than the one in which they were born, are more widely available and far easier to measure across countries than are flow data capturing movements over a period of time. This is especially true in regions where the collection of demographic data are less reliable. However, flow data are essential for understanding contemporary trends in international migration and for determining relationships. The discrepancies between the demand for flow data and the availability of migrant stock data have hindered theoretical development and have led to conjectures concerning increases in the overall volume of global migration (*4*, *5*) and shifts in spatial patterns (*6*).

The demand for bilateral migration flow data that can be the basis for robust comparisons has led researchers to develop indirect estimates. These have been limited to European data, in which flow statistics are plentiful, and have required model-based methods to harmonize reported flows and impute missing data (*7*–*9*). Outside of Europe, global bilateral migrant stock data that capture the size of foreign-born populations in each country—thus potentially allowing indirect estimations of flows—have only recently become available (*10*, *11*).

Here, we present a set of global bilateral migration flows estimated from sequential stock tables published by the United Nations (U.N.) for 1990, 2000, and 2010 (*11*). The data are primarily based on place-of-birth responses to census questions, details collected from population registers, and refugee statistics. First, we generated mid-decadal stock tables for the years 1995 and 2005 using a procedure similar to that used by the U.N. to align census and survey data to the beginning year of each decade (*11*). To quantify the global flow of people over 5-year periods, we then obtained maximum likelihood estimates for the number of movements required to meet the changes over time in migrant stock data, using an iterative proportional fitting algorithm (*12*). A detailed

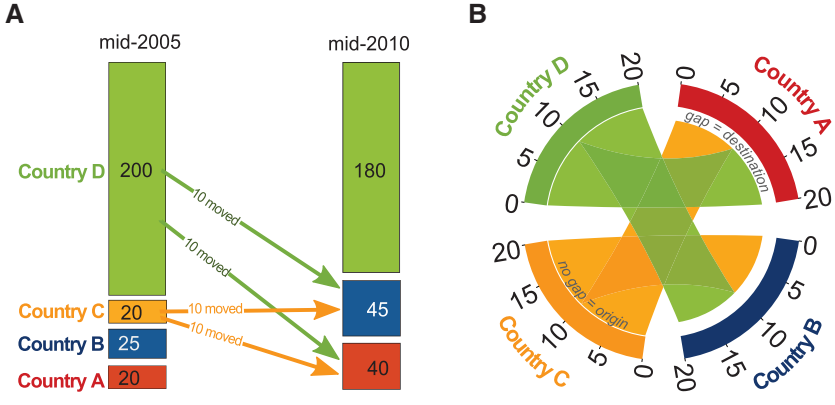

Fig. 1. Linking migrant flow to stock data and visualizing flows via circular plots. (A) The simplified example illustrates our method for estimating 5-year migration flows from changes in stock data between mid-2005 and mid-2010 (details are available in the supplementary materials). The number of people born in Country D and living in Country D (green field) decreased from 200 in 2005 to 180 in 2010. The number of people born in D and living in Country A (red field) increased from 20 to 40, and the number of people living in Country B (blue field) also increased from 25 to 45, but the number living in Country C (yellow field) decreased from 20 to 0. To match these differences in migrant stock data, our model provides an estimate of 20 people moving out of Country C, of whom 10 moved to A and 10 to B, and another 20 people moving out of Country D, with 10 moving to A and 10 to B. **(B)** The circular plot visualizes the migrant flows estimated in the hypothetical example. The origins and destinations of migrants (Countries A to D) are each assigned a color and represented by the circle's segments. The direction of the flow is encoded by both the origin country's color and a gap between the flow and the destination country's segment. The volume of movement is indicated by the width of the flow. Because the flow width is nonlinearly adapted to the curvature, it corresponds to the flow size only at the beginning and end points. Tick marks on the circle segments show the number of migrants (inflows and outflows).

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discussion of the input data and estimation methodology can be found in the supplementary materials and (*13*). Our methodology to obtain bilateral flows with a simplified example of changes in stock tables for people born in a hypothetical country is illustrated in Fig. 1A. We produced a comparable set of global migration flows by simultaneously replicating the birthplace-specific estimation procedure for all 196 countries and accounting for changes in populations from births and deaths. Refugee movements are included in our estimates when they are taken into account in the U.N. stock data.

