Quantifying Global International Migration Flows

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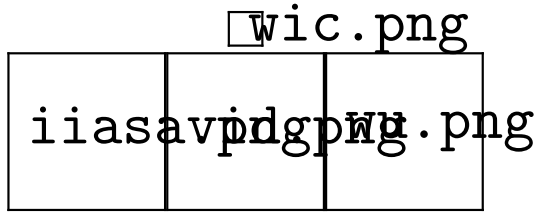
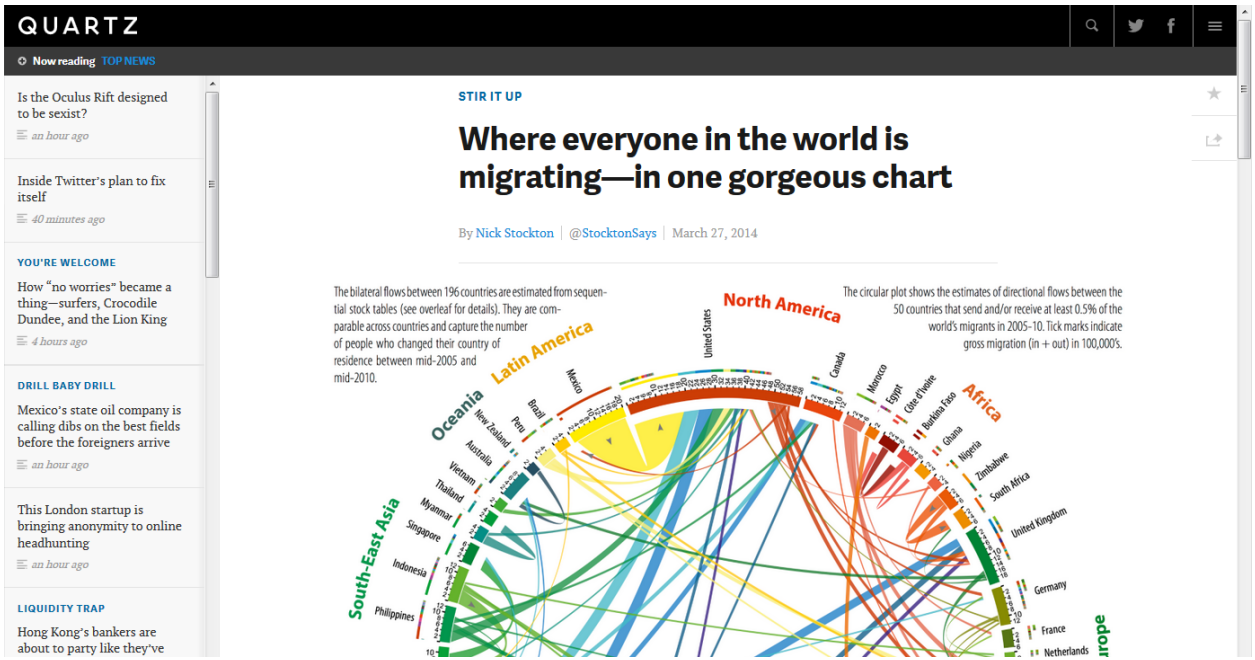


Overview

- Static measures of migration are plentiful.
- Dynamic flow data are trickier.



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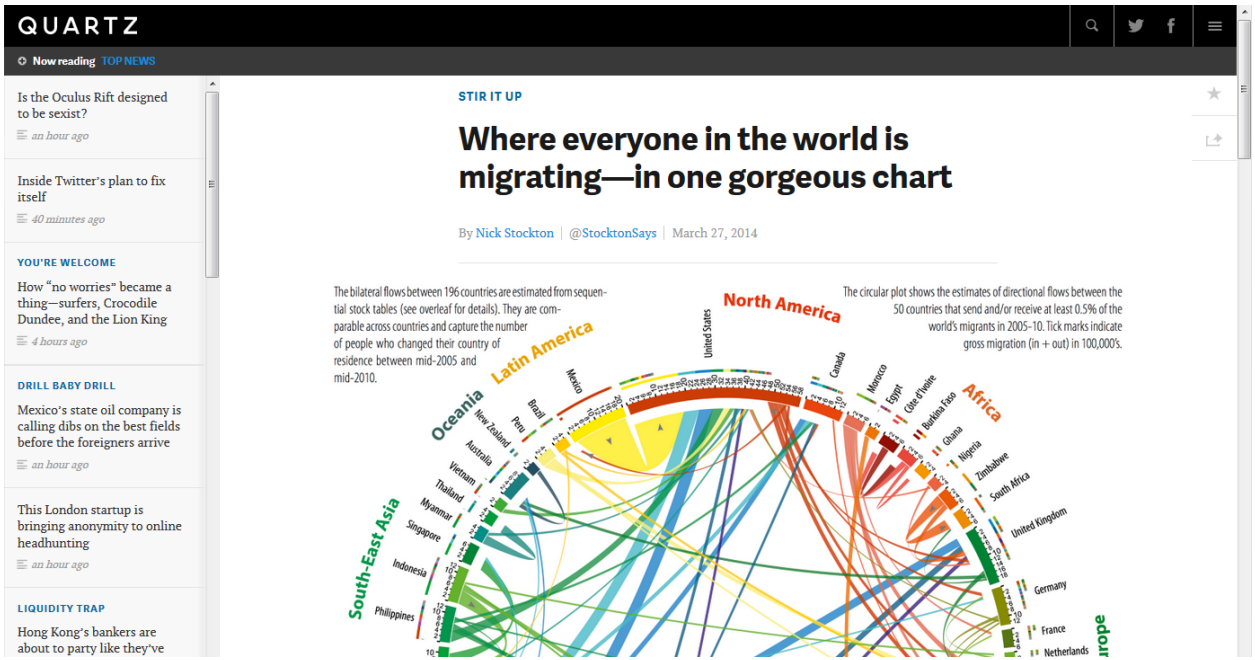
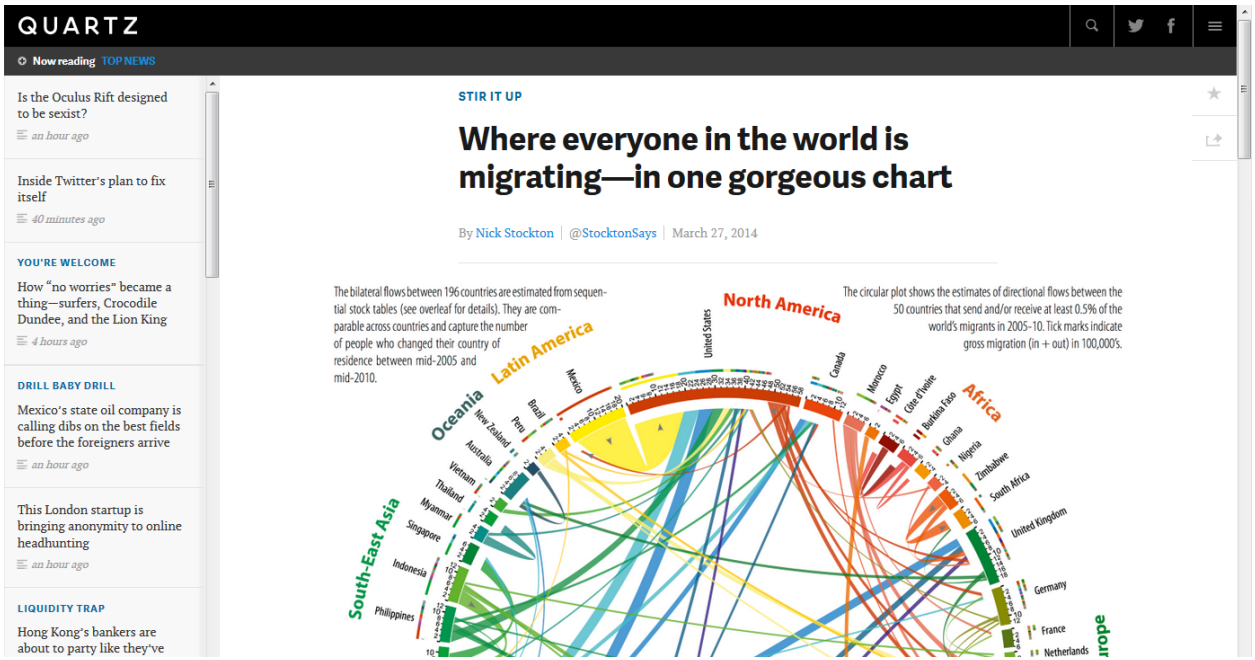
- No existing global database on bilateral flows



