Spatial Variation in the Twinning Rate in Sweden, 1751–1850

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Strong geographical variations in the twinning rate have been presented in the literature. In general, the rate is high among people of African origin, intermediate among Europeans and low among most Asiatic populations. In Europe, a progressive increase has occurred in the twinning rate from south to north, with a minimum around the Basque provinces. The highest twinning rates in Europe have been found among Nordic populations with the exception of the Saamis (Lapps). Within larger populations, some small isolated subpopulations have been identified to have extreme, mainly high, twinning rates. In this study, we investigated the regional variation of the twinning rate in Sweden. We analysed twinning rates for different counties for the period 1751–1850. From the middle of the 19th century, the environmental and genetic differences have decreased and the regional twinning rates have converged towards a common decreased level. The models applied have the geographical coordinates as regressors. The optimal model for the twinning rate has the longitude, the latitude and their product as regressors, indicating both horizontal and vertical trends. According to this model, the maximum twinning rate in Sweden is located in the eastern part of central Sweden, mainly on the island of Gotland and in the counties around Stockholm. Relatively low twinning rates are seen in the western and northern parts of Sweden.

Keywords: geographical coordinates, multicollinearity, regression analysis

Strong geographical variations in the twinning rate (TWR) have been noted in the literature. The rate is high among people of African origin, intermediate among Europeans and low among most Asiatic populations, including the American Indians (Bulmer, 1970; Eriksson, 1973a; Little & Thompson, 1988). In Europe, there tends to be a south–north cline, with a progressive increase in the TWR from south to north, a minimum occurring around the Basque provinces on the border between Spain and France. The highest TWRs in Europe have been found among Nordic populations (Bulmer, 1970; Eriksson, 1964, 1973a; James, 1985). Furthermore, within larger populations some small isolated subpopulations have been identified as having extreme, mainly high, TWRs (for references, see Eriksson & Fellman, 2009). In our studies of the regional variation of the TWR in Sweden, we have analysed TWRs for the different counties and observed marked but gradually diminishing regional differences (Eriksson & Fellman, 2004; Fellman & Eriksson, 2003, 2004, 2005).

Material

We analysed regional twinning data from over 6 millions maternities from 1751 to 1850 in Sweden. The data were collected from official statistics. In the middle of the 19th century, Statistics Sweden published in the journal 'Statistisk Tidskrift' a long term series of regional demographic data. The regional data were given for the counties. These time series started in 1749, corresponding to the launching of 'Tabellverket' (the predecessor to Statistics Sweden). Depending on the time of publication, the time series ended in 1858–1874. Therefore, periods with available data varied somewhat from county to county. The available official sources are presented in Table 1 and regional data in Table 2. For almost all counties (exceptions being Stockholm city and Gotland county) data are missing for 1774–1794. During this period the regional data were grouped according to dioceses, not according to counties, but for Stockholm city and Gotland the dioceses and counties were identical. Some counties were established markedly later than 1751, resulting in shorter observation periods (c.f. Table 1). In addition, for some counties some annual data were missing or incomplete, and these years were thus excluded. We have not considered more recent data because genetic and environmental variations have subsequently decreased and the regional TWRs have converged towards a common low level (Fellman & Eriksson, 2005).

Methods

Model Building

We applied spatial regression models on the regional TWRs. The location of the counties was defined as the

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Table 1

Regional Division of Sweden into 25 Counties (in Swedish län) and the Sources for Regional Data Concerning Population Size, Births and Twin Maternities for the Period 1749–1888 (ST = 'Statistisk Tidskrift')