Our bilateral flow estimates capture the number of people who change their country of residence over 5-year intervals, similar to transitions measured over fixed intervals that are recorded by population censuses (*14*). The net migration totals calculated from our bilateral flow tables match the 5-year net migration data in the U.N. World Population Prospects. A robust comparison with existing bilateral flow estimates for Europe (*7*–*9*) is prejudiced by migration being measured as the annual number of movements rather than only a transition over a 5-year period. As the ratio of movements to transitions differs across countries, depending on the amount of multiple and return moves, there is no simple algebraic solution to convert from one definition to the other (*15*).

Migrant stock data compare country of birth with country of residence so as to give an estimate of lifetime migration. Compared with our 5-year flow measurement, the longer observation interval provides less detail on the timing of the move (*15*, *16*). Using stock data as a proxy measure for contemporary flows is potentially misleading in the sense that the relative size of immigrant populations does not necessarily correspond to that of migrant flows.

The visualization of global migration flows allows for the visual quantification of directional gross migration flows and the identification of their spatial patterns. Using Circos, a software package widely used in genetics (*17*), we created circular migration plots (Fig. 1B) to illustrate the complex and dynamic nature of migration. The circular migration plots in Fig. 2 give a snapshot of our flow estimates in 1990 to 1995 and 2005 to 2010 (top) as compared with the U.N. sequential migrant stocks in 1990 and 2010 (bottom), which our estimates are based on (*11*). Designations of "more developed," "less developed," and "least developed" were according to the U.N. Population Division (*11*). The patterns of flows during the 1990 to 1995 period are noticeably different from those of the migrant stock data of 1990. Differences between flows and stocks at this aggregated level were not tested with *t* test because such significance tests neglect the array of assumptions behind the estimation model and complexities in the underlying data, and a more fully fledged model-building exercise is beyond the scope of the paper. Fig. 2A depicts a 13% lower share of migration within the developed world and a 6% lower share from the least to less developed world, whereas the share of migration between the least developed countries is 7% higher in comparison with that in Fig. 2C. These differences might reflect sudden changes in the global migration regime driven by the fall of the Iron Curtain and armed conflicts in Asia and Africa. The stock data do not capture these fluctuations in contemporary patterns of movement. The patterns shown in Fig. 2, B and D, are much more similar because migration flows appear to have followed long-term trends captured by stock data.

Contrary to common belief (*4*–*6*), our data (Fig. 3) do not indicate a continuous increase in migration flows over the past two decades, neither in absolute or relative terms. According to our estimates, the volume of global migration flows declined from 41.4 million (0.75% of world population) during 1990 to 1995, to 34.2 million (0.57% of world population) during 1995 to 2000. A substantial part of the fall might be accounted for by ceasing of cross-border movements triggered by the violent conflicts in Rwanda and the ending of the Soviet-installed Najibullah regime in Afghanistan. The number of global movements increased by 5.7 million between 1995–2000 and 2000–2005, and by 1.6 million between 2000–2005 and 2005–2010, whereas the percentage of the world population moving over 5-year periods has been relatively stable since 1995.

The size of migration flows within and between 15 world regions in 2005 to 2010 (estimates are in database S1) is shown in Fig. 4. Several migration patterns shown in Fig. 4 are broadly in line with previous assessments based on global stock data (*11*) and flow data for selected countries published by the U.N. (*3*, *4*, *18*, *19*). Earlier observations