Overview

- Static measures of migration are plentiful.
- Dynamic flow data are trickier.
- No existing global database on bilateral flows
- Without flow data, it is difficult to compare patterns and trends.



Stock and Flow Measures

Migration measures can be categorised into:

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1. Stocks:

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   - The numbers of migrants living in a area at a point in time.
   - Static, easy to define, and collected in censuses.
   - United Nations and World Bank have both collated historical bilateral stock measures for all countries

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2. Flows:

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   - Dynamic, difficult to define and compare across countries.

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   - Static, easy to define, and collected in censuses.
   - United Nations and World Bank have both collated historical bilateral stock measures for all countries
2. Flows:
   - Movements over boundaries during a defined period.
   - Dynamic, difficult to define and compare across countries.
   - The United Nations and Eurostat have collated some data predominately from Western countries.
   - MIMOSA and IMEM projects to harmonise and impute European flows.

Flow Measures

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   - Number of moves over a defined period
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   - Number of moves over a defined period
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   - Number of people with a different place of residence at the beginning and end of a period.
   - The United Nations have net estimates for all countries.
   - Form the base data for global population projections.

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1. Events:
   - Number of moves over a defined period
   - Focus of MIMOSA and IMEM.
2. Transitions:
   - Number of people with a different place of residence at the beginning and end of a period.
   - The United Nations have net estimates for all countries.
   - Form the base data for global population projections.

Note: Comparisons of events and transitions data are not straightforward.

Motivation

At the global level, transition flow data beyond a net measure does not exist.

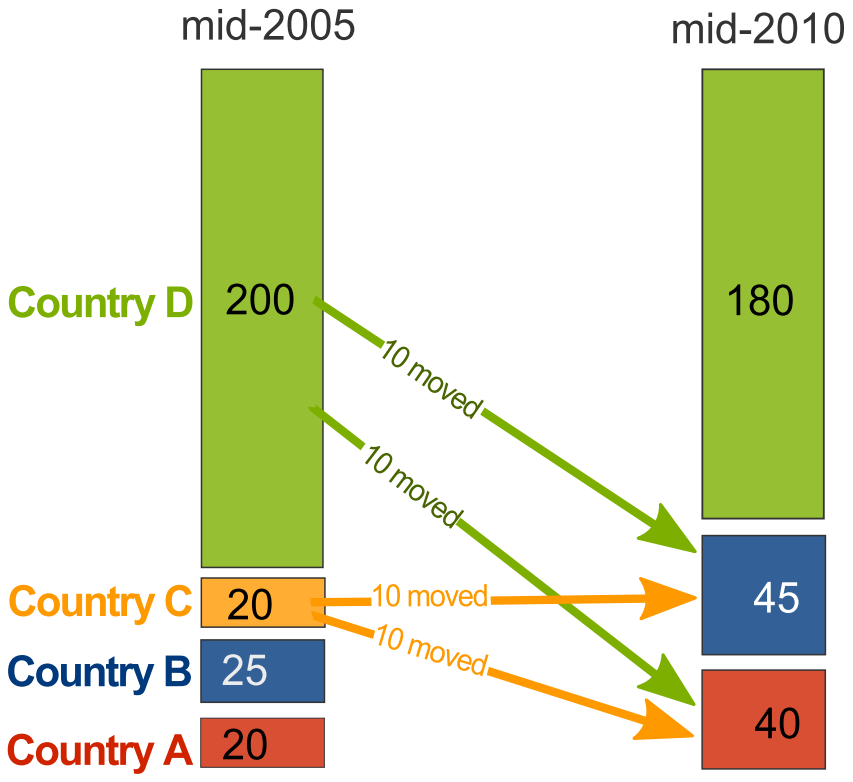
Aim

Derive a set of global migrant flow tables

- Use existing global migrant stock tables.
- Develop a flows from stock methodology.
- Account for natural change.
- Apply to United Nations stock data (1990-2010)
- Ensure net migration within the flow tables match to the United Nations net flows.

