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A MODEL FOR THE DISTRIBUTION OF DAILY NUMBER OF BIRTHS IN OBSTETRIC CLINICS BASED ON A DESCRIPTIVE RETROSPECTIVE STUDY

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Abstract

Objective: Does the Poisson distribution correspond precisely to actual random variation in the number of non-elective births for each fixed day of the week?

Design: A descriptive retrospective study.

Setting: All seven obstetric clinics in the Capital region of Denmark.

Population: All births in for each day in a 10 year period were extracted from the Danish Birth registry (n=211,290).

Methods: Simple descriptive plots and one-way analysis of variance were used to analyze the distribution of non-elective births for each day of the week.

Main outcome measures: After exclusion of elective Caesarean sections and births after induction of labor only 'non-elective' births (n=171,009) were included for the statistical analysis.

Results: The number of 'non-elective' births varies considerably over the days of the week and over the year for each obstetric clinic regardless of clinic size. However, for each fixed day of the week this variation is well described by a Poisson distribution, allowing simple prediction of the variability. For births at each fixed day of the week, the Poisson distribution is indistinguishable from a normal distribution.

Conclusion: We may estimate the variance from the mean as the Poisson distribution for these parameters is indistinguishable from a normal distribution. This model is suitable for planning of manpower in obstetric clinics and the model proposition is adequate to be used in smaller as well as larger clinics.

Article summary

Article focus: Does the Poisson distribution correspond precisely to actual random variation in the number of non-elective births for each fixed day of the week?

Key Message box:

- The Poisson distribution for 'non-elective' births is indistinguishable from a normal distribution.
- The Poisson distribution makes it easy to use for planning of manpower in obstetric clinics.
- The model is adequate for use in smaller as well as larger clinics and can be used in management of manpower in obstetric clinics.

Strengths and limitations of this study: The dataset contains quantitative data, but no qualitative data.

INTRODUCTION

There is a structural reorganization of hospitals going on in Denmark implying larger but fewer hospitals. This applies also for the departments of Gynecology and Obstetrics as smaller departments are being merged resulting in fewer larger departments (1-3). The main motivation for these changes has been that larger departments would enhance the capacity and quality of patient treatment and additionally reduce the costs for staff at shifts. In Denmark the overall year to year variation in number of births at each department is centrally determined as each department of obstetrics - on an administrative level - is intended to have a given number of births. An interesting organizational feature in obstetrics is the inherent random variation in onset of spontaneous labor which makes it difficult to precisely plan the necessary number of staff at the obstetric clinics. The planning of manpower in these departments is to our knowledge not based on published methods.

Statistics on the number of births on each day for each department every year is available online from Statistics Denmark (4). These numbers indicate considerable day to day variation and week to week variation. The observation of a weekly cycle is in accordance with reports from other countries such as England, Wales, Australia, the United States, Israel and Norway (5-13) and interestingly it has also been shown that the variation depends on whether the Sabbath occurs on a Friday (14), a Saturday (5) or Sunday (6-13) . However these former studies included all births regardless of whether or not there had been an elective obstetric intervention. Potentially the week variation disappears when births resulting from an obstetric intervention are excluded from the data set. There is a long tradition of describing the variation in the daily demand for hospital beds by the Poisson distribution (15-17) sometimes based on queuing theory and with varying efforts at empirical verification. In her well-known textbook Kirkwood (18) used an apparently hypothetical example of manpower planning under uncertainty in the face of merging two obstetrical departments to illustrate the Poisson distribution. In this note we examine from a broad Danish experience how well this suggestion corresponds to actual random variation in the number of non-elective births for each fixed day of the week.

MATERIAL AND METHODS

Data

The number of births for each day in the period from the 1st of January 2000 until the 31st of December 2009 at each of the seven obstetric clinics in the capital region of Denmark, respectively Rigshospitalet, Frederiksberg, Glostrup, Gentofte, Herlev, Hvidovre and Hillerød, were extracted from the Danish Birth registry. These data cover over 99% of all births in the region, as a dwindling number of births takes place at home in Denmark. The data include information on whether vaginal births resulted from induction of birth or occurred spontaneously and whether Caesareans were classified as elective or acute. To only consider variation in the 'non-elective' births potential, planned births (resulting from induced labors or elective Caesareans) were excluded.

Statistical methods

The strategy in this note is to exploit that for moderate and large mean values it is well known (and will be demonstrated in our graphs) that the Poisson distribution closely resembles a normal distribution with the same mean and variance. We can therefore reduce the statistical apparatus to simple analyses based on the normal distribution, here in particular one-way analyses of variance, available in all statistical packages; we used R. Since the Poisson distribution has variance identical to its mean, the criterion for Poisson distribution of births at a given day of the week could then be tested via comparison of the residual variance from the analysis of variance to the daily mean.

Details of ethics approval

An ethical approval for this study was not required. The data used are available online in an anonymous form.

RESULTS

There were 211,290 births distributed on seven departments in the capital region of Denmark from the 1st of January 2000 until the 31st of December 2009. In order to exclude potential 'planned' births, births were subdivided into induced or spontaneous labor and elective and acute Caesareans (Table I). Births where the mode of delivery were an elective Caesarean (n=16,325 (7.73 %)) and births initiated by induction of labor (n=23,956 (11.34%)) were excluded from the data set, thus leaving a total of 171,009 (80.94%) spontaneous births and acute Caesareans, to be denoted 'non-elective' below.

