Quantifying Global International Migration Flows

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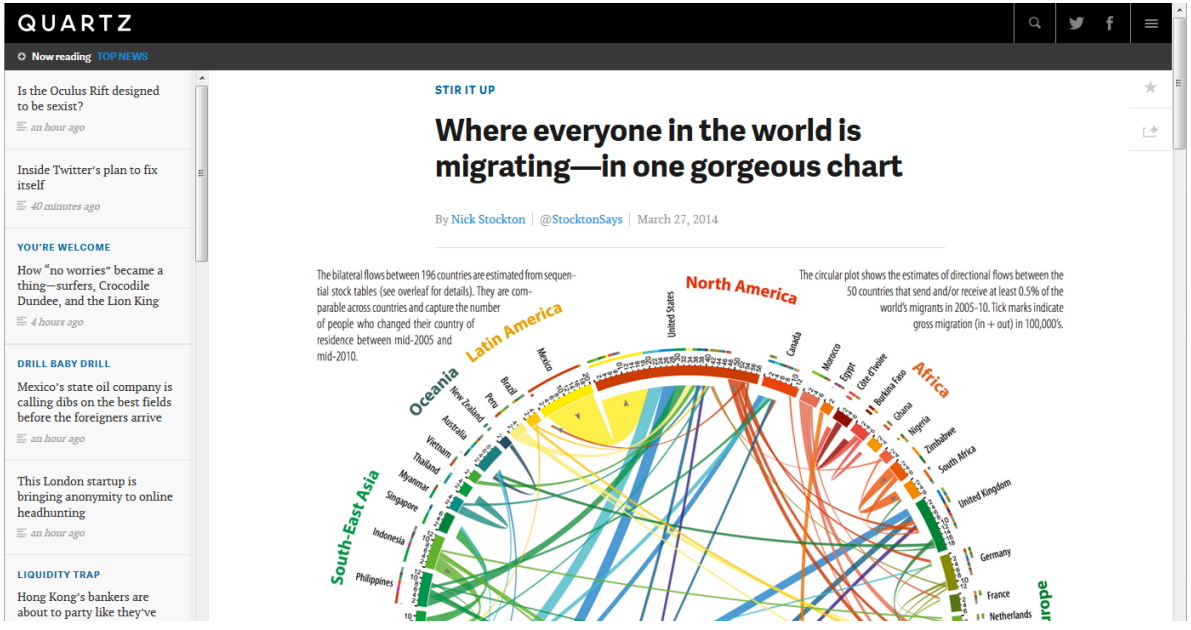
Motivations for Quantifying Global Migration Flows

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



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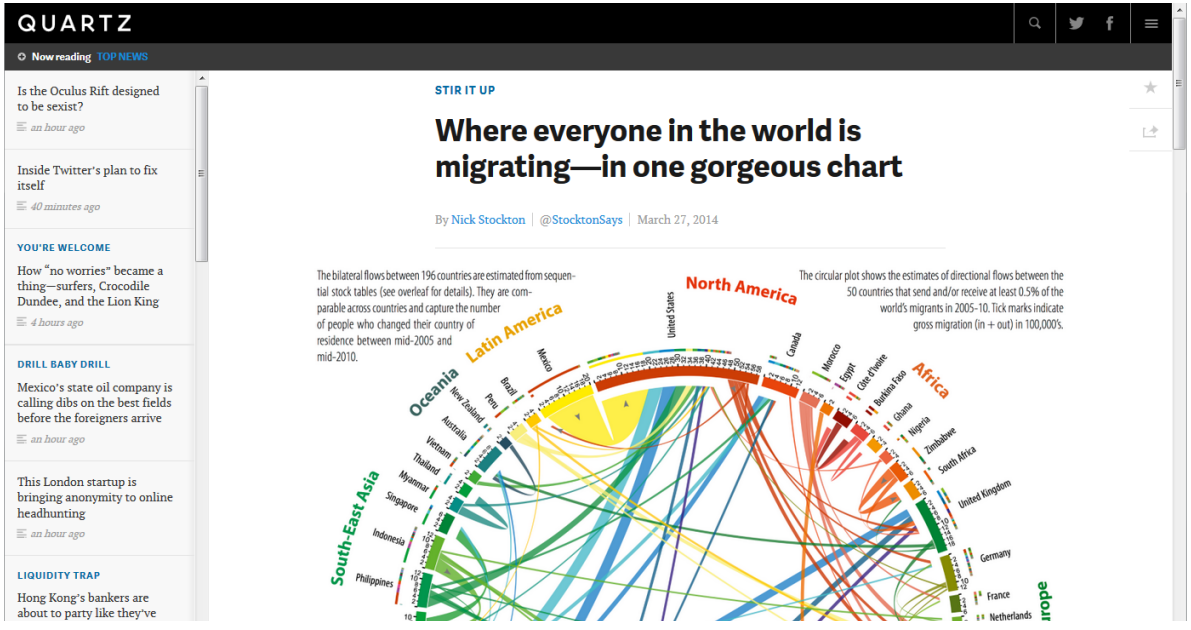