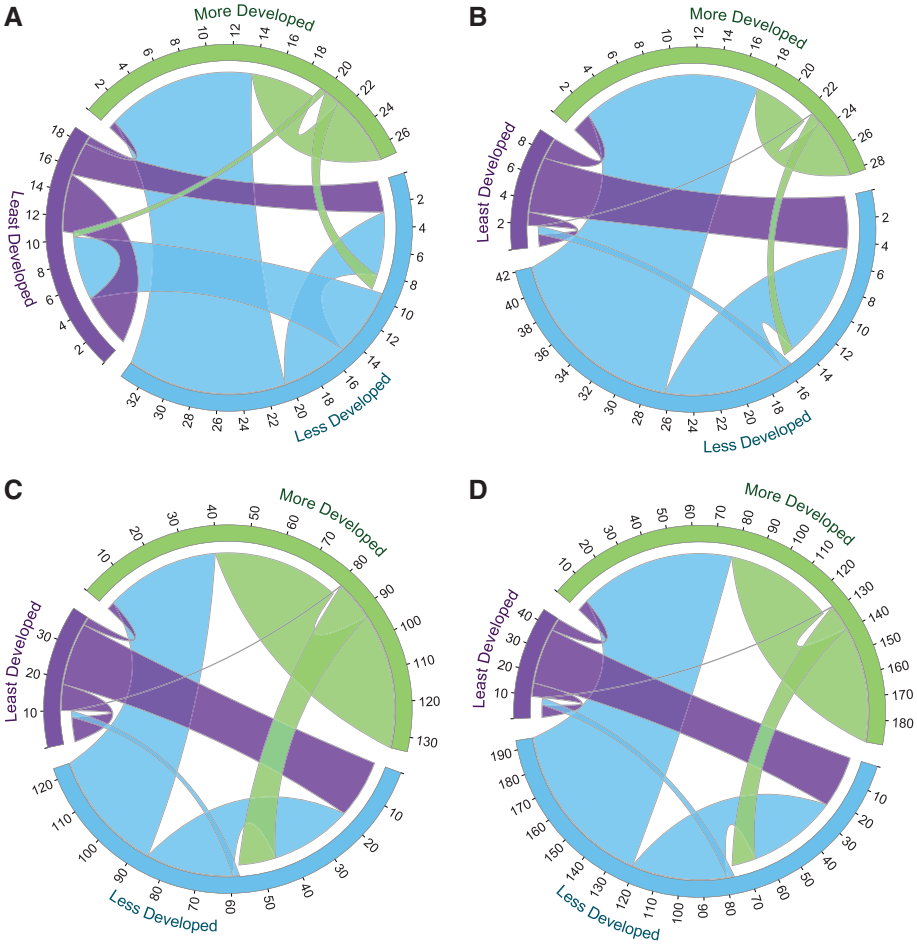

Fig. 2. Comparing estimated migrant flows to stocks in early 1990s and late 2000s. Migration flows between more developed (green), less developed (blue), and least developed (purple) countries. (**A**) Flows during 1990 to 1995. (**B**) Flows during 2005 to 2010. (**C**) Stock data from 1990. (**D**) Stock data from 2010. Tick marks on the circle segments show the number of migrants (inflows and outflows) in millions.

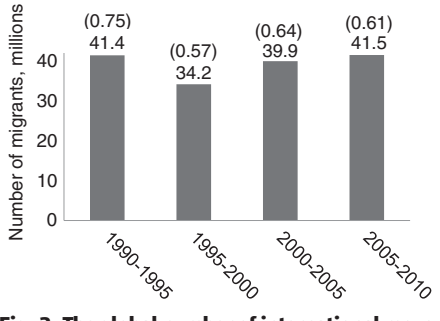

Fig. 3. The global number of international movements between 196 countries in four quinquennial periods, 1990 to 2010. Percentages (shown in parentheses) are calculated by using the world population at the beginning of the period.

include the attractiveness of North America as a migrant destination, the substantial movements from South Asia to the Gulf states in Western Asia, the diverse movements within and between the European regions, and the general tendency for more developed regions to record net migration gains, whereas the less developed countries in Asia, Africa, and Latin America sent more migrants than they received from 2005 to 2010.

A global comparison of migration flows based on our estimates extends these earlier observations and uncovers three striking features of the global migration system. First, African migrants from sub-Saharan Africa (who represent the vast majority of African migrants) appear to have moved predominantly within the African continent. From 2005 to 2010, an estimated 665,000 migrants moved within Eastern Africa, and 1 million people moved within Western Africa. Our data indicate that it is the movements between the member countries of the West African Economic and Monetary Union—especially Ivory Coast, Burkina Faso, and Guinea-Bissau—that drive this pattern (database S2). In contrast, the biggest flow from Western Africa to another continent comprised 277,000 people moving to Western Europe.

Second, migration flows originating in Asia and Latin America tended to be much more spatially focused than were flows out of Europe. Emigrants from South Asia and South-East Asia tend to migrate to Western Asia, North America, and to a lesser degree, Europe. Migrants from Latin America move almost exclusively to North America and Southern Europe. In contrast, migration to and from Europe is characterized by a much more diverse set of flows to and from almost all other regions in the world.