County (Län)	Code	Period	Reference
Stockholm (city)	a	1749–1858	ST, 1860–62:43–47
Stockholm (county)	b	1749–1773, 1795–1858	ST, 1860–62:134–141
Uppsala	c	1749–1773, 1795–1859	ST, 1860–62:280–288
Södermanland	d	1749–1773, 1795–1859	ST, 1860–62: 317–324
Östergötland	e	1749–1773, 1795–1860	ST, 1863–65:164–171
Jönköping	f	1749–1773, 1795–1862	ST, 1863–65:266–273
Kronoberg	g	1749–1773, 1795–1862	ST, 1863–65:274–281
Kalmar	h	1749–1773, 1795–1868	ST, 1870:211–220
Gotland	i	1759–1869	ST, 1870:27:221–231
Blekinge	k	1749–1773, 1795–1869	ST, 1870:232–240
Kristianstad	l	1749–1773, 1795–1871	ST, 1873:133–142
Malmöhus	m	1749–1773, 1795–1871	ST, 1873:143–152
Halland	n	1749–1773, 1795–1871	ST, 1873:153–162
Gothenburg and Bohus	o	1749–1773, 1795–1859	ST, 1860–62:388–400
Älvsborg	p	1749–1773, 1795–1874	ST, 1875:127–136
Skaraborg	r	1749–1773, 1795–1876	ST, 1877:156–160
Värmland	s	1795–1865	ST, 1877:170–176
Örebro	t	. .	. .
Västmanland	u	1749–1773, 1795–1887	ST, 1888:159–170
Kopparberg	w	1749–1773, 1795–1887	ST, 1888:171–182
Gävleborg	x	1763–1773, 1793–1888	ST, 1888:161–172
Västernorrland	y	1792–1888	ST, 1888:173–184
Jämtland	z	1792–1888	ST, 1888:185–196
Västerbotten	ac	1802–1860	ST, 1863–65:50–57
Norrbotten	bd	1802–1860	ST, 1863–65:44–49

Note: No data available for Örebro, 1751–1850. In addition, Statistics Sweden has published official statistics for the counties since 1871. The letter codes of the counties are the official codes given by Statistics Sweden.

geographical coordinates of the corresponding residences. The coordinates for Sweden are eastern longitude and northern latitude. The residences are not centrally located (see Figure 1), but we assume that they are sufficiently central with respect to the population density. The coordinates of the counties (residences) are given in Table 2.

We analysed the spatial variation in the TWR by weighted regression models. We used weighted models because sample sizes of the different counties were different. As weights we used the number of maternities (Fellman & Eriksson, 1987). The regressand was the observed TWR and the presumptive regressors were the longitude (meridian) M and the latitude L, and the regressors of second order, M^2, L^2 and LM. The regressors M and L were defined as deviations from the coordinates of the unweighted centre (15.90°E and 59.18°N) of the cluster of residences, and consequently, the intercept obtained is an estimate of the TWR in this centre. The maximal model is

$$TWR = \alpha + \beta_M M + \beta_{M^2} M^2 + \beta_L L + \beta_{L^2} L^2 + \beta_{LM} LM + \varepsilon. \quad (1)$$

Measures of the Multicollinearity

The elongated/drawn-out format of Sweden indicates that attention must be paid to the multicollinearity between regressors. In general, the multicollinearity pattern can show marked variations, and therefore, different measures have been proposed in the literature. In the following, a short presentation of these is given.

Consider a set of variables (regressors) $u_1, u_2, \ldots, u_n$ and their correlation matrix

$$\boldsymbol{C} = \begin{bmatrix} 1 & c_{12} & \ldots & c_{1j} & \ldots & c_{1n} \\ c_{21} & 1 & \ldots & c_{2j} & \ldots & c_{2n} \\ . & . & . & . & . & . \\ c_{i1} & c_{i2} & \ldots & c_{ij} & \ldots & c_{in} \\ . & . & . & . & . & . \\ c_{n1} & c_{n2} & \ldots & c_{nj} & \ldots & 1 \end{bmatrix}, \quad (2)$$

where $c_{ij} = cor(u_i, u_j)$. If the variables are mutually uncorrelated, the correlation matrix equals the identity matrix