Motivations for Quantifying Global Migration Flows

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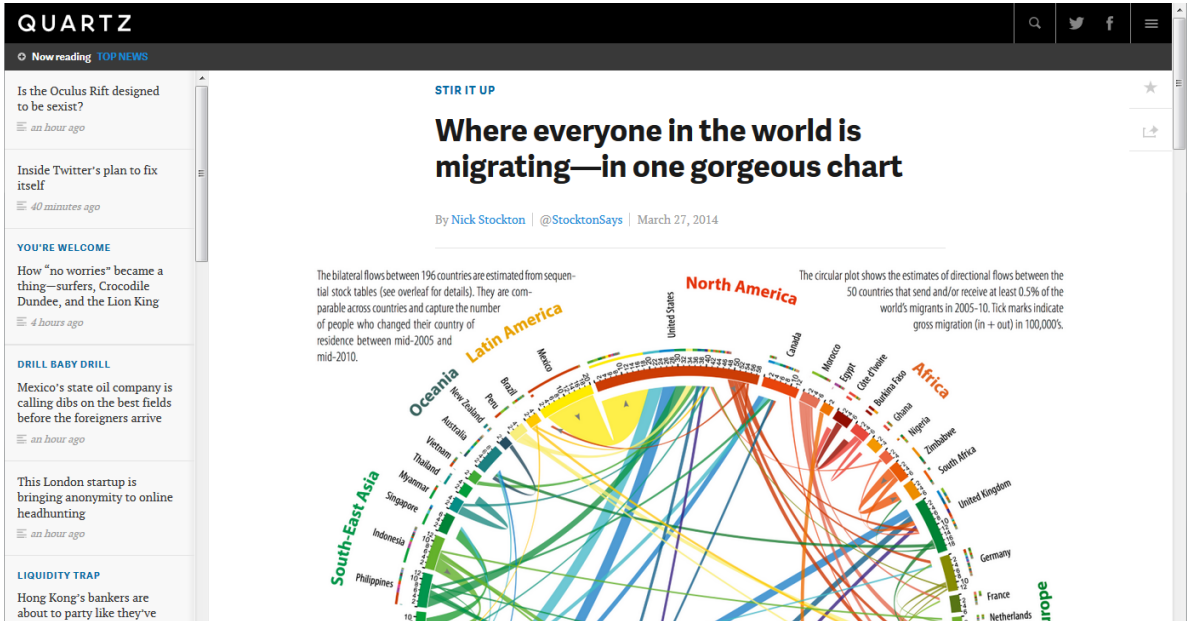
- Dynamic flow data are trickier.
- It's been hard to get a glimpse of where people move to and from
- Lack of understanding of patterns & trends, giving rise to speculations.



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- Stocks are numbers of migrants living in a country at a point in time
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- Stocks are static, easy to define, and collected in censuses.
- Flows are dynamic, difficult to define, and collected by registers & surveys.

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- They are plentiful in Europe, but sparse everywhere else.
- Flows can also be measured as **transitions**.
- $->$ number of people changing residence between 2 points in time.
- **Be warned:** events and transitions cannot be compared.

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- The UN recently published global bilateral stock tables for 1990, 2000 & 2010.

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- The UN recently published global bilateral stock tables for 1990, 2000 & 2010.

- Stocks cannot capture contemporary patterns & trends.

- But the new data allow indirect estimation of global flows.

Linking migrant flow to stock data

- A simplified example for people born in Country D.
- 5-year migration flows are estimated from changes in stocks between 2005 and 2010.

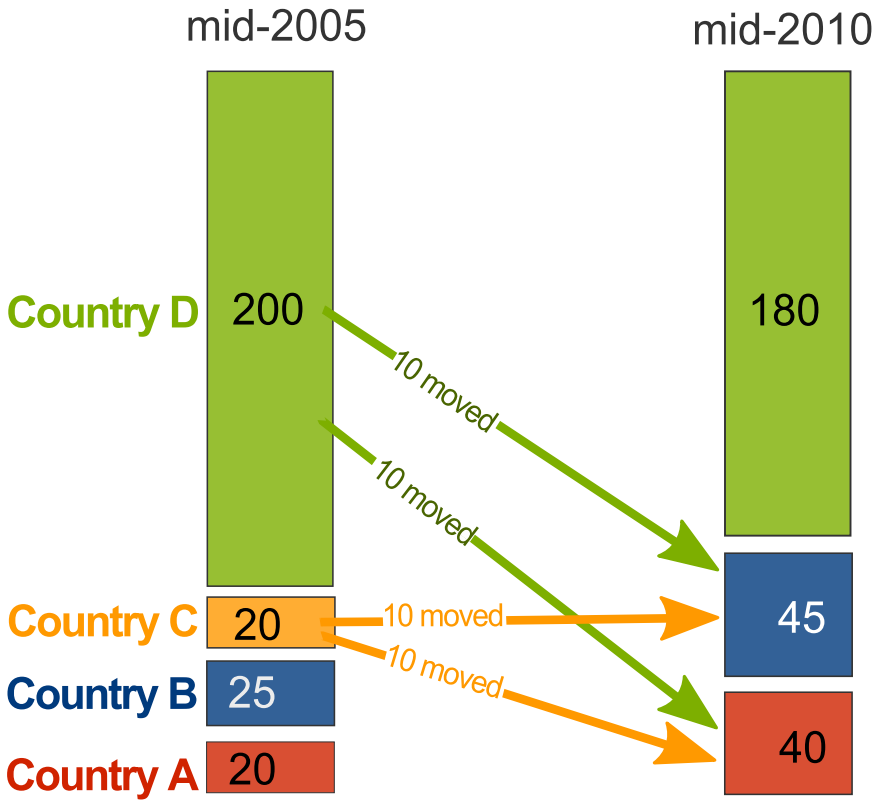

Figure source: Science Vol.343 (6178)

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

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

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

- 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:

		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

- People change their residence (column), not their birthplace (row).
- Birthplace (row) populations 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 non-diagonal elements represent the number of migrant transitions over the period required.
- 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:
- Internal migration estimation based on simple models:

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

  - 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.

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

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

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

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 by iteration using six steps for each parameter set:

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

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

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

Conditional maximization of the likelihood function and converges to give estimates of all the parameters in $\boldsymbol{\theta}$.

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
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
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
Sum	90	30	800	40	960

