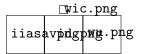
Quantifying Global International Migration Flows

Guy Abel

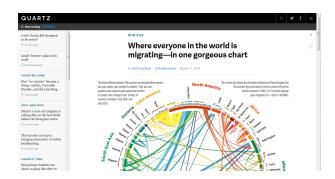
Wittgenstein Centre (IIASA, VID/ÖAW, WU), Vienna Institute of Demography of the Austrian Academy of Sciences

17th April 2014



Overview

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





Overview

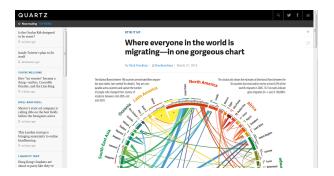
- Static measures of migration are plentiful.
- Dynamic flow data are trickier.
- No existing global database on bilateral flows





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.





Migration measures can be categorised into:

Stocks:

- Stocks:
 - 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

- Stocks:
 - 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
- Plows:

- Stocks:
 - 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
- Plows:
 - Movements over boundaries during a defined period.
 - Dynamic, difficult to define and compare across countries.

- Stocks:
 - 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
- Plows:
 - 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 can be categorised as:

Events:

- Events:
 - Number of moves over a defined period
 - Focus of MIMOSA and IMEM.

- Events:
 - Number of moves over a defined period
 - Focus of MIMOSA and IMEM.
- Transitions:

- Events:
 - Number of moves over a defined period
 - Focus of MIMOSA and IMEM.
- 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.

Flow measures can be categorised as:

- Events:
 - Number of moves over a defined period
 - Focus of MIMOSA and IMEM.
- 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

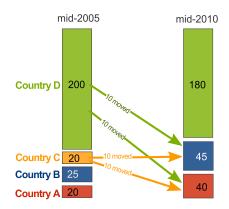
Derive a set of global migrant flow tables

- 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:

		Plac	ce of	Resid	dence	e (t)			Place	of F	Reside	ence	(t+1)
		Α	В	C	D	Sum			Α	В	C	D	Sum
a	A	1000	100	10		1110	a	Α	950	100	60	0	1110
lac	В	55	555	50	5	665	lace	В	80	505	75	5	665
Sirthplace	C	80	40	800	40	960	thp.	C	90	30	800	40	960
Bin	D	20	25	20	200	265	Birthpl	D	40	45	0	180	265
~	Sum	1155	720	880	245	3000	7	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:

		Plac	ce of	Resid	dence	e (t)			Place	of F	Reside	ence	$\overline{(t+1)}$
		Α	В	C	D	Sum			Α	В	C	D	Sum
a	Α	1000	100	10	0	1110	a	Α	950	100	60	0	1110
lac	В	55			5	665	lac	В	80	505	75	5	665
thp	C	80	40	800	40	960	thp.	C	90	30	800	40	960
Birthplace	D	20	25	20	200	265	Birthpl	D	40	45	0	180	265
7		1155	720	880	245	3000	7		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:

		Plac	ce of	Resid	dence	e (t)			Place	of F	Reside	ence	(t+1)
						Šum			Α	В	C	D	Sum
(D	Α	1000	100	10	0	1110	a)	Α	950	100	60	0	1110
Sirthplace	В	55	555	50	5	665	lace	В	80	505	75	5	665
thp	C	80	40	800	40	960	thp	C	90	30	800	40	960
Biri	D	20	25	20	200	265	Birt	D	40	45	0	180	265
_	Sum	1155	720	880	245	3000		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

Bi	rthplac	ce=A					Bii	thpla	ce=	В			
				stinat	tion						stin	ation	
		Α	В	C	D	Sum			Α	В	С	D	Sum
Origin	A B C D Sum	950	100	60	0	1000 100 10 0 1110	Origin	A B C D Sum	80	505	75	5	55 555 50 5 665
	Juili	930	100	00	U	1110		Juili	00	303	13	J	003
Bii	rthplac	ce=C					Bii	thpla	ce=	D			
	,			stinat	tion			•			stin	ation	
		Α	В	C	D	Sum			Α	В	C	D	Sum
Origin	A B C D Sum	90	30	800	40	80 40 800 40 960	Origin	A B C D Sum	40	40	0	180	20 25 20 200 265

Missing Data

- The marginal totals (from the stock tables) are known.
- Missing:
 - 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

Bi	rthplac	ce=A					Bii	thpla	ce=	В			
				stinat	tion						stin	ation	
		Α	В	C		Sum			Α	В	C	D	Sum
Origin	A B C D Sum	950	100	60	0	1000 100 10 0 1110	Origin	A B C D Sum	on	505	75	5	55 555 50 5 665
	Sum	950	100	00	U	1110		Sulli	00	303	13	3	005
Bii	rthplac	ce=C					Bii	rthpla	ce=	D			
	,			stinat	tion			,			stin	ation	
		Α	В	C	D	Sum			Α	В	С	D	Sum
Origin	A B C D Sum	90	30	800	40	80 40 800 40 960	Origin	A B C D Sum	40	40	0	180	20 25 20 200 265



