1 Calibration against independent human travel datasets

1.1 Calibration against United States Bureau of Transportation Statistics Data

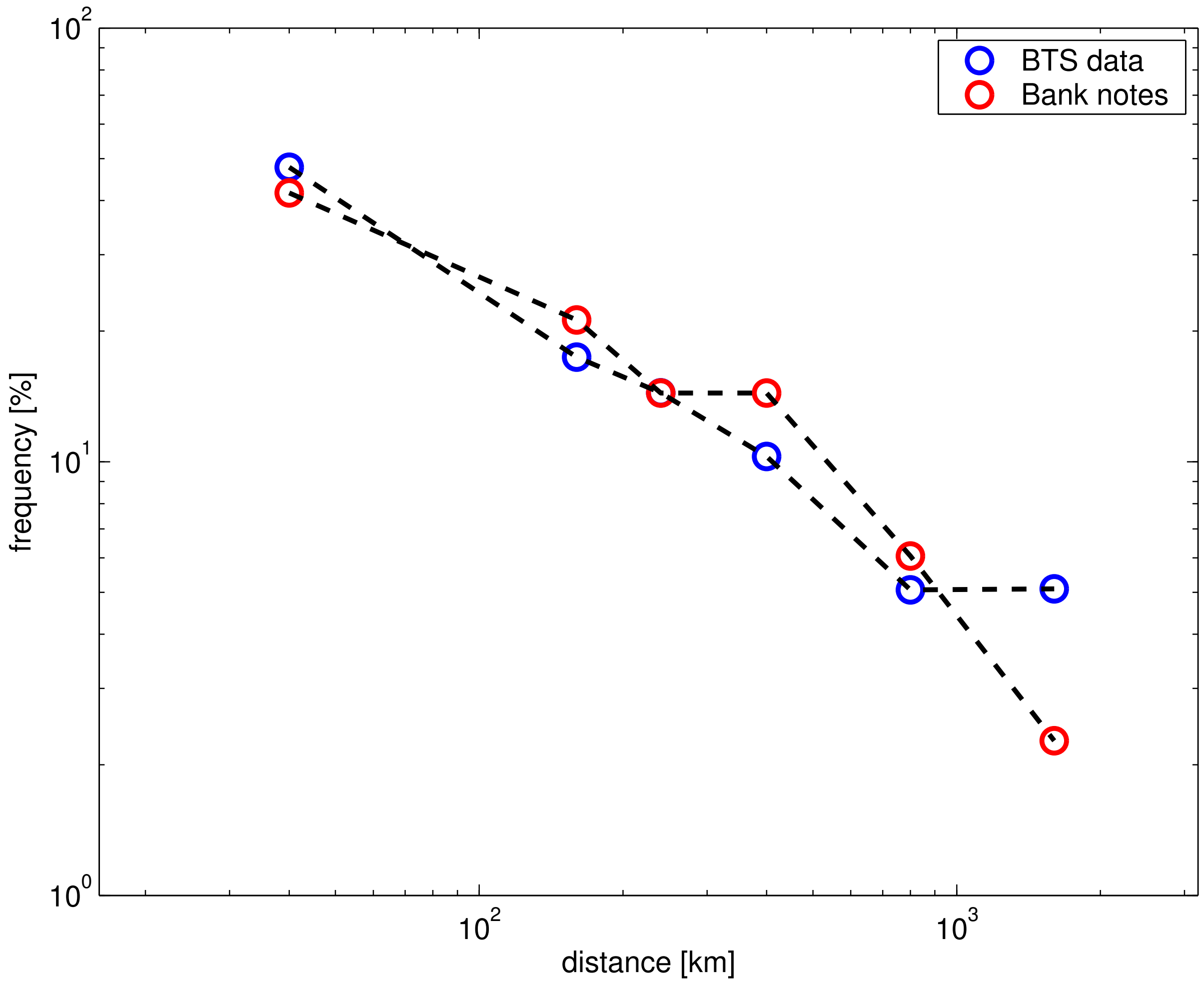

Figure 1.1: Histrograms comparing the travelling data published by the BTS with short time bank note dispersal. The symbols denote the percentage of distances travelled within the limits of the categories listed in table 1.1 as a function of the lower bound of the distance bins.

Along an independent line we have compared our results to data published by the United States Bureau of Transportation Statistics (BTS, www.bts.gov). The BTS has evaluated 2,617,126 round trip distances of at least 50 miles. Details of the survey can be found in Table 1-39 in the section *National Transportation Statistics* at www.bts.gov. Although the BTS dataset is large, the movements were histogrammed with a low spatial resolution: The distances d travelled were grouped into bins:

$$\begin{array}{ccc} 25\,\text{miles} & < d < & 100\,\text{miles} \\ 100\,\text{miles} & < d < & 150\,\text{miles} \\ 150\,\text{miles} & < d < & 250\,\text{miles} \\ 250\,\text{miles} & < d < & 500\,\text{miles} \\ 500\,\text{miles} & < d < & 1000\,\text{miles} \\ 1000\,\text{miles} & < d & \end{array} \tag{1.1}$$

We have computed the same histogram from the short time ($\Delta t < 2$ days) bank note dispersal, the results of which are shown in Fig. 1.1. The BTS data agrees well with the bank note dispersal data, thus confirming our results. We would like to point out, that our data permits a much higher spatial resolution than those published by the BTS.