Birthplace=D

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

Estimate Missing Using Log-linear Model

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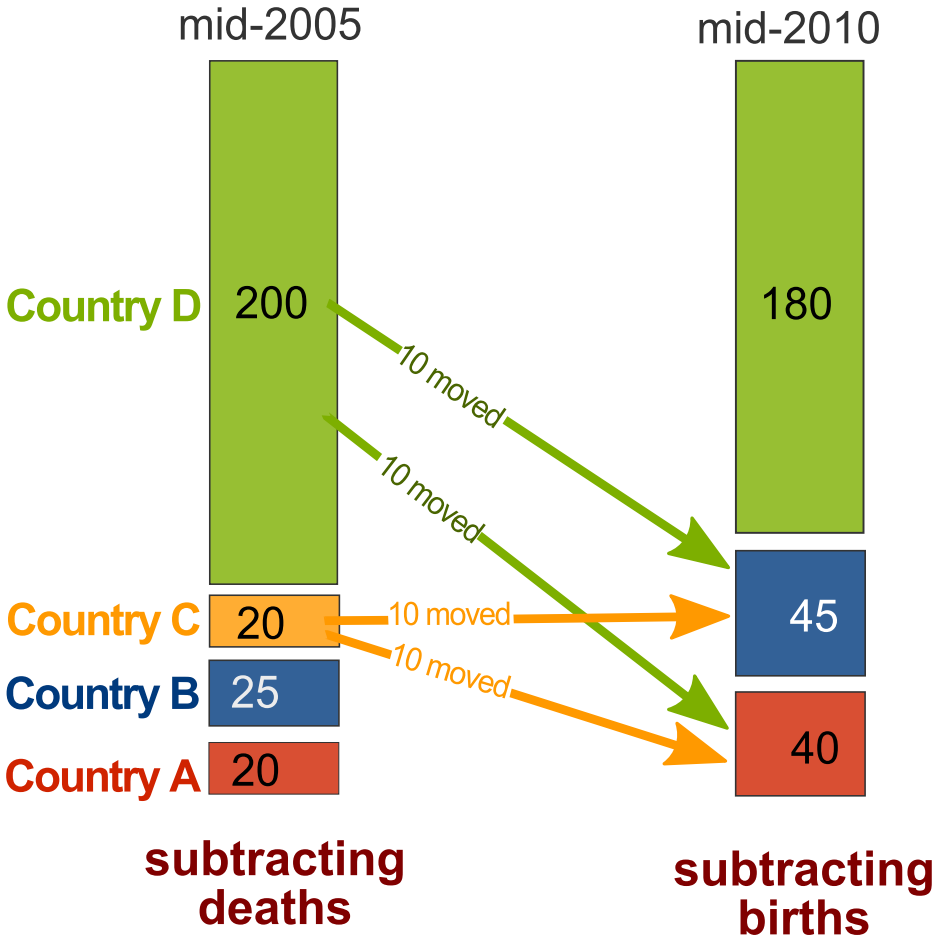
Flow Table

		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



To avoid estimating moves of dead or not yet born people.

Figure source: Science Vol.343 (6178)

Migrant Stock Data with Natural Change

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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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Demographic Data:

Deaths $(t, t+1)$

Birthplace	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:

Place of Residence (t)

Birthplace	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

Place of Residence $(t+1)$

Birthplace	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:

Deaths $(t, t+1)$

Birthplace	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 $(t, t+1)$

Birthplace	A	B	C	D
A				
B				
C				
D				
Sum	80	20	60	60

Migrant Stock Data with Natural Change

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D	1.2	1	1.1	8.2
Sum	70	30	50	10

Births $(t, t+1)$

Birthplace	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:

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

		Place of Residence (t + 1)				
		A	B	C	D	Sum
Birthplace	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					
B					
C					
D					
Sum					

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Average Across Row Differences:

Birthplace	*Place of Residence (t)* A	B	C	D	Sum
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B					620.2
C					915.7
D					251.7
Sum					

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Birthplace	*Place of Residence (t + 1)* A	B	C	D	Sum
A	976.1	56.5	9.9	9.8	1052.3
B	48.4	528.8	43	0	620.2
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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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Demographic Accounting:

	P^{t+1}
A	1205
B	705
C	840
D	310
Sum	3060

Altered Migrant Stock Data and Estimated Flows

Altered Migrant Stock Data:

Place of Residence (t)

Birthplace	A	B	C	D	Sum
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	P^{t+1}	$-P^{t}$
A	1205	1155
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Sum	3060	3000

Altered Migrant Stock Data and Estimated Flows

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A	942	101	9.4	0	1052.3
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Sum	46.6	39.5	1.8	38.8	127.7

Demographic Accounting:

	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

Altered Migrant Stock Data and Estimated Flows

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Birthplace	*Place of Residence (t)* A	B	C	D	Sum
A	942	101	9.4	0	1052.3
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Sum	46.6	39.5	1.8	38.8	127.7

Demographic Accounting:

	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

Altered Migrant Stock Data and Estimated Flows

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Birthplace	*Place of Residence (t)* A	B	C	D	Sum
A	942	101	9.4	0	1052.3
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Demographic Accounting:

	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

Altered Migrant Stock Data and Estimated Flows

Altered Migrant Stock Data:

Birthplace \ Place of Residence (t)	A	B	C	D	Sum
A	942	101	9.4	0	1052.3
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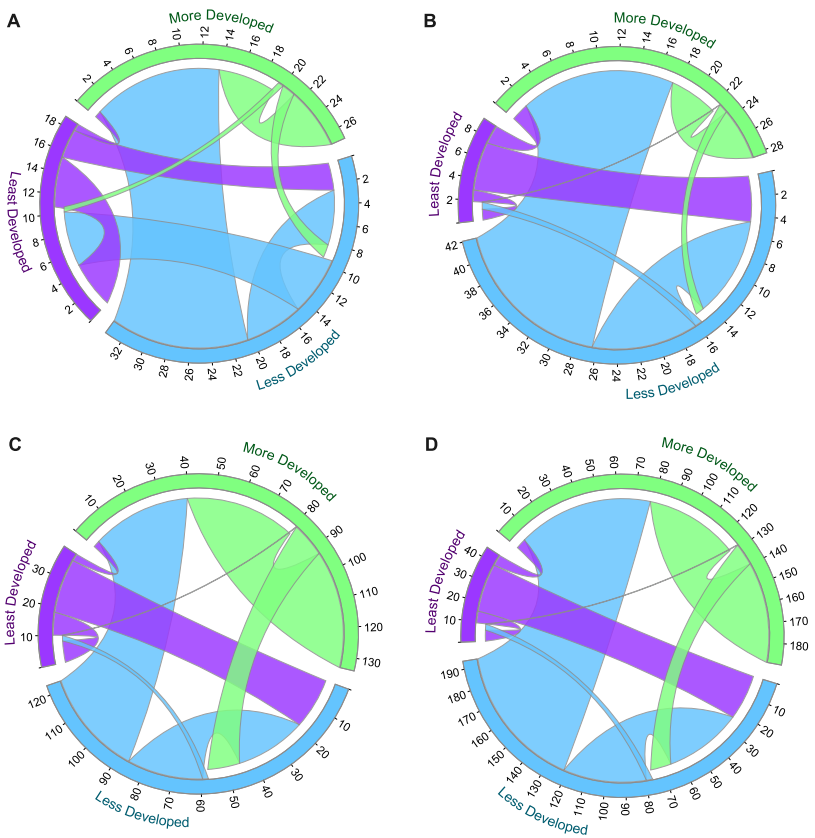
- **Gravity models** at the global level return plausible parameters.
- Comparing with **UN stocks** that our estimates are based upon:



A: flows 1990-95

B: flows 2005-10

C: stocks 1990

D: stocks 2010

Figure source: Science Vol.343 (6178)

Estimated global intensity of migration flows

- global intensity of migration has not been continuously upwards

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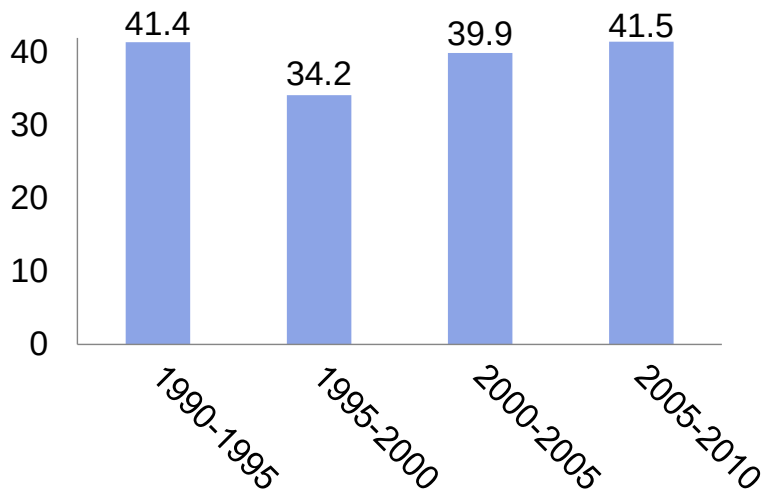

Number of migrants, in millions

Estimated global intensity of migration flows

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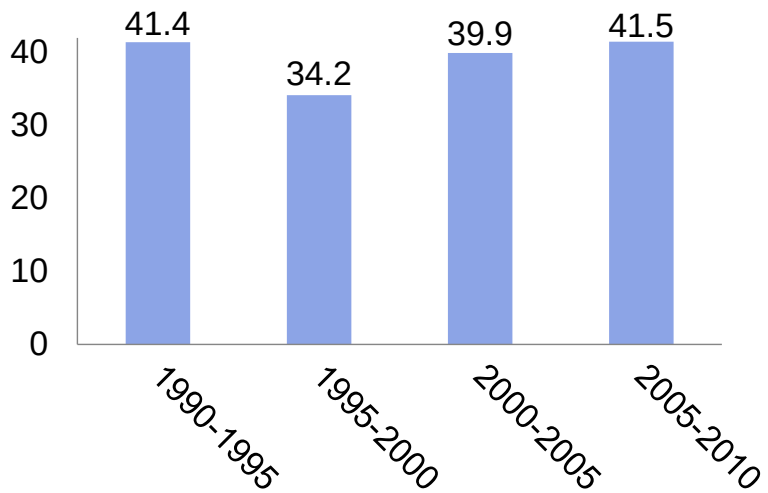

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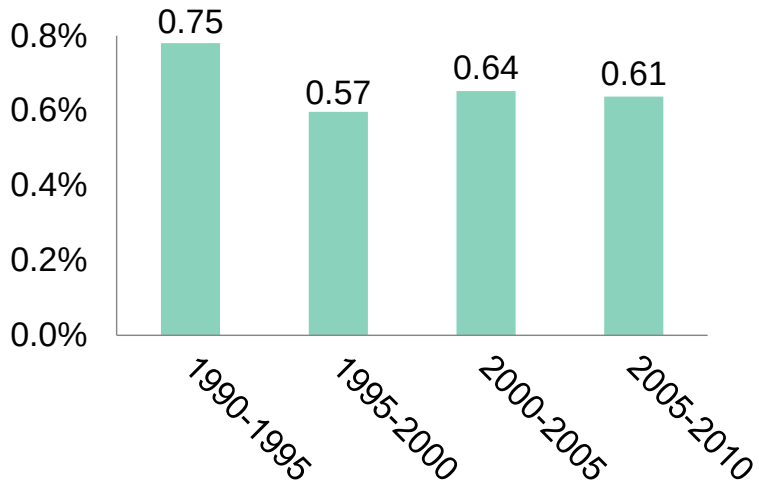
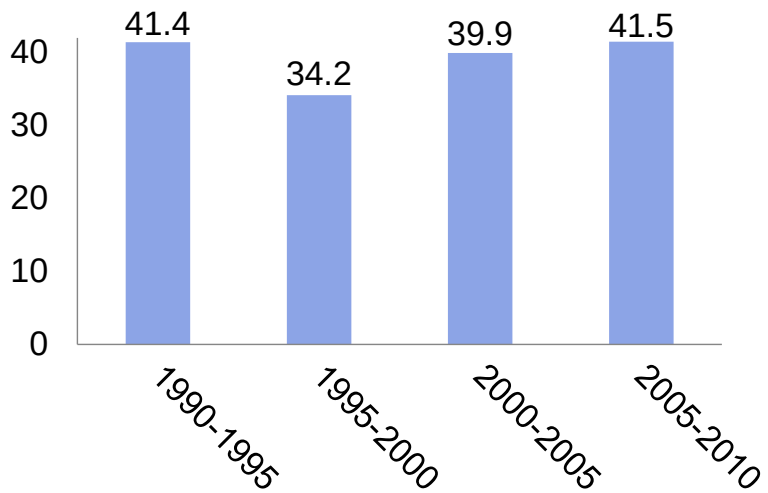


% of world population

Estimated global intensity of migration flows

- global intensity of migration has not been continuously upwards
- around 0.6% of the world's population move over 5-year periods