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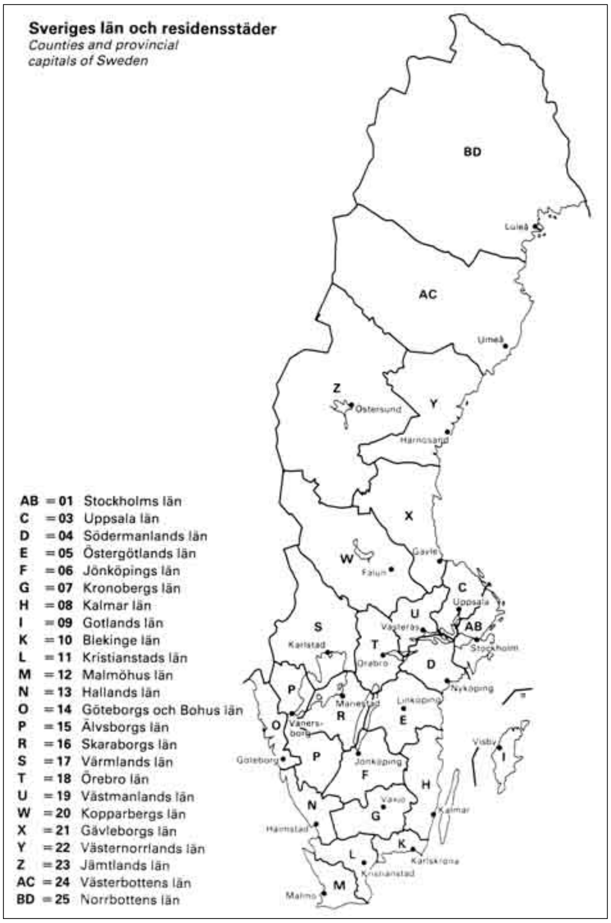

Figure 1

Map of Sweden including the counties and their residences and letter codes according to Statistics Sweden.

$$\boldsymbol{I} = \begin{bmatrix} 1 & 0 & \dots & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 & \dots & 0 \\ . & . & . & . & . & . \\ 0 & 0 & \dots & 1 & \dots & 0 \\ . & . & . & . & . & . \\ 0 & 0 & \dots & 0 & \dots & 1 \end{bmatrix}. \qquad (3)$$

The equation

$$det(\boldsymbol{C} - \lambda\boldsymbol{I}) = det \begin{bmatrix} 1-\lambda & c_{12} & \dots & c_{1j} & \dots & c_{1n} \\ c_{21} & 1-\lambda & \dots & c_{2j} & \dots & c_{2n} \\ . & . & . & . & . & . \\ c_{i1} & c_{i2} & \dots & c_{ij} & \dots & c_{in} \\ . & . & . & . & . & . \\ c_{n1} & c_{n2} & \dots & c_{nj} & \dots & 1-\lambda \end{bmatrix} = 0 \qquad (4)$$

is an algebraic equation of degree n. Consequently, it has n roots $\lambda_1, \lambda_2, \dots, \lambda_n$, which are defined as the *eigenvalues* of the matrix **C** in (2). For every correlation matrix, the roots are real and non-negative and

$$\sum_{i=1}^{n} \lambda_i = n .$$

We number the roots such that $0 \le \lambda_1 \le \lambda_2 \le \dots \le \lambda_n$. If the variables are uncorrelated, all eigenvalues are one. If there are marked correlations between the variables, one speaks about *multicollinearity* and there are small eigenvalues. This situation causes reduced accuracy in the estimates, that is, increased standard errors (SEs). If at least one exact linear relation between the variables can be found, then zero eigenvalues exist, the correlation matrix is singular and not all parameters are estimable. Under such circumstances, the set of regressors must be reduced.

Fellman (1981) has given a review of the literature and detailed presentations of measures of multicollinearity based on the eigenvalues of the correlation matrix. He discussed the pros and cons of the different multicollinearity measures and stated that a good measure should satisfy the following conditions:

1. The measure defines a critical level above (or below) which the corresponding correlation matrix should be considered strongly multicollinear.
2. The measure can be used for comparisons between different correlation matrices.

These properties imply that the measure must be (at least in a loose sense) 'monotonic', and the effect of the dimension of the matrix on the measure should not be too great.