Migrant Stock Data in Flow Tables

Ri	rthpla	ce=A					Bir	thplac	^e=	R			
	inpia.	,		stinat	ion		٥.,	· · · p·u·			ctin	ation	
						_					عرااا		_
		Α	В	C	D	Sum			Α	В	C	D	Sum
	Α	950				1000		Α	55				55
u	В		100			100	U	В		505			555
Origin	Ć		100	10		10	Origin	Č		303	50		50
\sim	D			10	0		\sim	5			50	_	
0					0	0	\circ	D				5	5
	Sum	950	100	60	0	1110		Sum	80	505	75	5	665
Bi	rthplac	ce=C	•				Bir	thplac	ce=	D			
	•				_								
			De:	stinat	ion			•		De	stin	ation	
		Α	De: B			Sum		·	Α	De B	stin C	ation D	Sum
										_	stin C		
	A	A 80				Sum 80		A	A 20	_	stin C		Sum 20
in							i	A B		_	stin C		
igin	— А В С		В	С		80 40	igin			В	stin C 0		20 25
Origin	B C		В		D	80 40 800	Origin	B C		В	С	D	20 25 20
Origin			В	С		80 40	Origin			В	С		20 25



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, ..., 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 $\mathbf{Y} = \{y_{ijk}, i, j, k = 1, \dots, R\}$ given $\mathbf{n} = \{n_{ijk}, i, j, k = 1, \dots, R\}$ migrant transitions, provided that migrant transitions are independent, is

$$L(\mathbf{Y}; \mathbf{n}) = P(N_{111} = n_{111}, N_{121} = n_{121}, \dots, N_{RRR} = n_{RRR})$$

$$= \prod_{ijk} \frac{y_{ijk}^{n_{ijk}!}}{n_{ijk}!} \exp(-y_{ijk})$$

$$I(\mathbf{Y}; \mathbf{n}) = \sum_{ijk} \{n_{ijk} \log(y_{ijk}) - y_{ijk} - \log(n_{ijk}!)\}$$

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

$$I(\boldsymbol{\theta}; \mathbf{n}) = \sum_{ijk} \{ n_{ijk} \log(\alpha_i \beta_j \lambda_k \gamma_{ik} \kappa_{jk} \delta_{iik} m_{ij}) - \alpha_i \beta_j \lambda_k \gamma_{ik} \kappa_{jk} \delta_{iik} m_{ij} - \log(n_{ijk}!) \}$$

$$= \sum_i n_{i++} \log(\alpha_i) + \sum_j n_{+j+} \log(\beta_j) + \sum_k n_{++k} \log(\lambda_j)$$

$$+ \sum_{ik} n_{i+k} \log(\gamma_{ik}) + \sum_{jk} n_{+jk} \log(\kappa_{jk}) + \sum_{ijk} n_{ijk} \log(\delta_{iik})$$

$$- \sum_{ijk} \alpha_i \beta_j \lambda_k \gamma_{ik} \kappa_{jk} \delta_{iik} m_{ij} + c,$$

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

$$\begin{split} &\frac{\partial I}{\partial \alpha_{i}} = \frac{n_{i++}}{\alpha_{i}} - \sum_{jk} \beta_{j} \lambda_{k} \gamma_{ik} \kappa_{jk} \delta_{iik} m_{ij} = 0, \quad \frac{\partial I}{\partial \gamma_{ik}} = \frac{n_{i+k}}{\gamma_{ik}} - \sum_{j} \alpha_{i} \beta_{j} \lambda_{k} \kappa_{jk} \delta_{iik} m_{ij} = 0, \\ &\frac{\partial I}{\partial \beta_{j}} = \frac{n_{+j+}}{\beta_{j}} - \sum_{ik} \alpha_{i} \lambda_{k} \gamma_{ik} \kappa_{jk} \delta_{iik} m_{ij} = 0, \quad \frac{\partial I}{\partial \kappa_{jk}} = \frac{n_{+jk}}{\kappa_{jk}} - \sum_{i} \alpha_{i} \beta_{j} \lambda_{k} \gamma_{ik} \delta_{iik} m_{ij} = 0, \\ &\frac{\partial I}{\partial \lambda_{k}} = \frac{n_{++k}}{\lambda_{k}} - \sum_{ii} \alpha_{i} \beta_{j} \gamma_{ik} \kappa_{jk} \delta_{iik} m_{ij} = 0, \quad \frac{\partial I}{\partial \delta_{iik}} = \frac{n_{ijk}}{\delta_{iik}} - \alpha_{i} \beta_{j} \lambda_{k} \kappa_{jk} \gamma_{ik} m_{ij} = 0, \end{split}$$

Iterative Soloution

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

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

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

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

Which require only the marginal totals, $(n_{i++}, n_{+j+}, n_{+k}, n_{i+k})$ and (n_{+ik}) and the diagonal values $(n_{iik}, \text{ where } i = j)$.