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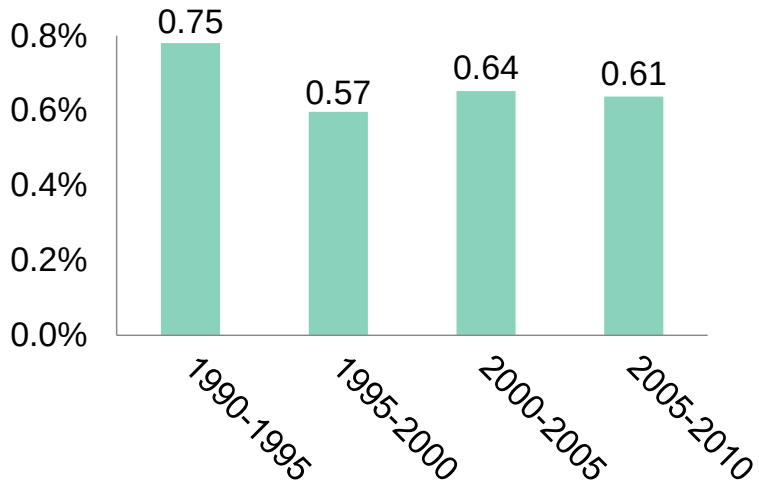

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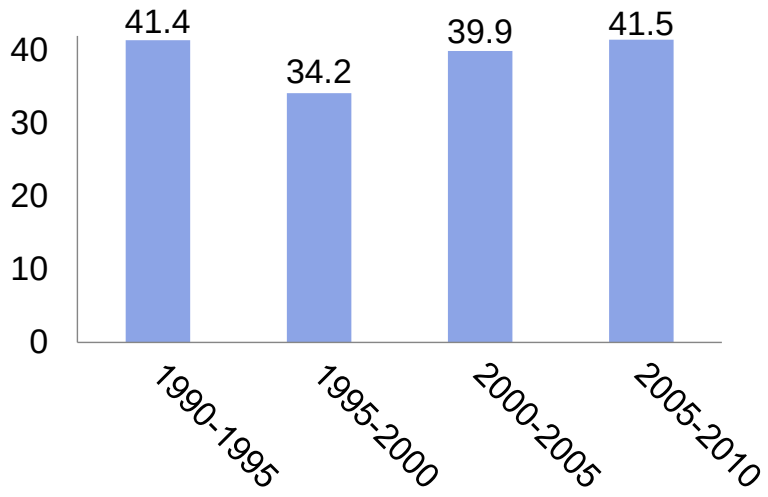
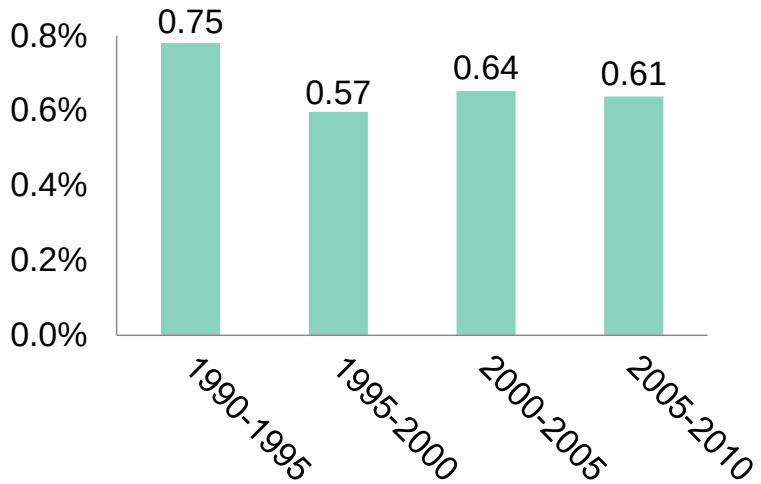
Estimated global intensity of migration flows

- global intensity of migration has not been continuously upwards
- 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