Below we present some standard measures of multicollinearity. The simplest measure is the inverse of the minimum eigenvalue $m_1 = \lambda_1^{-1}$. In the uncorrelated case $m_1 = 1$, but with increasing multicollinearity m_1 increases towards infinity. The next measure, proposed by Wichern and Churchill (1978) and Casella (1980), is

$$m_2 = \frac{\lambda_n}{\lambda_1}.$$

This measure is defined as the *condition number* of the matrix. In the uncorrelated case $m_2 = 1$, and with increasing multicollinearity m_2 increases towards infinity. The measures m_1 and m_2 are simple to handle, but their weakness is that they are mainly based on the smallest eigenvalue. Other small eigenvalues are mainly ignored.

The determinant of the correlation matrix, $m_3 = det(\mathbf{C}) = \lambda_1\lambda_2 \dots \lambda_n$, has also been used as a measure of multicollinearity. In the uncorrelated case $m_3 = 1$, but with increasing multicollinearity it *decreases* towards zero. The measure m_3 depends strongly on the dimension of the matrix and is suitable only for matrices with low dimension.

Mahajan et al. (1877) and Lawless (1978) considered the sum

$$m_4 = \sum \frac{1}{\lambda_i}.$$

For uncorrelated variables, its value is n. With increasing multicollinearity, it increases towards infinity. The

Table 2

Regional Data and Observed and Estimated Twinning Rates in Sweden, 1751–1850

County (Län)	Code	Period	Latitude	Longitude	Maternities	*TWR*	$\overline{TWR}$
Stockholm (city)	A	1751–1850	59.32	18.07	267273	15.972	17.161
Stockholm (county)	B	1751–1850	59.32	18.07	245049	17.898	17.161
Uppsala	C	1751–1850	59.90	17.80	192169	16.865	16.530
Södermanland	D	1751–1850	58.76	17.01	234636	17.210	16.634
Östergötland	E	1751–1850	58.42	15.64	415891	15.826	15.694
Jönköping	F	1751–1850	57.78	14.18	306345	14.232	14.759
Kronoberg	G	1751–1850	56.86	14.82	259619	13.797	15.498
Kalmar	H	1751–1850	56.80	16.00	379485	15.795	16.666
Gotland	I	1751–1850	57.63	18.30	93381	21.792	18.642
Blekinge	K	1751–1850	56.16	15.58	206449	15.161	16.472
Kristianstad	L	1751–1850	56.02	14.13	334802	15.197	15.007
Malmöhus	M	1751–1850	55.61	13.06	461182	15.224	13.997
Halland	N	1751–1850	56.67	12.86	200631	14.275	13.834
Göteborg and Bohus	O	1751–1850	58.35	11.93	347927	13.713	13.367
Älvsborg	P	1751–1850	58.37	12.32	431374	13.017	13.563
Skaraborg	R	1751–1850	58.71	13.82	377173	14.468	14.373
Värmland	S	1795–1850	59.38	13.50	304879	13.189	14.124
Västmanland	U	1751–1850	59.67	16.55	208759	16.747	15.778
Kopparberg	W	1751–1850	60.61	15.64	271635	15.109	14.811
Gävleborg	X	1763–1850	60.68	17.16	172042	16.798	15.579
Västernorrland	Y	1792–1850	62.63	17.94	137553	15.071	14.611
Jämtland	Z	1792–1850	63.18	14.65	60209	14.782	13.631
Västerbotten	AC	1802–1850	63.83	20.27	84630	12.584	14.422
Norrbotten	BD	1802–1850	65.59	22.17	78076	12.539	12.938
Total		1751–1850			6071169	15.146	

Note: For almost all counties (exceptions being Stockholm city and Gotland county) data are missing for the period 1774–1794. For some counties, some annual data are incomplete and the corresponding years are thus excluded. For detailed information about the periods available for the different counties, see Table 1. The latitudes and longitudes are the coordinates of the residences of the counties. The *TWR* is the observed and $\overline{TWR}$ the estimated TWR of the county according to model 5. For details, see the text.

advantage of m_4 over m_1 and m_2 is that it takes into account the effect of several small eigenvalues.