Iterative Soloution

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

$$\begin{split} \hat{\alpha}_{i}^{(1)} &= \frac{n_{i++}}{\sum_{jk} \hat{\beta}_{j}^{(0)} \hat{\lambda}_{k}^{(0)} \hat{\gamma}_{ik}^{(0)} \hat{\kappa}_{jk}^{(0)} \hat{\delta}_{iik}^{(0)} m_{ij}}, \quad \hat{\gamma}_{ik}^{(4)} = \frac{n_{i+k}}{\sum_{j} \hat{\alpha}_{i}^{(1)} \hat{\beta}_{j}^{(2)} \hat{\lambda}_{k}^{(3)} \hat{\kappa}_{jk}^{(0)} \hat{\delta}_{iik}^{(0)} m_{ij}} \\ \hat{\beta}_{j}^{(2)} &= \frac{n_{+j+}}{\sum_{ik} \hat{\alpha}_{i}^{(1)} \hat{\lambda}_{k}^{(0)} \hat{\gamma}_{ik}^{(0)} \hat{\kappa}_{jk}^{(0)} \hat{\delta}_{iik}^{(0)} m_{ij}}, \quad \hat{\kappa}_{jk}^{(5)} = \frac{n_{+jk}}{\sum_{i} \hat{\alpha}_{i}^{(1)} \hat{\beta}_{j}^{(2)} \hat{\lambda}_{k}^{(3)} \hat{\gamma}_{ik}^{(4)} \hat{\delta}_{iik}^{(0)} m_{ij}} \\ \hat{\lambda}_{k}^{(3)} &= \frac{n_{++k}}{\sum_{i:} \hat{\alpha}_{i}^{(1)} \hat{\beta}_{j}^{(2)} \hat{\gamma}_{ik}^{(0)} \hat{\kappa}_{jk}^{(0)} \hat{\kappa}_{jik}^{(0)} \hat{\delta}_{iik}^{(0)} m_{ij}}, \quad \hat{\delta}_{iik}^{(6)} &= \frac{n_{ijk}}{\hat{\alpha}_{i}^{(1)} \hat{\beta}_{j}^{(2)} \hat{\lambda}_{k}^{(3)} \hat{\gamma}_{ik}^{(4)} \hat{\kappa}_{jk}^{(5)} m_{ij}} \end{split}$$

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

Estimate Missing Using Log-linear Model

Rii	thpla	e = A					Rin	thplac	^e=	R			
				stinat	ion						ctin	ation	
		۸	B.) (D	C			۸) (D	C
		Α	D	C	D	Sum			Α	В	C	D	Sum
	Α	950				1000		Α	55				55
4	В	550	100			100	u	В	33	505			555
Origin	Б		100	10			Origin	0		303			
Ĭ.	C			10		10	. <u>;</u>	Ć			50	_	50
0	D				0	0	\circ	D				5	5
	Sum	950	100	60	0	1110		Sum	80	505	75	5	665
Rin	thpla	re=(Rin	thplac	~e=	D			
	unpia.												
				ctinat	ion		٥.,	inpia			ctin	ation	
			De:	stinat		C	٥.,	inpia		De	_	ation	C
		Α				Sum	υ.,	inpia	A		stin C		Sum
	A	Α	De:				Σ.,	•	Α	De	_		
-	A		De: B			80		A		De B	_		20
gin	A B	Α	De:	С		80 40		•	Α	De	С		20 25
rigin	B C	Α	De: B		D	80 40 800		A B C	Α	De B	_	D	20
Origin		Α	De: B	С		80 40	Origin	A	Α	De B	С		20 25
Origin	B C	Α	De: B	С	D	80 40 800		A B C	Α	De B	С	D	20 25 20

Estimate Missing Using Log-linear Model

Bii	rthpla	ce=A					Bii	rthpla	ce=	В			
			De	stinat	ion					_	stin	ation	
		Α	В	C	D	Sum			Α	В	C	D	Sum
	A	950	0	50	0	1000		A	55	0	0	0	55
2.	В	0	100	0	0	100	2.	В	25	505	25	Ō	555
Origin	Ċ	0	0	10	0	10	Origin	Ċ.	0	0	50	Ŏ	50
Ö	Ď	0	Õ	0	Õ	0	Õ	Ď	Ŏ	Õ	0	5	5
	Sum	950	100	60	0	1110		Sum	80	505	75	5	665
Rii	rthnlai	ce=C					Rii	rthnlai	ce=	D			
Bii	rthpla	ce=C		stinat	ion		Bii	rthpla	ce=		stin	ation	
Bii	rthpla	ce=C A		stinat C	ion D	Sum	Bii	rthpla	ce=		stin C	ation D	Sum
Bii	rthplac ——		Des			Sum 80	Bii	thplac ——		De			_
		Α	De:	С	D				Α	<i>De</i> B	С	D	Sum
	A	A 80	Des B	0 0	D 0	80		, A	A 20	De B	C 0	D 0	Sum 20
Origin Bi	A	80 10	Des B 0 30	0 0	D 0 0	80 40	Origin BI	, — А В	A 20 0	De B 0 25	0 0	D 0 0	Sum 20 25