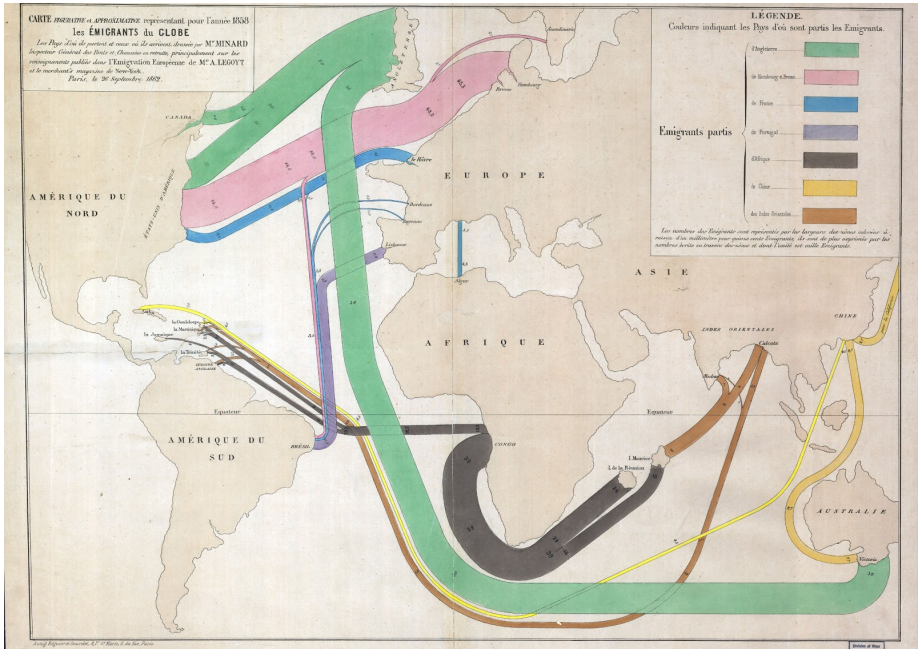


Number of migrants, in millions

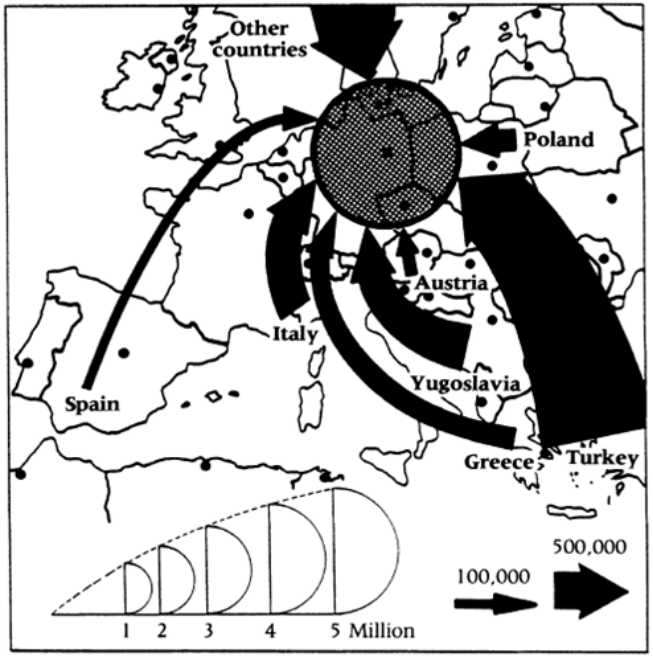


% of world population

Visualizing migration flow data: earlier approaches



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