1.2 Correlation of bank note transport and long distance aviation travel

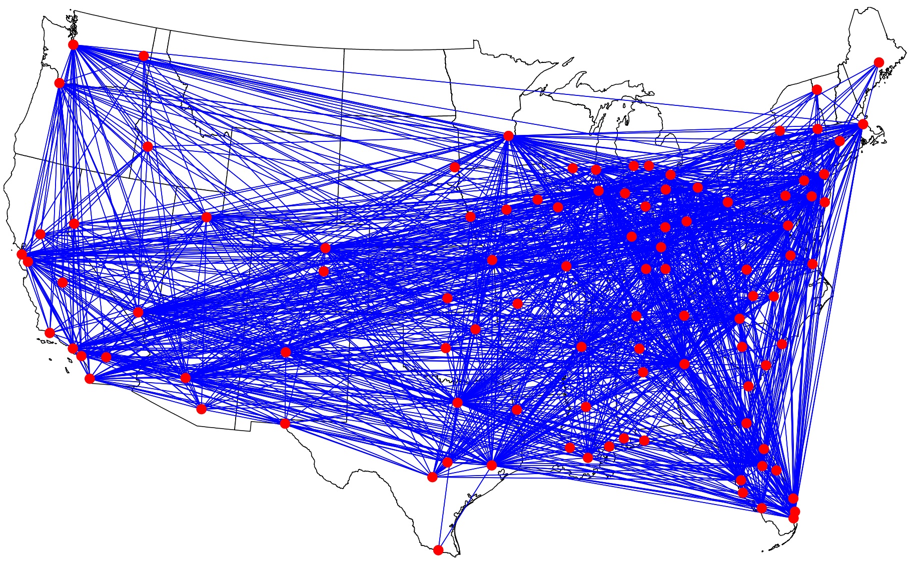

Figure 1.2: The civil aviation network of the United States. The 102 largest airports are depicted by red symbols. Blue lines represent connections between airports. The entire network consists of 2,743 weighed connections transporting approximately 3.9 million passengers per day.

In order to verify our results we compared the transport of bank notes with passenger flux on the US aviation network (Fig. 1.2). In this comparison we considered approx. 95% of the entire US-aviation network. This network can be represented by a matrix W each element W_{ij} of which represents the number of passengers travelling between airport i and j per unit time. The network represents a subnetwork of the entire worldwide aviation network which was recently employed in a study of the worldwide spread of human infectious disease [1].

The flux matrix W_{ij} represents an approximate measure for the short time travelling behavior of humans on large geographical scales between urban areas in the United States. If the inference from bank note dynamics to humans is valid, one expects the matrix W_{ij} to correlate significantly with the flux of bank notes between nodes i and j. The transport of bank notes can be represented by a matrix element M_{ij}, i.e. the number of bank notes which travelled from i to j in a short period of time Δt. This number

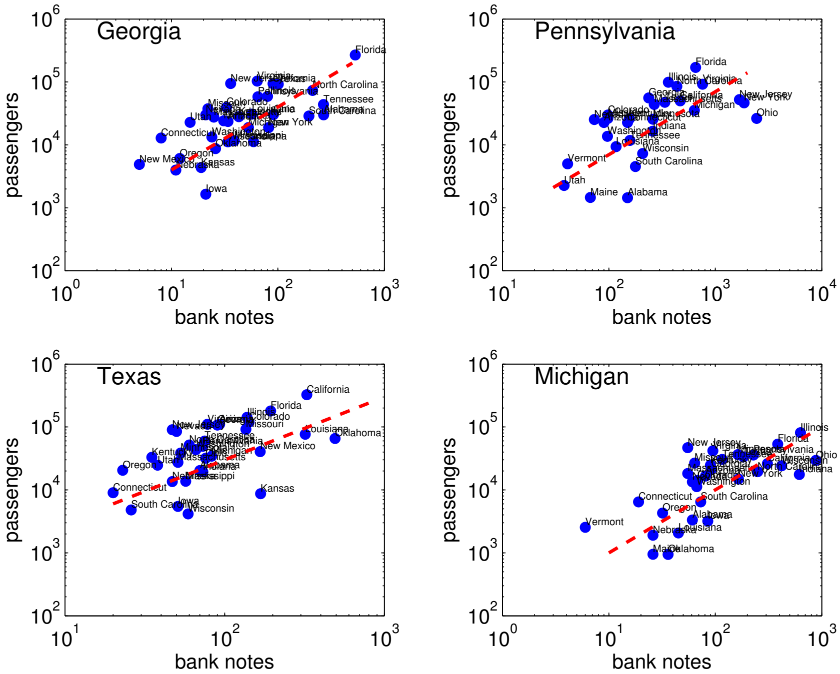

Figure 1.3: The correlation between human long distance travel and short time bank note transport. For the states n =Georgia, Pennsylvania, Texas and Michigan each panel depicts the number of passengers $\tilde{W}_{mn}$ travelling to target states per day versus the number of bank notes $\tilde{M}_{mn}$ transported within a time interval $\Delta t = 4$ weeks (blue symbols). The red dashed line represents a linear relationship.