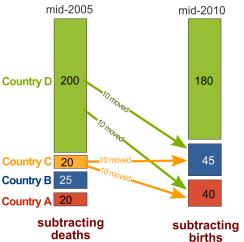
Flow Table

			De.	stina	atic	n
		Α	В	C	D	Sum
	Α		0	50	0	50
i.	В	35		25	0	60
Origin	C	10	10		0	20
0	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:

	J	Pla	ce of	Resid					Place	of F	Resid	ence	(t + 1)
		Α	В	C	D	Sum			Α	В	C	D	Sum
, G	Α	1000	100	10	0	1110	<i>b</i>	Α	1060	60	10	10	1140
lac	В	55	555	50	5	665		В	45	540	40	0	625
irthpi	C	80						C	70	75	770	70	985
	D					265	ï	D			20		310
B	Sum	1155	720	880	245	3000	В	Sum	1205	705	840	310	3060

Migrant Stock Data with Natural Change:

	•					e(t)							(t+1)
		А	B	C	D	Sum			А	В	C	D	Sum
Э	Α	1000	100	10	0	1110	e	Α	1060	60	10	10	1140
lac	В	55	555	50	5	665	lac	В	45	540	40		625
дų	C D	80	40	800	40	960	дų	C	70	75	770	70	985
irt	D	20	25	20	200	265	ij	D	30				310
\mathcal{B}	Sum	1155	720	880	245	3000	\mathcal{B}	Sum	1205	705	840	310	3060

Migrant Stock Data with Natural Change:

		Pla	ce of	Resid	dence	e (t)			Place of Residence (t +				
		Α	В	C		Šum			Α	В			` Sum
irthplace	Α	1000	100	10	0	1110	e	Α	1060	60	10	10	1140
	В	55	555	50	5	665	Įa(45				625
	C	80	40	800	40	960	hρ	C	70	75	770	70	985
	D	20	25	20	200	265		D	30	30	20	230	310
B	Sum	1155	720	880	245	3000	Β	Sum	1205	705	840	310	3060

Demographic Data:

Deatl	hs (t,	t+1	L)	
Α	B	C	Ď	

Births
$$(t, t+1)$$

A B C D

Sum 70 30 50 10

Sum 80 20 60 60



Migrant Stock Data with Natural Change:

		Pla	ce of	Resid	dence	e(t)	Place of Residence (t +					(t + 1)	
			В			Šum							` Sum
g	Α					1110			1060				1140
la(В	55	555	50	5	665	la(В	45				625
Birthplace	C	80	40	800	40	960	hρ	C	70	75	770	70	985
		20	25	20	200	265	ij	D	30				310
	Sum	1155	720	880	245	3000	В	Sum	1205	705	840	310	3060

			hs (t B	, <i>t</i> +	1) D		Birtl A	hs (t	, <i>t</i> +	1) D
<i>sirthplace</i>	A B C D Sum									
B	Sum	70	30	50	10	Sum	80	20	60	60



Migrant Stock Data with Natural Change:

	_	Pla	ce of	Resid	dence	e (t)			Place of Residence (t +				
		Α	В	C	D	Šum			Α	В	C	D	` Sum
lace	Α	1000	100	10	0	1110	e	Α	1060	60	10	10	1140
lac	В	55	555	50	5	665	Jac	В	45				625
Birthpl	C	80	40	800	40	960	hр	C	70	75	770	70	985
	D	20	25	20	200	265	ij	D	30	30	20	230	310
	Sum	1155	720	880	245	3000		Sum	1205	705	840	310	3060

	J			t, t + C			Birth A	s (t, B	t + C	1) D
Birthplace	A B C D Sum	60.6 3.3 4.9 1.2 70	4.2 23.1 1.7 1 30	0.6 2.8 45.5 1.1 50	0 0.2 1.6 8.2 10	Sum	80	20	60	60



Migrant Stock Data with Natural Change:

		Pla	ce of	Resid	dence	e(t)			Place of Residence (t -				
		Α	В	C	D	Šum							` Sum
Birthplace	Α	1000	100	10	0	1110	Э	Α	1060	60	10	10	1140
	В	55	555	50	5	665	Ja(В	45				625
	C	80	40	800	40	960	hр	C	70	75	770	70	985
	D	20	25	20	200	265	ij	D	30				310
	Sum	1155	720	880	245	3000		Sum	1205	705	840	310	3060

	J	Dea A	ths (t, t + C	1) D	$egin{array}{ccc} \textit{Births} \ (t,t+1) \ A \ B \ C \ D \end{array}$
Birthplace	A B C D Sum	60.6 3.3 4.9 1.2 70	4.2 23.1 1.7 1 30	0.6 2.8 45.5 1.1 50	0 0.2 1.6 8.2 10	B Sum 80 20 60 60 60 60