Framing migrant stock data in flow tables

Separate populations by their place of birth. Find the flows required to match the changes in place of residence...



Hypothetical stocks and flows for people born in Country D

Migrant Stock Data

Consider stock data where no natural change:

		Place of Residence (t)						*Place of Residence (t + 1)*				
		A	B	C	D	Sum		A	B	C	D	Sum
Birthplace	A	1000	100	10	0	1110	*Birthplace*	950	100	60	0	1110
	B	55	555	50	5	665		80	505	75	5	665
	C	80	40	800	40	960		90	30	800	40	960
	D	20	25	20	200	265		40	45	0	180	265
	Sum	1155	720	880	245	3000		1160	680	935	225	3000

- Column sums are total population
- Diagonal elements represent native born population

Migrant Stock Data

Consider stock data where no natural change:

Birthplace	*Place of Residence (t)* A	B	C	D	Sum
A	1000	100	10	0	1110
B	55	555	50	5	665
C	80	40	800	40	960
D	20	25	20	200	265
Sum	1155	720	880	245	3000

Birthplace	*Place of Residence (t + 1)* A	B	C	D	Sum
A	950	100	60	0	1110
B	80	505	75	5	665
C	90	30	800	40	960
D	40	45	0	180	265
Sum	1160	680	935	225	3000

- Row totals match over time (no births or deaths)
- Difference in table elements are due to migrations flows

Migrant Stock Data

Consider stock data where no natural change:

Birthplace	*Place of Residence (t)* A	B	C	D	Sum
A	1000	100	10	0	1110
B	55	555	50	5	665
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Sum	1160	680	935	225	3000

- People change their residence (column), not their birthplace (row)
- Birthplace (row) counts at t and $t + 1$ are margins in a flow table

Migrant Stock Data in Flow Tables

Birthplace=A

Origin \ *Destination*	A	B	C	D	Sum
A					1000
B					100
C					10
D					0
Sum	950	100	60	0	1110

Birthplace=B

Origin \ *Destination*	A	B	C	D	Sum
A					55
B					555
C					50
D					5
Sum	80	505	75	5	665

Birthplace=C

Origin \ *Destination*	A	B	C	D	Sum
A					80
B					40
C					800
D					40
Sum	90	30	800	40	960

Birthplace=D

Origin \ *Destination*	A	B	C	D	Sum
A					20
B					25
C					20
D					200
Sum	40	40	0	180	265

Missing Data

- The marginal totals (from the stock tables) are known.
- Missing:
  1. Missing non-diagonal elements represent the number of migrant transitions over the period required.
  2. Missing diagonal elements are the non-movers over the period.
- Migration is a rare event. Make a simple assumption of maximising the missing diagonals.
- Use model based methods for the non-diagonal elements.

Migrant Stock Data in Flow Tables

Birthplace=A

Origin \ *Destination*	A	B	C	D	Sum
A					1000
B					100
C					10
D					0
Sum	950	100	60	0	1110

Birthplace=B

Origin \ *Destination*	A	B	C	D	Sum
A					55
B					555
C					50
D					5
Sum	80	505	75	5	665

Birthplace=C

Origin \ *Destination*	A	B	C	D	Sum
A					80
B					40
C					800
D					40
Sum	90	30	800	40	960

Birthplace=D

Origin \ *Destination*	A	B	C	D	Sum
A					20
B					25
C					20
D					200
Sum	40	40	0	180	265

Migrant Stock Data in Flow Tables

Birthplace=A

Origin \ *Destination*	A	B	C	D	Sum
A	950				1000
B		100			100
C			10		10
D				0	0
Sum	950	100	60	0	1110

Birthplace=B

Origin \ *Destination*	A	B	C	D	Sum
A	55				55
B		505			555
C			50		50
D				5	5
Sum	80	505	75	5	665

Birthplace=C

Origin \ *Destination*	A	B	C	D	Sum
A	80				80
B		30			40
C			800		800
D				40	40
Sum	90	30	800	40	960

Birthplace=D

Origin \ *Destination*	A	B	C	D	Sum
A	20				20
B		25			25
C			0		20
D				180	200
Sum	40	40	0	180	265

Missing Flow Model

- Estimate the missing flows using a spatial interaction model:
- Commonly used in internal migration estimation literature:

$$y_{ij} = \alpha_i \beta_j m_{ij}$$

  - y_{ij} is the expected number of migrants in transition from origin i to destination j and $i, j = 1, 2, \ldots, R$ for R origins and destinations.
  - α_i and β_j parameters represent the background factors that are related to the characteristics of the origin and destination.
  - m_{ij} is an some auxiliary information on migration flows, such as inverse of distance.
- A spatial interaction model is a log-linear or Poisson regression model.

$$\log y_{ij} = \log \alpha_i + \log \beta_j + \log m_{ij}$$

Model Based Impuation

- We need a slightly modified version for our data array y_{ijk}:

$$\log y_{ijk} = \log \alpha_i + \log \beta_j + \log \lambda_k + \log \gamma_{ik} + \log \kappa_{jk} + \delta_{ijk} I(i = j) + \log m_{ij}$$

  - λ_k parameters represent background factors that related to the characteristics of each birthplace
  - γ_{ik} and κ_{jk} parameter sets represent the factors specific to each origin-birthplace and destination-birthplace specific combinations respectively.
  - δ_{ijk} is the parameter set of non-movers and $I(\cdot)$ is the indicator function,

$$I(i = j) = \begin{cases} 1 & \text{if } i = j \\ 0 & \text{if } i \neq j \end{cases}$$

- We can obtain the maximum likelihood estimate of all parameters in the model without the non-diagonal cells.
- Once we have estimated the parameters we can predict the non-diagonal cells.