Third, although the largest flows occurred within or to neighboring regions, the plot depicts numerous flows that go through the center of the circle. These long-distance flows are effective in redistributing population to countries with higher income levels, whereas the return flows are negligible.

Will strong population growth in sub-Saharan Africa lead to mass migration from lower-income countries in Africa to higher-income countries in Europe and North America over the coming decades? Our findings provide evidence for a stable intensity of global migration flows and a concentration of African migration within the continent, with only a small percentage moving to the more developed countries in 1990 to 2010. Therefore, it seems unlikely that if these observed trends persist, emigration from Africa will play a key role in shaping global migration patterns in the future. Nevertheless, human capital and demographic trends create a considerable potential for change in the global migration system. If, for example, future population growth in sub-Saharan Africa were to be paralleled by a commensurate expansion in education, the growth of a more skilled workforce may lead to an increase in skilled migration from Africa to the more developed world.

In quantifying global migration flows, our data provide a better basis for analyses of the spatial structure of international migration flows that extend beyond the discipline's theoretical and methodological boundaries. A better understating of the causes and consequences behind current migration patterns may allow for a more informed speculation on future trends.

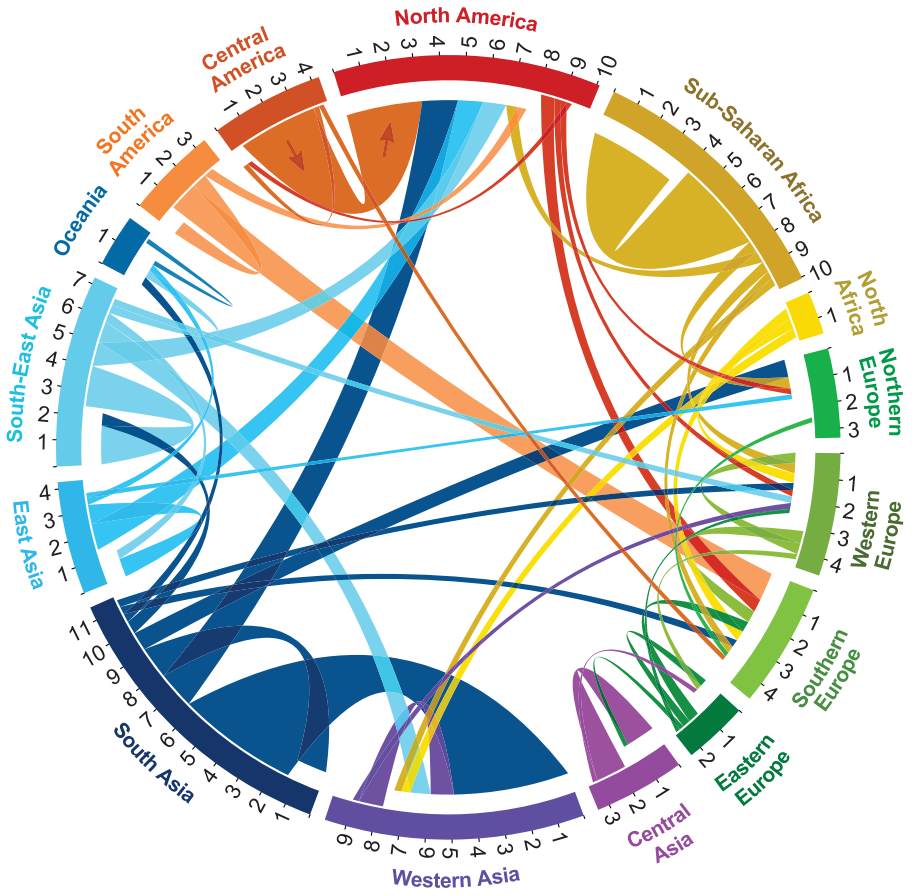

Fig. 4. Circular plot of migration flows between and within world regions during 2005 to 2010. Tick marks show the number of migrants (inflows and outflows) in millions. Only flows containing at least 170,000 migrants are shown.

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Supplementary Materials

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Tables S1 to S5
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Databases S1 and S2

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