Migrant Stock Data with Natural Change:

		Pla	ce of	Resid	dence	e(t)			Place of Residence (t +				
		Α	В	C	D	Šum			Α	В	C	D	` Sum
g	Α						Э		1060				1140
Įa(В	55	555	50	5	665	la(В	45	540	40	0	625
hρ	A B C D	80	40	800	40	960	hρ	C	70	75	770	70	985
Birt		20	25	20	200	265	ij	D	30	30	20	230	310
	Sum	1155	720	880	245	3000		Sum	1205	705	840	310	3060

	0	Dea A		t, t + C			Birti A		, <i>t</i> +	
Birthplace	A B	60.6 3.3	4.2 23.1	0.6 2.8	0.2	Sirthplace COBB	80 0	_	0	0
	C	4.9	1.7	45.5	1.6	<i>ط</i> ر	0	0	60	0
	D	1.2	1	1.1	8.2	Ľ, D	0	0	0	60
Β	Sum	70	30	50	10	™ Sum	80	20	60	60



Migrant Stock Data Altered for Natural Change:

	0	Р	lace o	f Resid	dence	(t)			Plac	e of R	esiden	ce (t -	+1)
						` ´Sum			Α	В			Sum
ы	Α	939.4	95.8	9.4	0	1044.7	ы	Α	980	60	10	10	1060
lac	В	51.7	531.9	47.2	4.8	1044.7 635.5	lac	В	45	520	40	0	605
4	C	75.2	38.3	754.5	38.4	906.4	4	C	70	75	710	70	925
₽.	D	18 8	24	18 9	191 8	253 4	Ξ.	D	30	30	20	170	250
В	Sum	1085	690	830	235	2840	В	Sum	1125	685	780	250	2840

Migrant Stock Data Altered for Natural Change:

	0	P	lace o	f Resid	dence	(t)			Plac	e of R	esiden	ce (t -	+1)
						` ´Sum				В			Sum
ю	Α	939.4	95.8	9.4	0	1044.7	Э	Α	980	60	10	10	1060
la(В	51.7	531.9	47.2	4.8	1044.7 635.5	lac	В	45	520			605
۲,	C	75.2	38.3	754.5	38.4	906.4	7	C	70	75	710	70	925
エ	D	18 8	24	18 9	191 8	253.4	Ţ	D	30	30	20	170	250
В	Sum	1085	690	830	235	2840	В	Sum	1125	685	780	250	2840

Migrant Stock Data Altered for Natural Change:

	Ü	Ρ	lace o	f Resid	dence	(t)			Plac	e of R	esiden	ce (t -	+1)
			В							В			Sum
ы	Α	939.4	95.8	9.4	0	1044.7	e	Α	980	60	10	10	1060
lac	В	51.7	531.9	47.2	4.8	1044.7 635.5	lac	В	45	520	40	0	605
4		75.2	38.3	754.5	38.4	906.4	4	. (70	75	710	70	925
₽.	D	18 8	24	18 9	191 8	253.4	٦.	D	30	30	20	170	250
Β	Sum	1085	690	830	235	2840	Β	Sum	1125	685	780	250	2840

		Pla	ce of I	Reside	nce (t)			Place	of Re	esidenc	e (t -	⊢1)
		Α	В	C	D`	Sum			Α	В	C	Ď	Sum
e,	A							Α					
lace	В						laα	В					
lρ	C						hρ	C					
ij	D						ir	D					
В	Sum						В	Sum					



Migrant Stock Data Altered for Natural Change:

	•	P	lace o	f Resid	dence	(t)			Plac	e of R	esiden	ce (t -	+1)
		Α	В	C	D	` ´Sum			Α	В	C	Ď	Sum
ы	Α	939.4	95.8	9.4	0	1044.7	Э	Α	980	60	10	10	1060
la(В	51.7	531.9	47.2	4.8	1044.7 635.5 906.4	lac	В	45	520	40	0	605
									70	75		70	
エ	D	18 8	24	18 9	191 8	253.4	Z	D	30	30	20	170	250
В	Sum	1085	690	830	235	2840	Β	Sum	1125	685	780	250	2840

		Plac	ce of I	Reside	nce (t)			Place	of Re	sidenc	:e (t -	+1)
		Α	В	C	D`	Sum			Α	В	C	Ď	Sum
	Α					1052.3	۔ ا	Α				1	1052.3
lac	В					620.2	laα	В					620.2
lди	C					915.7	ή	C					915.7
Sirt	D					251.7	ïr	D					251.7
$^{\circ}$ S	um						B G	Sum					



Migrant Stock Data Altered for Natural Change:

		P	lace o	f Resid	dence	(t)			Plac	e of R	esiden?	ce (t -	+1)
		Α	В	C	D	Sum			Α	В	C	Ď	Sum
ы	Α	939.4	95.8	9.4	0	1044.7	Э	Α	980	60	10	10	1060
la(В	51.7	531.9	47.2	4.8	635.5	lac	В	45	520	40	0	605
7	C	75.2	38.3	754.5	38.4	906.4	η,	C	70	75	710	70	925
Ţ	D	18 8	24	18 9	191 8	253.4	Ţ	D	30	30	20	170	250
В	Sum	1085	690	830	235	2840	В	Sum	1125	685	780	250	2840

		Pl	ace of	Resid	ence	(t)			Plac	e of R	esiden'	ce (t -	+ 1)
		Α	В	C	D	` ´Sum			Α	В	C	Ď	Sum
e,	Α					1052.3	بع	Α					1052.3
lac	В					620.2	Jac	В					620.2
Birthplace	C					915.7	hρ	C					915.7
ï	D					251.7	ij	D					251.7
Ω	Sum	1085	690	830	235	2840	B	Sum	1125	685	780	250	2840



Migrant Stock Data Altered for Natural Change:

	•	P	lace o	f Resid	dence	(t)			Plac	e of R	esiden	ce (t -	+1)
		Α	В	C	D	` ´Sum			Α	В	C	Ď	Sum
Ą	A	939.4	95.8	9.4	0	1044.7	ы	Α	980	60	10	10	1060
lac	В	51.7	531.9	47.2	4.8	1044.7 635.5 906.4	lac	В	45	520	40	0	605
									70	75	710	70	925
Ξ.	D	18 8	24	18 9	191 8	253.4	Z	D	30	30	20	170	250
В	Sum	1085	690	830	235	2840	Β	Sum	1125	685	780	250	2840

		Ρ	'lace o	t Resid	dence	(t)			Pla	ce ot I	Residei	nce (t	+1)
		Α	В	C	D	Sum			Α	В	C	Ď	Sum
e G	Α	942	101	9.4	0	1052.3	e	Α	976.1	56.5	9.9	9.8	1052.3 620.2 915.7
lac	В	48.4	523.5	43.7	4.6	620.2	lac	В	48.4	528.8	43	0	620.2
₽.	D	18.3	24.5	18 2	190 7	251.7	Ξ.	D	30.7	29	20.5	171 5	251.7
В	Sum	1085	690	830	235	2840	Β	Sum	1125	685	780	250	2840

Altered Migrant Stock Data:

				of Resid		(t)			Pla	ce of I	Reside	nce (t	+1)
						` ´Sum							Śum
e,	Α	942	101	9.4	0	1052.3	e	Α	976.1	56.5	9.9	9.8	1052.3
ļα	В	48.4	523.5	43.7	4.6	620.2	ļα	В	48.4	528.8	43	0	620.2
4	C	76.3	40.9	758.7	39.7	915.7	4	C	69.8	70.6	706.6	68.7	915.7
۷.	D	18 3	24 5	18 2	190 7	251.7	٦.	D	30.7	29	20.5	171 5	251.7
\mathcal{B}	Sum	1025	600	830	235	2840	$\boldsymbol{\mathcal{B}}$	Sum	1125	685	780	250	2840

Altered Migrant Stock Data:

		F	Place o	of Resid	dence	(t)			Pla	ce of I	Reside	nce (t	+1)
						` ´Sum			Α	В	C	Ď	Śum
e	Α	942	101	9.4	0	1052.3	ė	Α	976.1	56.5	9.9	9.8	1052.3
ä	В	48 4	523 5	43 7	4 6	620.2	ğ	B	48 4	528 8	43	0	620.2
4	C	76.3	40.9	758.7	39.7	915.7	4	C	69.8	70.6	706.6	68.7	915.7
۷.	D	18.3	24.5	18.2	190.7	251.7	۷.	D	30.7	29	20.5	171 5	251.7
$\boldsymbol{\omega}$	Sum	1085	690	830	235	2840	Ω	Sum	1125	685	780	250	2840

Altered Migrant Stock Data:

	Place of Residence (t) A B C D Su											nce (t	
		Α	В	C	D	Sum			Α	В	C	Ď	Sum
9	Α	942	101	9.4	0	1052.3	e	Α	976.1	56.5	9.9	9.8	1052.3
Э	В	48.4	523.5	43.7	4.6	620.2	ļac	В	48.4	528.8	43	0	1052.3 620.2 915.7
dų.	C	76.3	40.9	758.7	39.7	915.7	d4.	C	69.8	70.6	706.6	68.7	915.7
۷.	D	18 3	24 5	18.2	190 7	251.7	٦.	D	30.7	29	20.5	171 5	251.7
Ш	Sum	1005	600	830	33 E	2840	$\boldsymbol{\omega}$	Sum	1125	685	790	250	2840

Altered Migrant Stock Data:

	,												
	Place of Residence (t)								Pla	ce of I	Reside	nce (t	+1)
						` ´Sum							Sum
<i>i</i>	Α	942	101	9.4	0	1052.3	, S	Α	976.1	56.5	9.9	9.8	1052.3
hplac	В	48 4	523 5	43 7	4.6	620.2	ä	В	48 4	528 8	43	0	620.2
7.	D	18 3	24 5	18.2	190 7	251.7	7.	D	30.7	29	20.5	171 5	251.7
Ш	Sum	1085	690	830	235	2840	Ш	Sum	1125	685	780	250	2840

Estimated Flow Table:

			Destination								
		Α	В	C	D	Sum					
	Α		3.3	0	3.2	6.6					
11.	В	34.1		0.6	9.8	44.5					
Origin	C	0	27.1		25.7	52.8					
0	D	12.4	9.7	2.3		23.8					
	Sum	46.6	39.5	1.8	38.8	127.7					

Altered Migrant Stock Data:

									Place of Residence $(t+1)$				+1)
		Α	В	C	D	` ´Sum			Α	В	C	Ď	Sum
ė	Α	942	101	9.4	0	1052.3	e	Α	976.1	56.5	9.9	9.8	1052.3
irt	В	48.4	523.5	43.7	4.6	620.2	a	В	48.4	528.8	43	0	620.2
	D	18.3	24.5	18.2	190.7	251.7	ij	D	30.7	29	20.5	171.5	251.7
В	Sum	1085	690	830	235	2840	В	Sum	1125	685	780	250	2840

Estimated Flow Table:

			DE	Sunat	1011			
		Α	В	C	D	Sum		P^{t+1}
	Α		3.3	0	3.2	6.6	Α	1205
12	В	34.1		0.6	9.8	44.5	В	705
'n.	B C D	0	27.1		25.7	52.8	C	840
0	D	12.4	9.7	2.3		23.8	D	310
	Sum	46.6	39.5	1.8	38.8	127.7	Sum	3060

Altered Migrant Stock Data:

Place of Residence (t)								
	Α	В	C	D	Sum			
Α								
В	48.4	523.5	43.7	4.6	620.2			
C	76.3	40.9	758.7	39.7	915.7			
D								
Sum	1085	690	830	235	2840			
	C D	A 942 B 48.4 C 76.3 D 18.3	A 942 101 B 48.4 523.5 C 76.3 40.9 D 18.3 24.5	A B C A 942 101 9.4 B 48.4 523.5 43.7 C 76.3 40.9 758.7 D 18.3 24.5 18.2	A B C D			

		Pla	ce ot I	Reside	nce (t	+1)
		Α				Sum
e	Α	976.1	56.5	9.9	9.8	1052.3 620.2 915.7 251.7 2840
g	В	48.4	528.8	43	0	620.2
d u	C	69.8	70.6	706.6	68.7	915.7
Ĕ	D	30.7	29	20.5	171.5	251.7
IJ	Sum	1125	685	780	250	2840

Estimated Flow Table:

			De	stınat	ion	
		Α	В	C	D	Sum
	Α		3.3	0	3.2	6.6
12.	В	34.1		0.6	9.8	44.5
Origin	C	0	27.1		25.7	52.8
0	D	12.4	9.7	2.3		23.8
	Sum	46.6	39.5	1.8	38.8	127.7

Altered Migrant Stock Data:

Place of Residence (t)

A B C D Sum

A 942 101 9.4 0 1052.3

B 48.4 523.5 43.7 4.6 620.2

C 76.3 40.9 758.7 39.7 915.7

D 18.3 24.5 18.2 190.7 251.7

Sum 1085 690 830 235 2840

		Pla	ce ot i	Reside	nce (t	+1)
		Α	В	C	Ď	Sum
e,	Α	976.1	56.5	9.9	9.8	1052.3 620.2 915.7 251.7 2840
ğ	В	48.4	528.8	43	0	620.2
9	C	69.8	70.6	706.6	68.7	915.7
Ĕ	D	30.7	29	20.5	171.5	251.7
נו	Sum	1125	685	780	250	2840

Estimated Flow Table:

			Destination							
		Α	В	C	D	Sum				
	Α		3.3	0	3.2	6.6				
12.	В	34.1		0.6	9.8	44.5				
Origin	C	0	27.1		25.7	52.8				
0	D	12.4	9.7	2.3		23.8				
	Sum	46.6	39.5	1.8	38.8	127.7				

$$P^{t+1}$$
 $-P^t$ $+D$

A 1205 1155 70

B 705 720 30

C 840 880 50

D 310 245 10

Sum 3060 3000 160

Altered Migrant Stock Data:

Place of Residence (t)

A B C D Sum

A 942 101 9.4 0 1052.3

B 48.4 523.5 43.7 4.6 620.2

C 76.3 40.9 758.7 39.7 915.7

D 18.3 24.5 18.2 190.7 251.7

Sum 1085 690 830 235 2840

		Pla	ce ot i	Reside	nce (t	+1)
		Α	_			Sum
e,	Α	976.1	56.5	9.9	9.8	1052.3 620.2 915.7 251.7 2840
ĕ	В	48.4	528.8	43	0	620.2
9	C	69.8	70.6	706.6	68.7	915.7
Ĕ	D	30.7	29	20.5	171.5	251.7
נו	Sum	1125	685	780	250	2840