Poisson Likelihood

- The probability of observing n_{ijk} migrant transitions during a unit interval, is given by the Poisson distribution function:

$$P(N_{ijk} = n_{ijk}) = \frac{y_{ijk}^{n_{ijk}}}{n_{ijk}!} \exp(-y_{ijk}).$$

- The likelihood function for $\mathbf{Y} = \{y_{ijk}, i, j, k = 1, \ldots, R\}$ given $\mathbf{n} = \{n_{ijk}, i, j, k = 1, \ldots, R\}$ migrant transitions, provided that migrant transitions are independent, is

$$\begin{aligned} L(\mathbf{Y}; \mathbf{n}) &= P(N_{111} = n_{111}, N_{121} = n_{121}, \ldots, N_{RRR} = n_{RRR}) \\ &= \prod_{ijk} \frac{y_{ijk}^{n_{ijk}}}{n_{ijk}!} \exp(-y_{ijk}) \\ l(\mathbf{Y}; \mathbf{n}) &= \sum_{ijk} \{n_{ijk} \log(y_{ijk}) - y_{ijk} - \log(n_{ijk}!)\} \end{aligned}$$

Poisson Log-Likelihood

The log-likelihood function corresponding to the spatial interaction model, where for simplicity δ_{ijk} is now referred to as δ_{iik}, is

$$
\begin{aligned}
l(\boldsymbol{\theta}; \mathbf{n}) &= \sum_{ijk} \{ n_{ijk} \log(\alpha_i \beta_j \lambda_k \gamma_{ik} \kappa_{jk} \delta_{iik} m_{ij}) - \alpha_i \beta_j \lambda_k \gamma_{ik} \kappa_{jk} \delta_{iik} m_{ij} - \log(n_{ijk}!) \} \\
&= \sum_i n_{i++} \log(\alpha_i) + \sum_j n_{+j+} \log(\beta_j) + \sum_k n_{++k} \log(\lambda_j) \\
&\quad + \sum_{ik} n_{i+k} \log(\gamma_{ik}) + \sum_{jk} n_{+jk} \log(\kappa_{jk}) + \sum_{ijk} n_{ijk} \log(\delta_{iik}) \\
&\quad - \sum_{ijk} \alpha_i \beta_j \lambda_k \gamma_{ik} \kappa_{jk} \delta_{iik} m_{ij} + c,
\end{aligned}
$$

where $\boldsymbol{\theta} = \{\alpha_i, \beta_j, \lambda_k, \gamma_{ik}, \kappa_{jk}, \delta_{iik}, i, j, k = 1, \ldots, R\}$ and

$$
c = \sum_{ijk} n_{ijk} \log(m_{ij}) - \sum_{ijk} \log(n_{ijk}!).
$$

Partial Differentials

Differentiation of the likelihood function with respect to each parameter gives the likelihood equations:

$$\frac{\partial l}{\partial \alpha_i} = \frac{n_{i++}}{\alpha_i} - \sum_{jk} \beta_j \lambda_k \gamma_{ik} \kappa_{jk} \delta_{iik} m_{ij} = 0, \quad \frac{\partial l}{\partial \gamma_{ik}} = \frac{n_{i+k}}{\gamma_{ik}} - \sum_{j} \alpha_i \beta_j \lambda_k \kappa_{jk} \delta_{iik} m_{ij} = 0,$$

$$\frac{\partial l}{\partial \beta_j} = \frac{n_{+j+}}{\beta_j} - \sum_{ik} \alpha_i \lambda_k \gamma_{ik} \kappa_{jk} \delta_{iik} m_{ij} = 0, \quad \frac{\partial l}{\partial \kappa_{jk}} = \frac{n_{+jk}}{\kappa_{jk}} - \sum_{i} \alpha_i \beta_j \lambda_k \gamma_{ik} \delta_{iik} m_{ij} = 0,$$

$$\frac{\partial l}{\partial \lambda_k} = \frac{n_{++k}}{\lambda_k} - \sum_{ij} \alpha_i \beta_j \gamma_{ik} \kappa_{jk} \delta_{iik} m_{ij} = 0, \quad \frac{\partial l}{\partial \delta_{iik}} = \frac{n_{ijk}}{\delta_{iik}} - \alpha_i \beta_j \lambda_k \kappa_{jk} \gamma_{ik} m_{ij} = 0,$$

Iterative Soloution

The likelihood equations can be used to derive maximum likelihood estimators for $\hat{\boldsymbol{\theta}} = (\hat{\alpha}_i, \hat{\beta}_j, \hat{\lambda}_k, \hat{\gamma}_{ik}, \hat{\kappa}_{jk}, \hat{\delta}_{iik})$;

$$\hat{\alpha}_i = \frac{n_{i++}}{\sum_{jk} \hat{\beta}_j \hat{\lambda}_k \hat{\gamma}_{ik} \hat{\kappa}_{jk} \hat{\delta}_{iik} m_{ij}}, \quad \hat{\gamma}_{ik} = \frac{n_{i+k}}{\sum_{j} \hat{\alpha}_i \hat{\beta}_j \hat{\lambda}_k \hat{\kappa}_{jk} \hat{\delta}_{iik} m_{ij}}$$

$$\hat{\beta}_j = \frac{n_{+j+}}{\sum_{ik} \hat{\alpha}_i \hat{\lambda}_k \hat{\gamma}_{ik} \hat{\kappa}_{jk} \hat{\delta}_{iik} m_{ij}}, \quad \hat{\kappa}_{jk} = \frac{n_{+jk}}{\sum_{i} \hat{\alpha}_i \hat{\beta}_j \hat{\lambda}_k \hat{\gamma}_{ik} \hat{\delta}_{iik} m_{ij}}$$

$$\hat{\lambda}_k = \frac{n_{++k}}{\sum_{ij} \hat{\alpha}_i \hat{\beta}_j \hat{\gamma}_{ik} \hat{\kappa}_{jk} \hat{\delta}_{iik} m_{ij}}, \quad \hat{\delta}_{iik} = \frac{n_{ijk}}{\hat{\alpha}_i \hat{\beta}_j \hat{\lambda}_k \hat{\gamma}_{ik} \hat{\kappa}_{jk} m_{ij}}$$

Which require only the marginal totals, (n_{i++}, n_{+j+}, n_{++k}, n_{i+k} and n_{+jk}) and the diagonal values (n_{ijk}, where $i = j$).