Foreign population in Germany,
1990. By Fassmann & Münz

Introducing the Circular Migration Plot

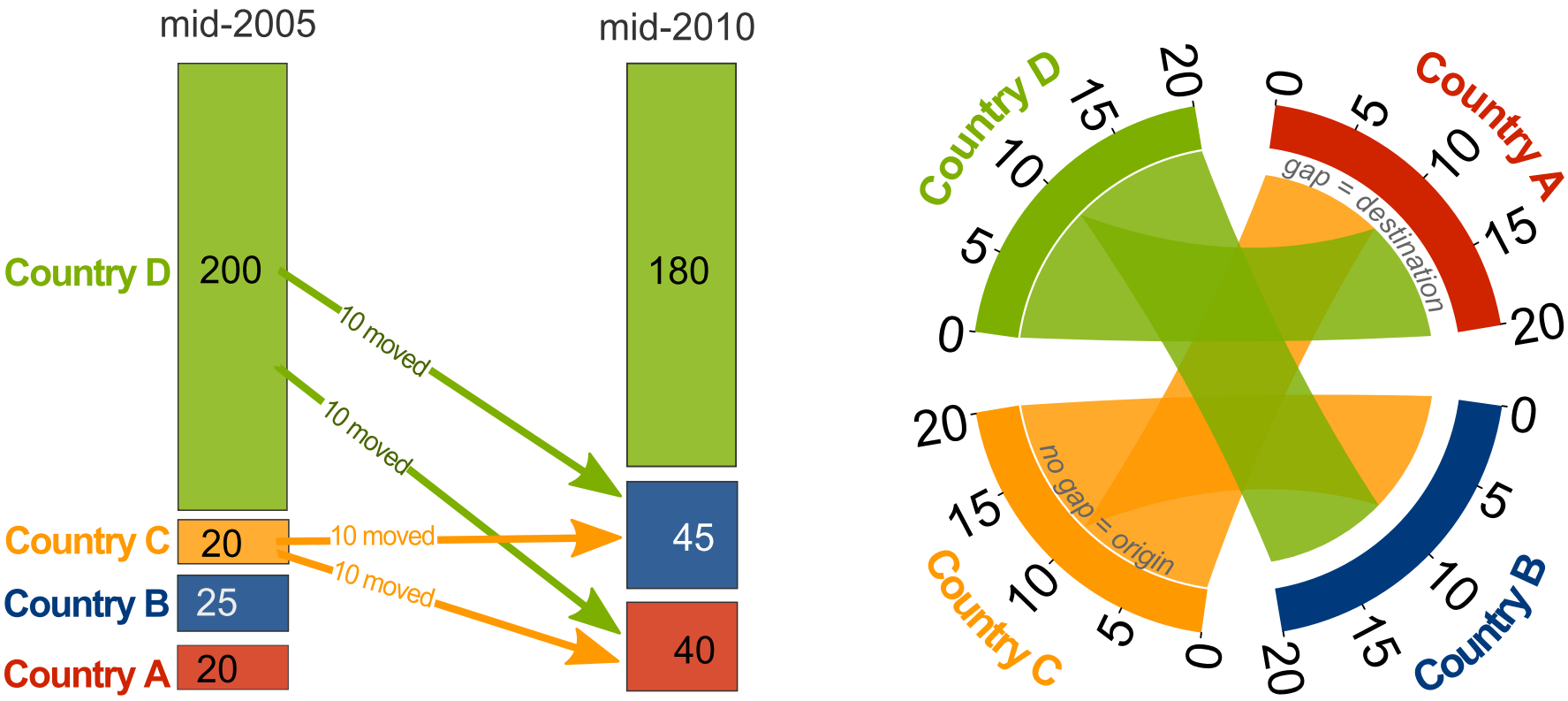
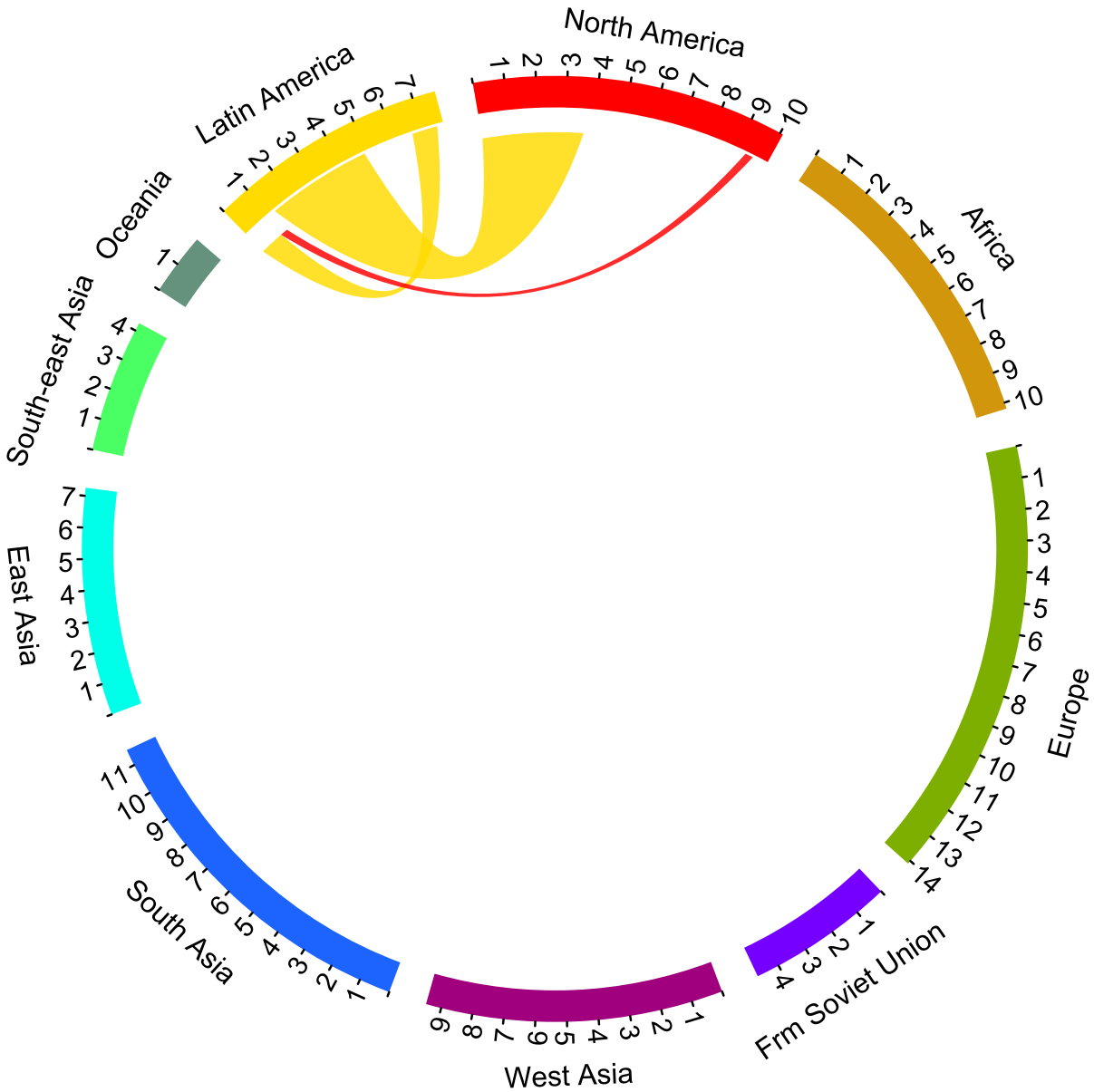
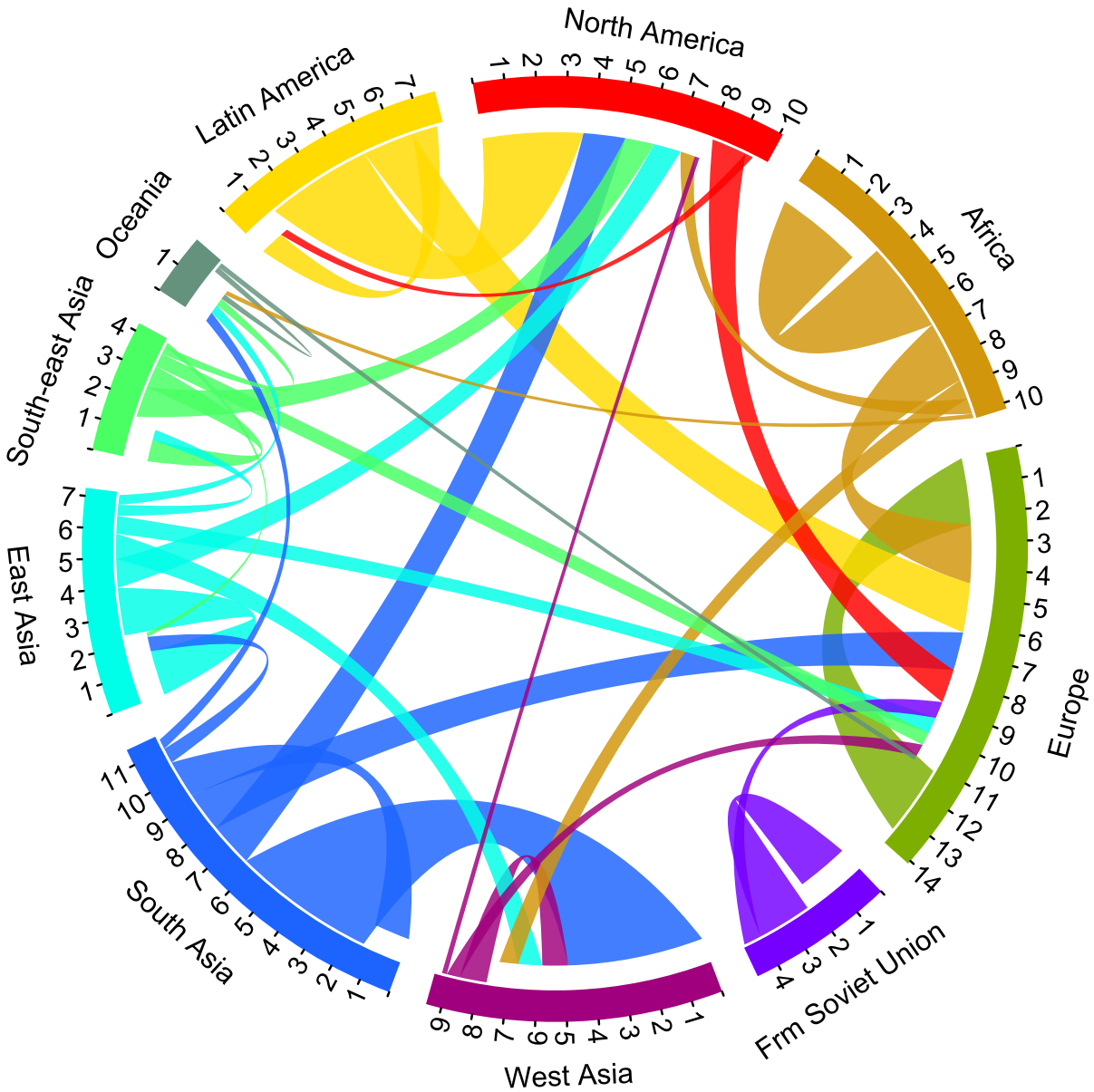


Figure source: Science Vol.343 (6178)