Dlana of Danidon on (+ + 1)

Estimated Flow Table:

			Destination							
		Α	В	C	D	Sum				
	Α		3.3	0	3.2	6.6				
12.	В	34.1		0.6	9.8	44.5				
Origin	C	0	27.1		25.7	52.8				
0	D	12.4	9.7	2.3		23.8				
	Sum	46.6	39.5	1.8	38.8	127.7				

$$P^{t+1}$$
 $-P^t$ $+D$ $-B$

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:

	Place of Residence (t)					
		Α	В	C	D	` ´Sum
e)	Α	942	101	9.4	0	1052.3
Birthplace	В	48.4	523.5	43.7	4.6	620.2
J.	C	76.3	40.9	758.7	39.7	915.7
i.t	D					251.7
В	Sum	1085	690	830	235	2840

		Pia	се от г	resiaei	nce (t	+ 1 $/$
		Α	_			Śum
e,	Α	976.1	56.5	9.9	9.8	1052.3 620.2 915.7 251.7 2840
npiac	В	48.4	528.8	43	0	620.2
	C	69.8	70.6	706.6	68.7	915.7
Ĕ	D	30.7	29	20.5	171.5	251.7
נו	Sum	1125	685	780	250	2840

Dlana of Danidon on (+ + 1)

Estimated Flow Table:

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

Altered Migrant Stock Data:

	Place of Residence (t)					
		Α	В	C	D	` ´Sum
e,	Α	942	101	9.4	0	1052.3
lac	A B C D	48.4	523.5	43.7	4.6	620.2
d4	C	76.3	40.9	758.7	39.7	915.7
ij	D					251.7
Е	Sum	1085	690	830	235	2840

		Pla	ce ot f	Reside	nce (t	+1)
		Α				Sum
ή	Α	976.1	56.5	9.9	9.8	1052.3 620.2 915.7 251.7 2840
ğ	В	48.4	528.8	43	0	620.2
₹	C	69.8	70.6	706.6	68.7	915.7
=	D	30.7	29	20.5	171.5	251.7
7	Sum	1125	685	780	250	2840

Estimated Flow Table:

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

$$P^{t+1}$$
 $-P^t$ $+D$ $-B$ =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

Application: Science (2014)

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

- Complete bilateral stock tables
- Issues of definitions, changes in geography, aggregated data and missing values were addressed.
- Interpolated reported data to beginning of each decade (1990, 2000 and 2010)

Application: Science (2014)

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

- Complete bilateral stock tables
- Issues of definitions, changes in geography, aggregated data and missing values were addressed.
- Interpolated reported data to beginning of each decade (1990, 2000 and 2010)

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.
- ullet Inverse of distance matrix for offset term, m_{ij}
- Estimate are of 5-year migrant transition flows.



 Difficult due to lack of migrant transition bilateral flow data available.



- Difficult due to lack of migrant transition bilateral flow data available.
- Match UN net migration estimates.



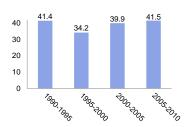
- Difficult due to lack of migrant transition bilateral flow data available.
- Match UN net migration estimates.
- Comparisons with census questions on previous residence 5 years ago reveal similar origin patterns.

- Difficult due to lack of migrant transition bilateral flow data available.
- Match UN net migration estimates.
- Comparisons with census questions on previous residence 5 years ago reveal similar origin patterns.
- Gravity models at the global level return plausible parameters.

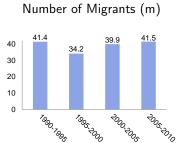
• Global intensity of migration has not been continuously upwards

Global intensity of migration has not been continuously upwards

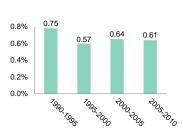
Number of Migrants (m)



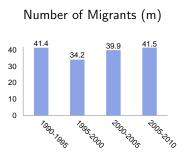
Global intensity of migration has not been continuously upwards



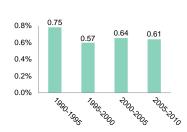
Percentage of Global Population



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

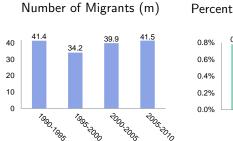


Percentage of Global Population

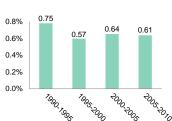




- Global intensity of migration has not been continuously upwards
- Around 0.6% of the world's population move over 5-year periods
- Higher intensities in 1990-95 mostly due to violent conflicts in Afghanistan and Rwanda. Fall of Iron Curtain.



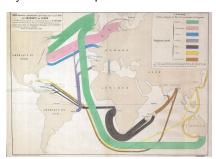
Percentage of Global Population





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!