Iterative Soloution

Can be solved using an IPF algorithm with six sub-steps for each parameter:

$$\hat{\alpha}_i^{(1)} = \frac{n_{i++}}{\sum_{jk} \hat{\beta}_j^{(0)} \hat{\lambda}_k^{(0)} \hat{\gamma}_{ik}^{(0)} \hat{\kappa}_{jk}^{(0)} \hat{\delta}_{iik}^{(0)} m_{ij}}, \quad \hat{\gamma}_{ik}^{(4)} = \frac{n_{i+k}}{\sum_{j} \hat{\alpha}_i^{(1)} \hat{\beta}_j^{(2)} \hat{\lambda}_k^{(3)} \hat{\kappa}_{jk}^{(0)} \hat{\delta}_{iik}^{(0)} m_{ij}}$$

$$\hat{\beta}_j^{(2)} = \frac{n_{+j+}}{\sum_{ik} \hat{\alpha}_i^{(1)} \hat{\lambda}_k^{(0)} \hat{\gamma}_{ik}^{(0)} \hat{\kappa}_{jk}^{(0)} \hat{\delta}_{iik}^{(0)} m_{ij}}, \quad \hat{\kappa}_{jk}^{(5)} = \frac{n_{+jk}}{\sum_{i} \hat{\alpha}_i^{(1)} \hat{\beta}_j^{(2)} \hat{\lambda}_k^{(3)} \hat{\gamma}_{ik}^{(4)} \hat{\delta}_{iik}^{(0)} m_{ij}}$$

$$\hat{\lambda}_k^{(3)} = \frac{n_{++k}}{\sum_{ij} \hat{\alpha}_i^{(1)} \hat{\beta}_j^{(2)} \hat{\gamma}_{ik}^{(0)} \hat{\kappa}_{jk}^{(0)} \hat{\delta}_{iik}^{(0)} m_{ij}}, \quad \hat{\delta}_{iik}^{(6)} = \frac{n_{ijk}}{\hat{\alpha}_i^{(1)} \hat{\beta}_j^{(2)} \hat{\lambda}_k^{(3)} \hat{\gamma}_{ik}^{(4)} \hat{\kappa}_{jk}^{(5)} m_{ij}}$$

A new cycle commences using the last set of parameter estimates, $\hat{\alpha}_i^{(7)} = n_{i++} \Big/ \sum_{jk} \hat{\beta}_j^{(2)} \hat{\lambda}_k^{(3)} \hat{\gamma}_{ik}^{(4)} \hat{\kappa}_{jk}^{(5)} \hat{\delta}_{iik}^{(6)} m_{ij}$, and so on.

Estimate Missing Using Log-linear Model

Birthplace=A

Origin \ *Destination*	A	B	C	D	Sum
A	950				1000
B		100			100
C			10		10
D				0	0
Sum	950	100	60	0	1110

Birthplace=B

Origin \ *Destination*	A	B	C	D	Sum
A	55				55
B		505			555
C			50		50
D				5	5
Sum	80	505	75	5	665

Birthplace=C

Origin \ *Destination*	A	B	C	D	Sum
A	80				80
B		30			40
C			800		800
D				40	40
Sum	90	30	800	40	960

Birthplace=D

Origin \ *Destination*	A	B	C	D	Sum
A	20				20
B		25			25
C			0		20
D				180	200
Sum	40	45	0	180	265

Estimate Missing Using Log-linear Model

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Origin \ *Destination*	A	B	C	D	Sum
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B	0	100	0	0	100
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Birthplace=B

Origin \ *Destination*	A	B	C	D	Sum
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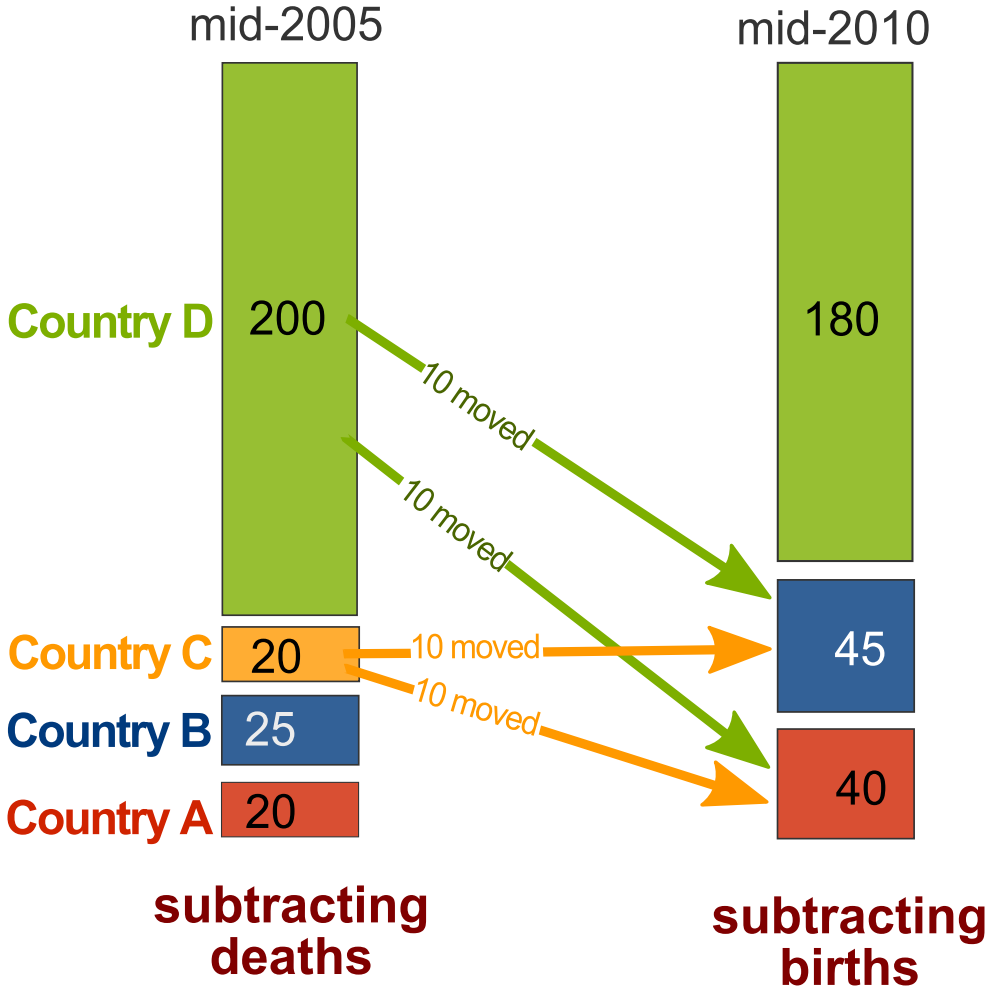
Flow Table

		Destination				
		A	B	C	D	Sum
Origin	A		0	50	0	50
	B	35		25	0	60
	C	10	10		0	20
	D	10	10	0		20
	Sum	55	20	75	0	150

Accounting for births and deaths

Need to avoid estimating moves of dead or not yet born people...