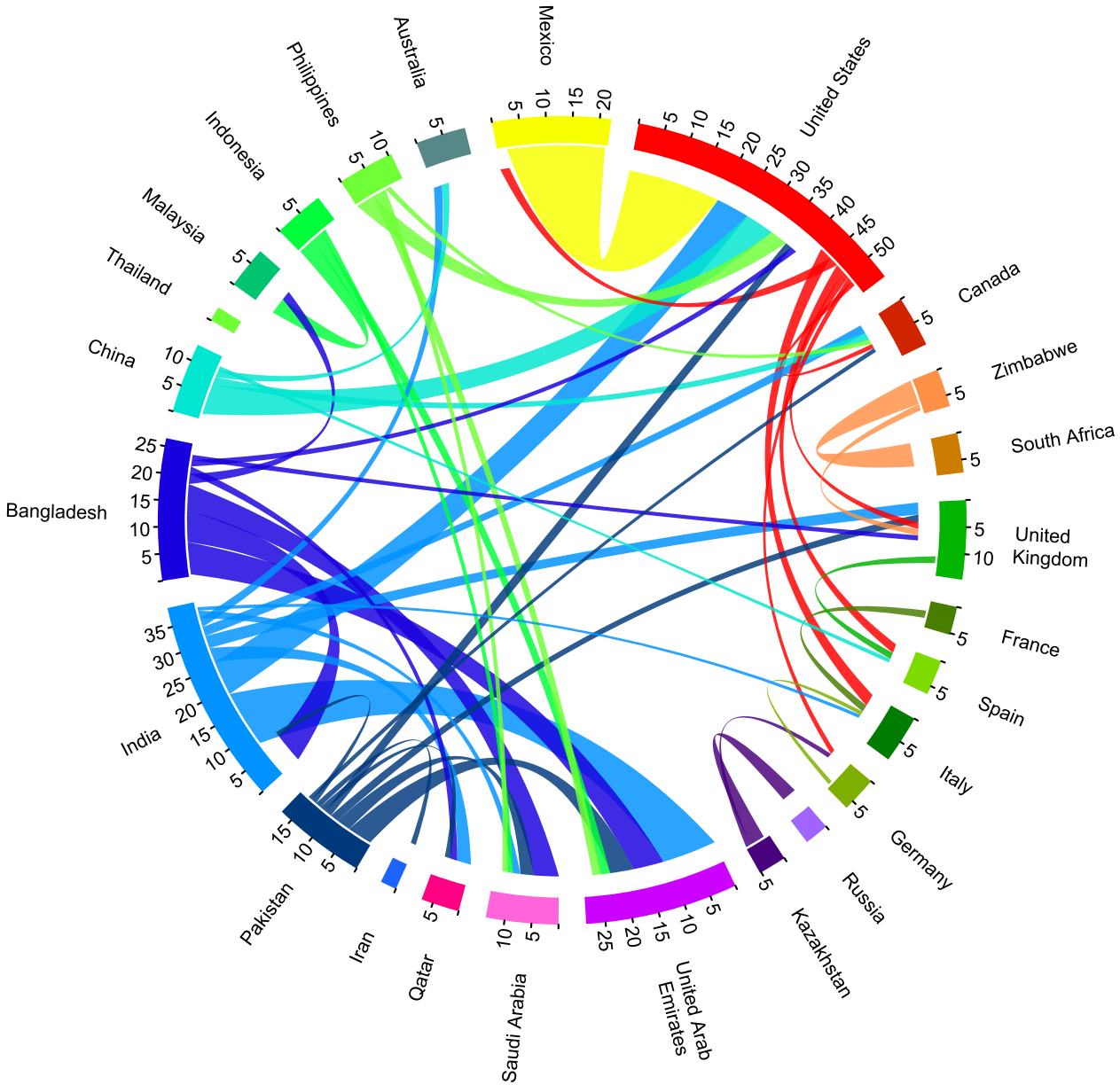
Circular Migration Plot for world regions, 2005-10



Circular Migration Plot for world regions, 2005-10



Circular Plot for key senders & receivers, 2005-10



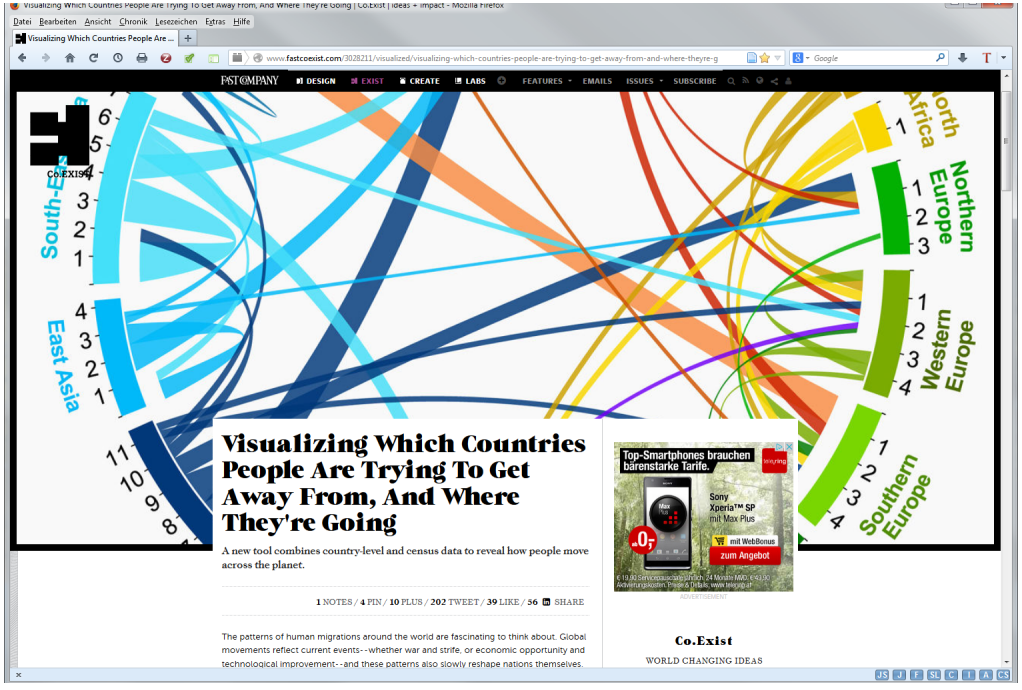
An interactive data visualisation

The Global Flow of People

Developed together with Null2, Berlin

Key Findings

- Present estimates of global international migration flows.
- Our methodology is fully transparent and results are replicable.
- 5-year migration flows estimated from changes in bilateral stock data.
- Our estimates suggest a stable rate of global migration since 1990.
- Circular migration plots convey the complexities of migration in a clear and compelling manner.



Questions?? Comments??

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