Thisted (1980) suggested two measures,

$$m_5 = \sum\left(\frac{\lambda_1}{\lambda_i}\right)^2 \text{ and } m_6 = \sum\left(\frac{\lambda_1}{\lambda_i}\right).$$

These measures satisfy the inequalities $1 < m_5 \le m_6 \le n$. The equality signs hold only in the orthogonal case. For uncorrelated variables, these measures obtain the value n, and when the multicollinearity increases they decrease towards one. Thisted (1980) recommended m_5 in estimation and m_6 in prediction situations. The main criticism against these measures is that while they can be used when there is one extremely small eigenvalue, if there are several small eigenvalues the measures are rather worthless.

The measure

$$m_7 = \sum\left(\frac{n}{\lambda_i m_4} - 1\right)^2$$

was introduced by Vinod (1976). It is zero for complete orthogonal systems, but according to Vinod the components in the sum will be large for non-orthogonal data. However, the value of m_7 depends to a large extent on the relative proportions between eigenvalues and does not satisfy the assumption of a monotone function. Consequently, it is useful only when dealing with a correlation matrix with only one small eigenvalue.

Fellman (1981) introduced the measure

$$m_8 = \sum\left(\frac{1-\lambda_i}{\lambda_i^2}\right).$$

He presented arguments for its suitability as a multicollinearity measure and proved that $m_8 \ge 0$, with equality in the orthogonal case, and that

$$\lim_{\lambda_1 \to 0} m_8 = \infty.$$

When we consider the variables M, M^2, L, L^2 and LM, the dimension is low and several small eigenvalues may exist, and consequently, in this study we consider the measures m_3, m_4 and m_8, and in Table 3 we list them and their basic properties.

Table 3

Definition and Properties of Some Measures of Multicollinearity (the multicollinearity measures for our Swedish data are also included; for details, see the text)

Measure	Formula	Theoretical range Multicollinearity No	Exact	Reference	Sweden Regression model Full[1]	Optimal[2]
m_3	$\lambda_1\lambda_2\ldots\lambda_n$	1	0		0.0096	0.3972
m_4	$\sum \frac{1}{\lambda_i}$	n	∞	Lawless (1978) Mahajan (1977)	32.56	6.267
m_8	$\sum \left(\frac{1-\lambda_i}{\lambda_i^2} \right)$	0	∞	Fellman (1981)	425.6	6.988

(1) *M, M², L, L², LM*

(2) *M, L, ML*

Results

Multicollinearity

A map of Sweden and its counties together with their residences and letter codes published by Statistics Sweden (1987; p. 8) is presented in Figure 1. In the text, we use the official letter codes of the counties in accordance with Statistics Sweden,. To study the multicollinearity, we start from the full regression model (1) with the variables M, M^2, L, L^2 and LM. Including the intercept in the weighted regression model, we obtain the eigenvalues $\lambda_1 = 0.04731$, $\lambda_2 = 0.1531$, $\lambda_3 = 0.4680$, $\lambda_4 = 0.5449$, $\lambda_5 = 1.6629$ and $\lambda_6 = 3.1238$. The first eigenvalue is extremely small and the second also is rather small, and a notable multicollinearity is obvious. The multicollinearity measures for our full regression model are presented in Table 3.

The stepwise regression procedure yields an optimal model containing the variables M, L and LM. The multicollinearity is reduced and it improves the accuracy of the estimates. Now, the eigenvalues are $\lambda_1 = 0.3682$, $\lambda_2 = 0.4492$, $\lambda_3 = 1.2293$ and $\lambda_4 = 1.9532$. The corresponding multicollinearity measures are also included in Table 3. We note that m_3 increases from 0.0096 to 0.3972, and m_4 and m_8 decrease from 32.56 to 6.267 and from 425.6 to 6.988, respectively. Consequently, for the optimal model the residences are, with respect to the analyses, rather well distributed over the country (Figure 1).