Migrant Stock Data with Natural Change

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Sum	1155	720	880	245	3000

Birthplace	*Place of Residence* ($t+1$) A	B	C	D	Sum
A	1060	60	10	10	1140
B	45	540	40	0	625
C	70	75	770	70	985
D	30	30	20	230	310
Sum	1205	705	840	310	3060

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Demographic Data:

	Deaths $(t, t+1)$ A	B	C	D
Sum	70	30	50	10

	Births $(t, t+1)$ A	B	C	D
Sum	80	20	60	60

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Birthplace	*Deaths* $(t, t+1)$ A	B	C	D
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Sum	1205	705	840	310	3060

Demographic Data:

Birthplace	*Deaths* $(t, t+1)$ A	B	C	D
A	60.6	4.2	0.6	0
B	3.3	23.1	2.8	0.2
C	4.9	1.7	45.5	1.6
D	1.2	1	1.1	8.2
Sum	70	30	50	10

	Births $(t, t+1)$ A	B	C	D
Sum	80	20	60	60

Migrant Stock Data with Natural Change

Migrant Stock Data with Natural Change:

Birthplace	*Place of Residence* (t) A	B	C	D	Sum
A	1000	100	10	0	1110
B	55	555	50	5	665
C	80	40	800	40	960
D	20	25	20	200	265
Sum	1155	720	880	245	3000

Birthplace	*Place of Residence* $(t+1)$ A	B	C	D	Sum
A	1060	60	10	10	1140
B	45	540	40	0	625
C	70	75	770	70	985
D	30	30	20	230	310
Sum	1205	705	840	310	3060

Demographic Data:

Birthplace	*Deaths* $(t, t+1)$ A	B	C	D
A	60.6	4.2	0.6	0
B	3.3	23.1	2.8	0.2
C	4.9	1.7	45.5	1.6
D	1.2	1	1.1	8.2
Sum	70	30	50	10

Birthplace	*Births* $(t, t+1)$ A	B	C	D
A				
B				
C				
D				
Sum	80	20	60	60

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Sum	70	30	50	10

Birthplace	*Births* $(t, t+1)$ A	B	C	D
A	80	0	0	0
B	0	20	0	0
C	0	0	60	0
D	0	0	0	60
Sum	80	20	60	60

Correct for Births and Deaths

Migrant Stock Data Altered for Natural Change:

Birthplace	*Place of Residence (t)* A	B	C	D	Sum
A	939.4	95.8	9.4	0	1044.7
B	51.7	531.9	47.2	4.8	635.5
C	75.2	38.3	754.5	38.4	906.4
D	18.8	24	18.9	191.8	253.4
Sum	1085	690	830	235	2840

Birthplace	*Place of Residence (t + 1)* A	B	C	D	Sum
A	980	60	10	10	1060
B	45	520	40	0	605
C	70	75	710	70	925
D	30	30	20	170	250
Sum	1125	685	780	250	2840

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Average Across Row Differences:

Birthplace	*Place of Residence (t)* A	B	C	D	Sum
A					
B					
C					
D					
Sum					

Birthplace	*Place of Residence (t + 1)* A	B	C	D	Sum
A					
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Estimated Flow Table:

Origin	*Destination* A	B	C	D	Sum
A		3.3	0	3.2	6.6
B	34.1		0.6	9.8	44.5
C	0	27.1		25.7	52.8
D	12.4	9.7	2.3		23.8
Sum	46.6	39.5	1.8	38.8	127.7

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	P^{t+1}
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C	840
D	310
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	P^{t+1}	$-P^t$	$+D$
A	1205	1155	70
B	705	720	30
C	840	880	50
D	310	245	10
Sum	3060	3000	160

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	P^{t+1}	$-P^t$	$+D$	$-B$
A	1205	1155	70	80
B	705	720	30	20
C	840	880	50	60
D	310	245	10	60
Sum	3060	3000	160	220

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	P^{t+1}	$-P^t$	$+D$	$-B$	=Net
A	1205	1155	70	80	40
B	705	720	30	20	-5
C	840	880	50	60	-50
D	310	245	10	60	15
Sum	3060	3000	160	220	0

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Application: *Science* (2014)

United Nations global bilateral migrant stock database for the last three census rounds

- Complete bilateral stock tables
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Apply flows to stock methodology:

- Replicated UN interpolations to obtain mid-decade stock tables.
- Use stock tables at start and end of each decade period to estimate 4 bilateral flow tables (1990-95, 1995-2000, 2000-05, 2005-10) between 197 countries.
- Inverse of distance matrix for offset term, m_{ij}
- Estimate are of 5-year migrant transition flows.

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- Gravity models at the global level return plausible parameters.

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- Global intensity of migration has not been continuously upwards

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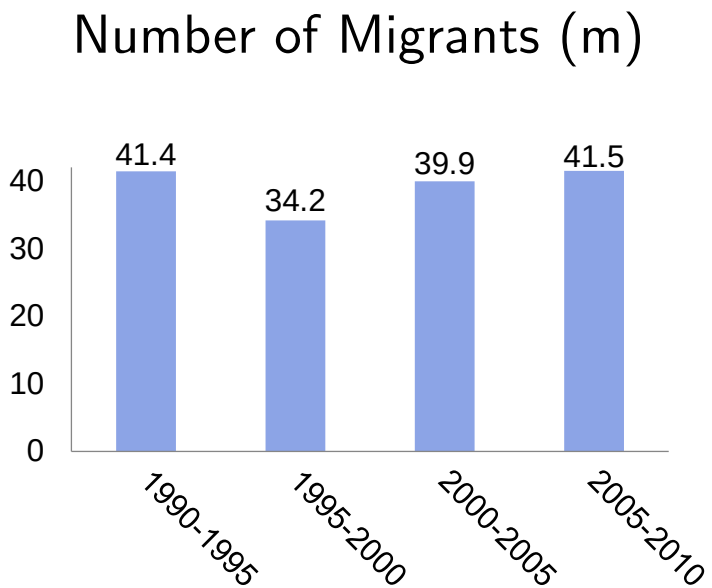