can be extracted from our bill tracking dataset. In order to obtain reliable statistics, we computed the flux of passengers on one hand and bank notes on the other between 48 states. For each state n we determined the number of passengers $\tilde{W}_{mn}$ and bank notes $\tilde{M}_{mn}$ which travelled to state m from the underlying matrices W_{ij} and M_{ij}, respectively.

Fig. 1.3 depicts scatter plots of $\tilde{W}_{mn}$ versus $\tilde{M}_{mn}$ for four representative states, i.e. n =Georgia, Pennsylvania, Texas and Michigan on a log-log scale. Flux elements for which either $\tilde{M}_{mn} = 0$ or $\tilde{W}_{mn} = 0$ we excluded. Apart from fluctuations, the scatter plots are in agreement with a linear relation between human and bank note dispersal which supports the idea put forward in this work. Of course, an exact proportionality can not be expected. For example passenger flux between geographically adjacent states is less than bank note flux as bank notes primarily travel by other means of transportation (car, train) between such states. On the other hand, passenger flux to an airport with a catchment area overlapping with a number of geographically small but highly populated states (New England States such as Rhode Island, Delaware, etc.) is larger than the associated bank note dispersal. In order to obtain a significant flux of bank notes we had to increase the inter report time interval to four weeks. Despite these and other error sources, the correlation is significantly positive.

The degree of correlation can be quantified by the correlation coefficient

$$R = \frac{\left\langle \tilde{W}_{mn} \tilde{M}_{mn} \right\rangle - \left\langle \tilde{W}_{mn} \right\rangle \left\langle \tilde{M}_{mn} \right\rangle}{\sqrt{\left(\left\langle \tilde{W}_{mn}^2 \right\rangle - \left\langle \tilde{W}_{mn} \right\rangle^2\right)\left(\left\langle \tilde{M}_{mn} \right\rangle - \left\langle \tilde{M}_{mn} \right\rangle^2\right)}}. \tag{1.2}$$

For perfectly correlated and anti-correlated quantities $R = 1$ and $R = -1$, respectively. For statistically independent variables $R = 0$. The correlation coefficient for all 48 States individually and together is listed in Table 1. The transport of passengers and bank notes to all other states exhibit a significant degree of correlation with an overall correlation coefficient of approximately 0.5.

State	R	**# target states** m	**State**	R	**# target states** m
All States	**0.47**	**882**			
Illinois	0.51	37	Connecticut	0.03	17
Kentucky	0.57	36	New Mexico	0.42	16
Georgia	0.67	34	Nebraska	0.73	16
Texas	0.57	33	Oklahoma	0.69	15
New Jersey	0.57	33	Alabama	0.69	15
Minnesota	0.47	33	Iowa	0.64	13
Arizona	0.68	33	South Carolina	0.64	10
Missouri	0.24	32	Kansas	0.50	10
Michigan	0.69	32	Vermont	-0.30	9
Nevada	0.79	31	Idaho	0.45	9
Colorado	0.53	31	Mississippi	0.39	8
Florida	0.68	30	Maine	0.34	7
Tennessee	0.67	29	South Dakota	0.93	4
Pennsylvania	0.62	29	Wyoming	-	-
North Carolina	0.67	27	West Virginia	-	-
Massachusetts	0.40	26	Rhode Island	-	-
California	0.63	26	North Dakota	-	-
Ohio	0.53	25	New Hampshire	-	-
Wisconsin	0.31	23	Montana	-	-
Washington	0.49	23	Maryland	-	-
Utah	0.50	21	Delaware	-	-
Indiana	0.21	21	Arkansas	-	-
Louisiana	0.63	20			
New York	0.57	17			

Table 1.1: The correlation between long distance travel and short time bank note transport. For each state n and the set of connected target states (i.e. those states m for which both $\tilde{W}_{mn}$ and $\tilde{M}_{mn}$ are nonzero) the correlation coefficient (Eq. 1.2) is computed. For all states the correlation is significantly positive as well as for the entire set of flux connection $n \to m$ (ensemble size: 882).

Bibliography

[1] L. Hufnagel, D. Brockmann, and T. Geisel, *Forecast and control of epidemics in a globalized world*, PNAS **101** (2004), 15124–15129.