The optimal regression model

The estimated optimal model is

$$TWR = 15.676483 + 0.636943M - 0.376847L - 0.111854ML. \quad (5)$$

For this model, the adjusted coefficient of determination is $\overline{R}^2 = 0.602$, indicating an acceptable fit. The estimated TWR in the centre of the cluster of residences is $\hat{\alpha} = 15.676$. The SEs of the estimated parameters are $SE_{\hat{\alpha}} = 0.258$, $SE_{\hat{\beta}_M} = 0.117$, $SE_{\hat{\beta}_L} = 0.131$ and $SE_{\hat{\beta}_{ML}} = 0.037$, and all parameter estimates are statistically significant. This model indicates that both a west-east and a south-north trend exist. We assume that the regional TWR estimates obtained by model 5 are the best, and together with the observed TWRs they are included in Table 2 and Figure 2.

If we assume that model 5 holds, then we obtain hyperbolic level curves for the TWRs. Let $TWR_0 = R$ be a constant value, then the equation of the corresponding level curve is $\beta_M M + \beta_L L + \beta_{LL} ML + \alpha - R = 0$, indicating a hyperbolic curve with a horizontal and a vertical axis. Furthermore, the axes are independent of the chosen TWR level. According to the parameter estimates, the vertical axis is the longitude 12.53°E and the horizontal axis the latitude 64.87°N. The residences and the level curves are depicted in Figure 3.

The gradients for the TWR levels, being orthogonal to the level curves and directed towards increasing TWRs, have south-eastern directions and indicate that the TWR obtains its maximum for Sweden in an eastern region in the county of the island of Gotland (I) and the counties of Stockholm (B), Uppsala (C) and Södermanland (D) around the city of Stockholm on the eastern coast of central Sweden. The TWR in the city of Stockholm (15.97) was slightly above the total mean 15.15 for Sweden, but lower than the TWRs in the surrounding rural counties. During the period studied the approximate number of inhabitants in the city of Stockholm was 56,000 in 1750, 75,500 in 1800 and 93,000 in 1850, and Stockholm was the only big city in Sweden, being a melting pot of Swedes and foreigners from different regions and countries. The total number of inhabitants in all Swedish towns outside Stockholm was 154,000 in 1800 and 258,000 in 1850. The rural nature of Sweden is reflected by the fact that in 1800 there were only two towns outside the city of Stockholm with more than 10,000 inhabitants, namely Gothenburg (12,800) and Karlskrona (10,200). In addition, the average number of inhabitants in the rest of the towns was less than 1,600.

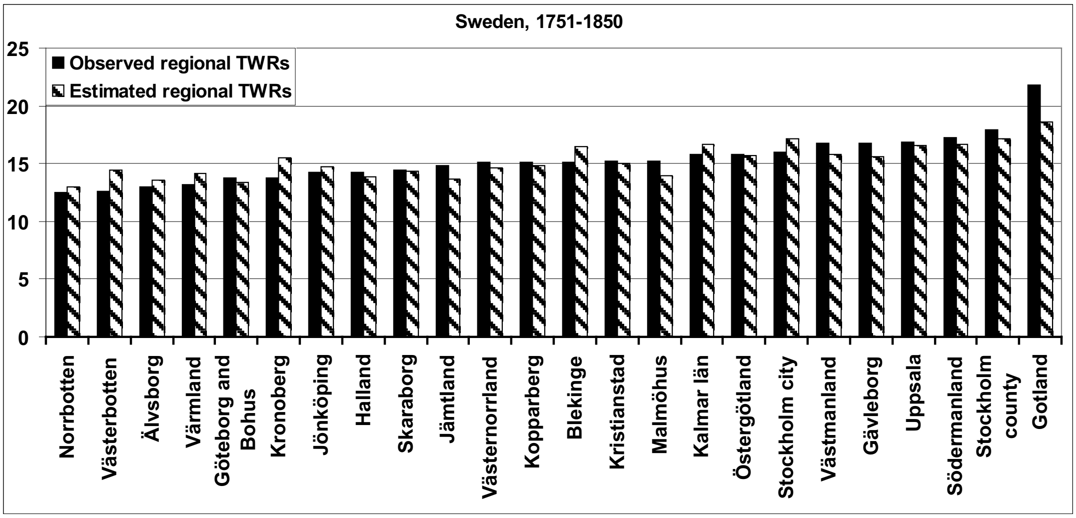

Figure 2

Observed and estimated regional TWRs. The counties are presented according to increasing observed TWRs. The estimated TWRs are based on the optimal model 5.