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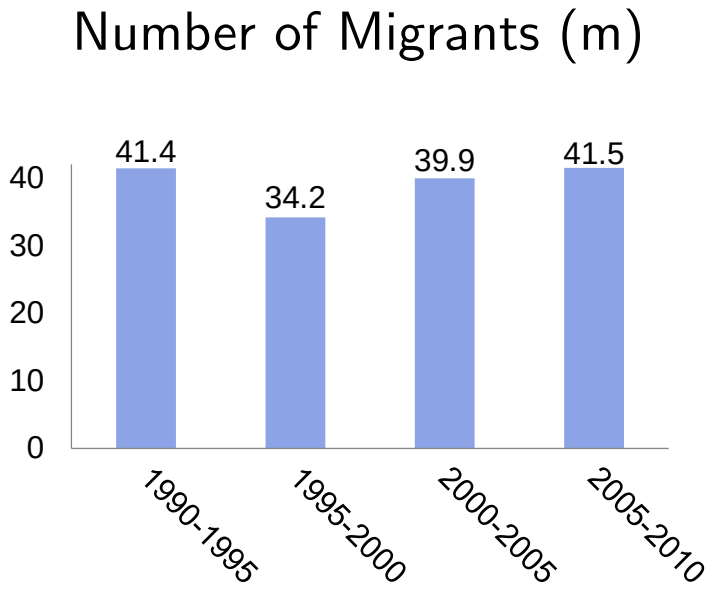

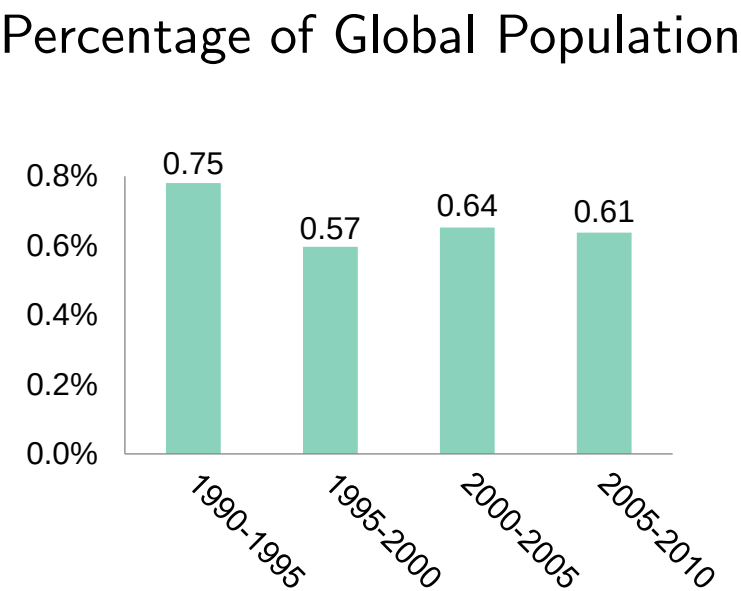

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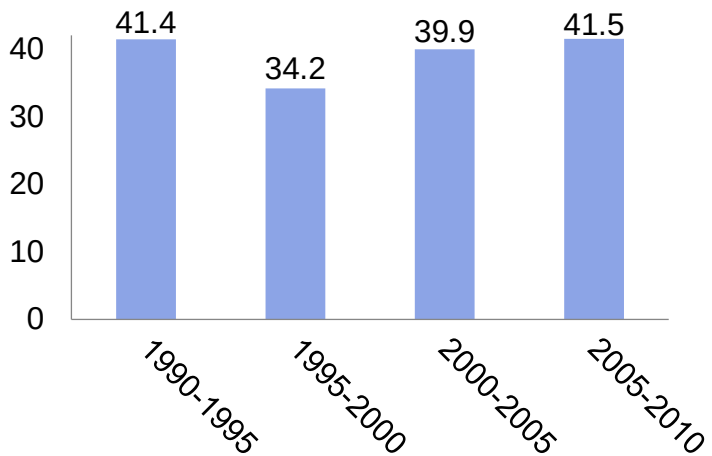
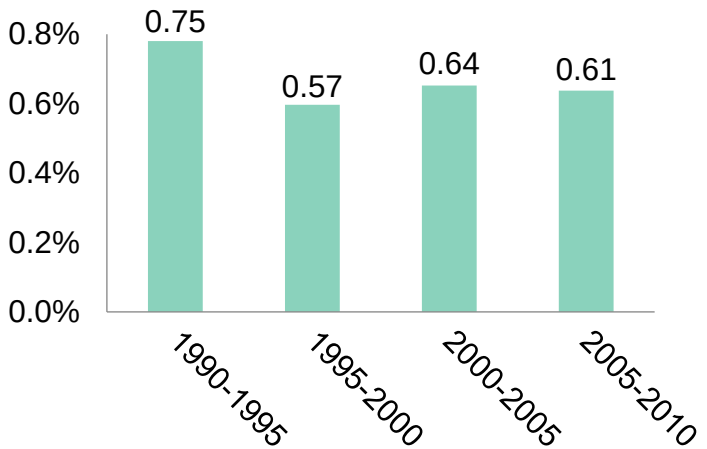


Percentage of Global Population



Global Flow Trends

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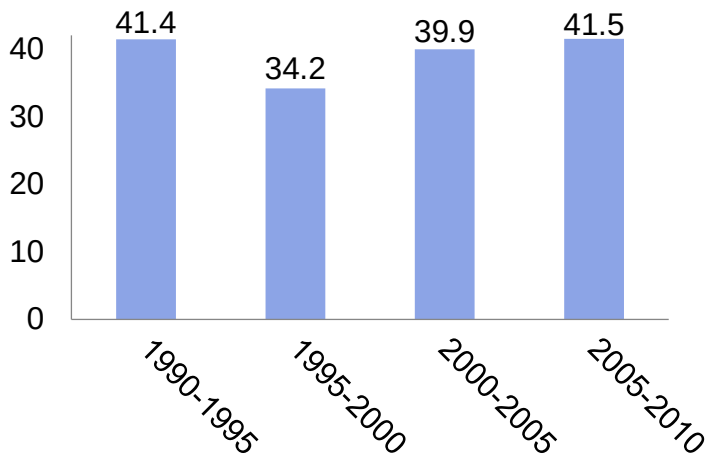
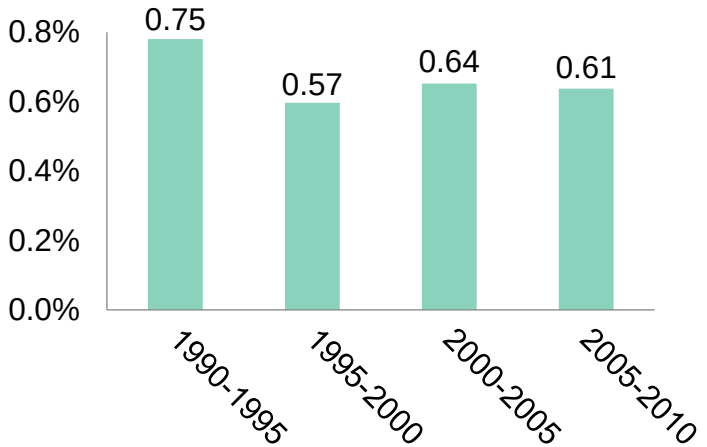
- Around 0.6% of the world's population move over 5-year periods
- Higher intensities in 1990-95 mostly due to violent conflicts in Afghanistan and Rwanda. Fall of Iron Curtain.

Number of Migrants (m)

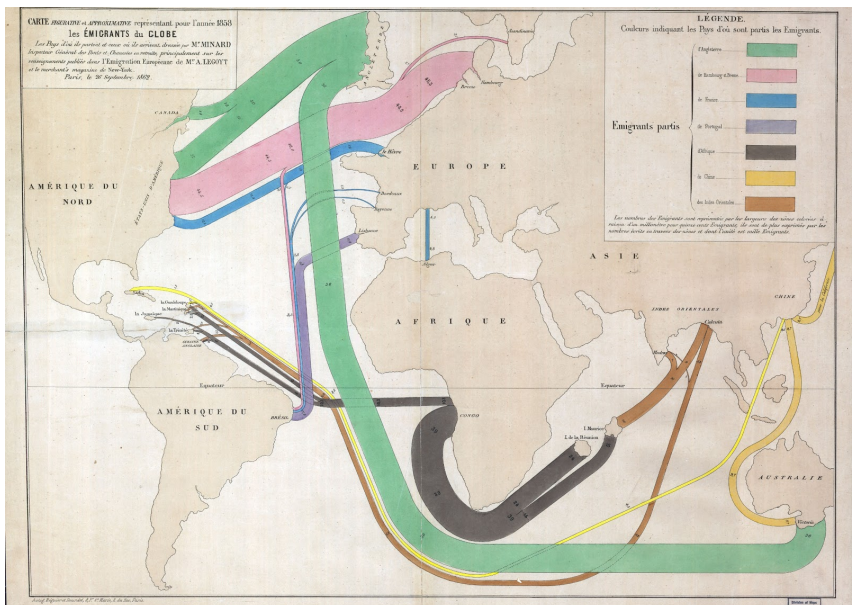


Percentage of Global Population

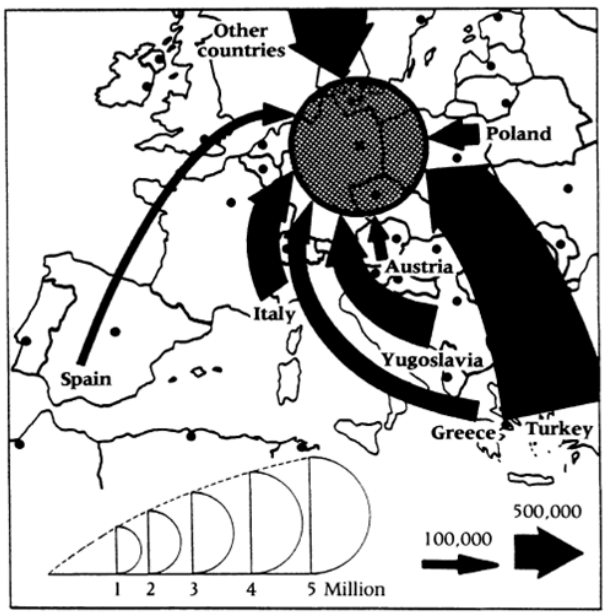


Visualizing International Migration Flows: Previous Approaches

The Emigrants of the World, 1858.
By Charles Joseph Minard



Germany Foreign Born Population, 1990.
By Fassmann & Münz



Circular Migration Plot for World Regions, 2005-10

rregion0.pdf

Circular Migration Plot for World Regions, 2005-10

rregion.pdf

Circular Plot for Key Senders and Receivers, 2005-10

rcountry.pdf

Interactive Data Visualisation

http://www.global-migration.info

Developed together with Null2, Berlin

Summary

Developed a flow from stock estimation method and applied to global migrant stock tables.

- Provides first estimates of global migration flow tables.
- At an aggregated level results seem plausible.
- Estimates suggest a stable rate of global migration since 1990.
- Circular migration plots clearly convey the complexities of migration.

Summary

Developed a flow from stock estimation method and applied to global migrant stock tables.

- Provides first estimates of global migration flow tables.
- At an aggregated level results seem plausible.
- Estimates suggest a stable rate of global migration since 1990.
- Circular migration plots clearly convey the complexities of migration.

Current work on:

- Applying method to longer series. Identified some implausible stocks or demographic data.
- Different specifications of migration in a global population projection model. Distinctly different forecasts for developed world countries using constant immigration and emigration rates, compared to net migration counts.

Acknowledgements

More details in:

- Abel, G. J., and Sander, N. (2014). Quantifying Global International Migration Flows. *Science*, 343 (6178), 15201522. doi:10.1126/science.1248676
- Abel, G. J. (2013). Estimating global migration flow tables using place of birth data. *Demographic Research* 28 (18) 505-546. doi:10.4054/DemRes.2013.28.18
- Flow from stock estimation done in R using the `ffs` function in the *migest* package (on CRAN).

Thank you for listening!

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