In the northern counties of Västerbotten (AC) and Norrbotten (BD), the TWRs are lowest for Sweden. Low TWRs were also observed in the western counties of Älvsborg (P), Värmland (S) and Gothenburg and Bohus (O) (cf. Figures 1 and 2 and Table 2). This heterogeneity is in good agreement with earlier results (Fellman & Eriksson, 2003, 2005).

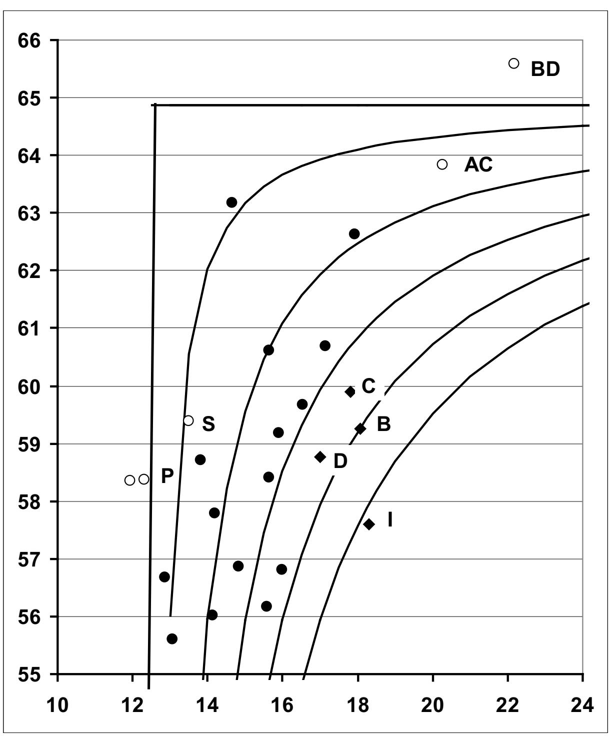

Figure 3

A graphical depiction of the regional TWRs. The counties of Stockholm (B), Uppsala (C), Södermanland (D) and Gotland (I) with high TWRs (♦) and Älvsborg (P), Värmland (S), Västerbotten (AC) and Norrbotten (BD) with low TWRs (o) are indicated. Compare this figure with Figure 4, where the temporal trends of extreme TWRs are presented.

Figure 4 shows the temporal trends in the TWRs of four regions with extreme TWRs. The highest is the TWR on the island of Gotland (I). The next highest TWR is in the eastern region consisting of the counties of Stockholm (B), Uppsala (C) and Södermanland (D). The western region with low TWR comprises of the counties of Älvsborg (P), Värmland (S) and Gothenburg and Bohus (O). Finally, the northern region, including Västerbotten (AC) and Norrbotten (BD), has the lowest TWR. The figure shows a common slight decreasing trend, but heterogeneity in the TWRs is rather constant for 1751–1850.

Discussion

The analyses of the regression models for Sweden indicate that both vertical and horizontal trends must be considered. An increasing gradient appears in the eastern direction, and high TWRs were observed in the eastern part of central Sweden. Notably, this part is geographically close to the Åland Islands and the archipelago of Åboland in south-western Finland. The results indicate that for the period 1751–1850 the TWR had a distinct maximum in many regions surrounding the north-western part of the Baltic Sea (Eriksson, 1973a).

The observed decreasing tendency with respect to increasing latitude may at least partly be caused by the Saamis (Lapps) living in the northern part of Sweden (e.g. Västernorrland (Y), Jämtland (Z), Västerbotten (AC) and Norrbotten (BD)). The Saamis also have some anthropometric and genetic characteristics that are quite different from those of surrounding populations (Eriksson, 1973b, 1988; Beckman, 1996). The Saamis, like the Basques, are supposed to be an

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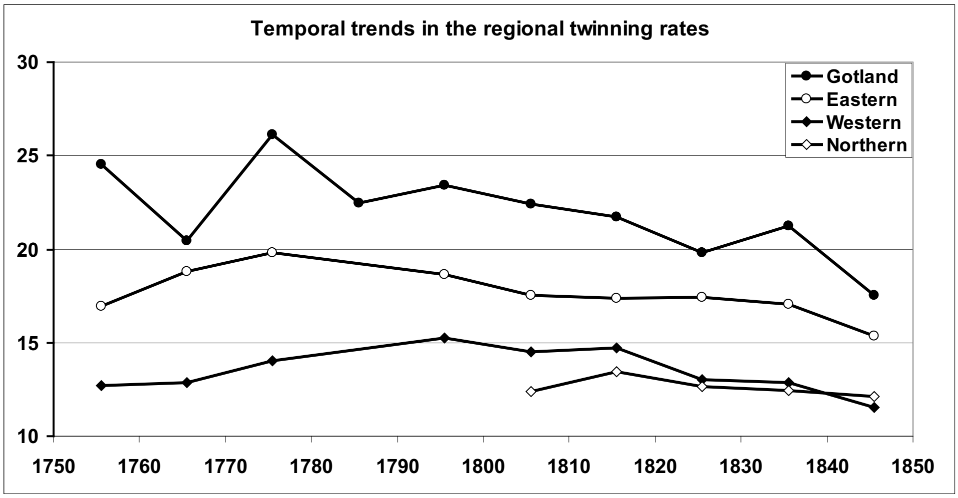

Figure 4

Temporal trends in TWRs in the county of Gotland and the eastern counties (Stockholm, Uppsala and Södermanland) with high TWRs, and the western counties (Älvsborg and Värmland) and northern counties (Västerbotten and Norrbotten) with low TWRs. The figure indicates slightly decreasing trends, but the relation between the TWRs levels is rather constant.

ancient population in Europe, and both seem to have rather low TWRs, only about 7–9 per 1000 for the Saamis, thus approximately one half of that of other Fenno-Scandinavian populations (Eriksson, 1973a).

Torgersen (1951) studied the regional variation in the TWR in Norway (1875–1948). Although he examined more recent data than ours, interesting comparisons can be made. Norway is a narrow, neighbouring country to Sweden, and they have a long common border in the south-north direction. Torgersen divided Norway into four regions: two southern regions (eastern and western), a middle region and a northern region. He noted that the TWR was high in the eastern (*13.64 ± 0.09* per 1000) and the middle (*13.81 ± 0.16*) regions. In the western region the TWR was low (*13.02 ± 0.14*), and in the northern region there was a minimum (*12.73 ± 0.16*). The low TWR in the northern region agrees with our results. Torgersen's eastern region is close to our western region of Sweden, but here he noted a relatively high rate for Norway, while we found a low rate for Sweden. These rates are nevertheless comparable (see Table 2 and Figure 4). To explain the variation in the TWRs, he compared the rates with different anthropometric variables, such as stature, iris colour, cephalic index and blood groups.

Timonen and Carpén (1968) observed that the percentage of multiple pregnancies 1960–1964 was highest in central, eastern and northern Finland. Fellman and Eriksson (1990) studied the regional variation in the TWR in Finland for 1974–1983, but contrary to Timonen and Carpén, identified no marked regional variations. We attributed this negative result to decreasing environmental and genetic differences.

Bulmer (1970) speculated that geographical variation in dizygotic TWRs in Europe may have some genetic basis. James (1985) observed a positive Spearman correlation coefficient between the age-standardized TWR and latitude. He wondered whether this association of photoperiodicity with latitude is relevant. As alternative factors, he suggested diet (milk consumption) and birth weight. In addition, James stated that there is no reason to suppose that genetic clines in the Old World have been duplicated in the New World, and the latitudinal variation in dizygotic twinning and birth weight being similar in Europe and US suggests an environmental rather than a genetic cause.

Acknowledgments

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