As mentioned in the introduction a main problem in obstetrics management is the variation over days of the week. This variation is to a large degree a result of decisions by the obstetricians on how to distribute elective Caesareans and electively induced labor over the days of the week (6, 12). Various preliminary descriptive analyses of the data clearly indicated that such policies varied considerably over the ten years for each department and that the patterns were rather different between departments, however overall a mid-weekly peak in births remained even when 'planned' births were excluded. The staffing required to handle these 'elective births' is a consequence of management decisions, and we focus from now on how to dimension the 'non-elective' births. Because of the strong heterogeneity in the day-to-day pattern for several of the involved departments over the ten years under study, we performed a set of 70 one-way analyses of variance comparing the number of spontaneous births at each day of the week for each fixed combination of department (n=7) and year (n=10).The residual variances from these 70 analyses were compared to the annual mean number of births for each department. As seen in Figure I, the residual variances were very close to the means, indicating a Poisson distribution of the variation in number of non-elective births for each day of the week around the yearly average for that day.

To illustrate our findings three selected combinations of department and year, a small, medium and large clinic, were chosen. For each a histogram for each day of the week with fitted normal distribution and fitted Poisson distribution was produced (Figure II). It is seen that there is a nice fit throughout of the Poisson distributions, and also that they are very close to the normal distributions with the same variance. This means that calculations of the likely variation in number of non-elective births can be based on the normal distribution with variance given by the average number of non-elective births per day over the year.

For example, if at a particular department in a particular year the mean number of non-elective births is 9, the residual variance is estimated as 9 and the standard deviation as the square root of 9, that is, 3. Assume that the mean number of non-elective births on Tuesdays for that department for that year is 10.5. In 95% of Tuesdays the actual number of non-elective births at that department will be in the interval:

$$(10.5 - 3 \times 1.96, 10.5 + 3 \times 1.96) = (4.6, 17.4)$$

while in 80% of Tuesdays there will be between 10.5 – 3 x 1.28 = 6.7 and 10.5 + 3 x 1.28 = 14.3 non-elective births.

This model is suitable for planning of manpower in obstetric clinics and the model is adequate to be used in smaller as well as larger clinics (Figure I).

Discussion

Management of manpower in obstetric clinics is a difficult task, due to the relatively unpredictable nature of labor onset. Nowadays many births are 'elective' births in the sense that elective Caesarean sections or medically induced labor governs the time of the week where the birth happens.

It has been assumed that data over births fits a Poisson distribution on a day to day variation (13, 18), but suitable data on live births, including mode of delivery, from a larger population has not previously been studied, thus limiting the means of studying day to day variation (7, 13). Furthermore the impact of elective obstetric intervention on the distribution has not been considered in any of the previous studies addressing birth variation (5-14, 19).

Interestingly we find that even with the exclusion of births where an obstetric intervention has occurred, the remaining data still show significant weekly variation with a mid-weekly peak. As such this variation might not only be ascribed to measurable obstetric interventions, but also less tangible practices, for instance the time of admittance of a woman in early stages of labor might depend on staff numbers which vary during the week. Also traditional non-medical methods of starting labor (hot baths, sexual intercourse, etc.) might be less likely to be tried by mothers in the weekends (7).

However regardless of any obstetric practices or mothers practice, we found that the distribution of the remaining 'non-elective' births for each day of the week, each year, and each department is still well approximated by a Poisson distribution, where the mean equals the variance. For the relevant parameter values, this Poisson distribution is indistinguishable from a normal distribution, where we then may estimate the variance from the mean. Therefore, no special statistical tables are necessary.

CONCLUSIONS

We may estimate the variance from the mean, as the Poisson distribution for these parameters is indistinguishable from a normal distribution. This model is suitable for planning of manpower in obstetric clinics and the model proposition is adequate to be used in smaller as well as larger clinics.

COMPETING INTEREST

All authors have completed the Unified Competing Interest form at http://www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare: no support from any organization for the submitted work, no financial relationships with any organization that might have an interest in the submitted work in the previous three, no other relationships or activities that could appear to have influenced the submitted work.

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CONTRIBUTION TO AUTHORSHIP

CMG, NK, JT and EL have all been involved in the conception of this study. The statistical analysis has been carried out mainly by JT under the guidance of NK, EL and CMG. The writing of this article has been done by CMG, NK, JT and EL. Coordination of the correspondence between authors has been taken care of by CMG.

DATA SHARING

The informal descriptive analyses and the formal two-way analyses of variances preceding and leading to the main analysis, a one-way analysis of variance comparing days of the week for each fixed combination of department (7) and year (10) described in the article are available on request to anyone from the corresponding author.

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Table I Type of births in each department in the capital region of Denmark during 2000-2009, with number and percentages of spontaneous births, acute caesarean after spontaneous onset of labour, births after induction of labour and. elective caesarean sections.

Obstetric clinic	Births per clinic	Non-elective births (81 %)				Elective births (19 %)			
		Spontaneus birth	%	Acute caesarean	%	Induced birth	%	Elective caesarean	%
Rigshospitalet	35.657	19.144	54	5.740	16	6.345	18	4.428	12
Hvidovre	53.300	39.335	74	7.264	14	2.375	4	4.326	8
Frederiksberg	17.751	13.784	78	1.794	10	1.266	7	907	5
Gentofte	21.988	14.216	65	2.863	13	3.349	15	1.560	7
Glostrup	22.737	15.972	70	2.883	13	2.808	12	1.074	5
Herlev	23.967	17.352	72	2.800	12	2.680	11	1.135	5
Hillerød	35.890	23.209	65	4.653	13	5.133	14	2.895	8
All seven clinics	211.290	143.012	68	27.997	13	23.956	11	16.325	8

Figure I Residual variance almost identical to the mean number of births per day, in accordance with the Poisson distribution.

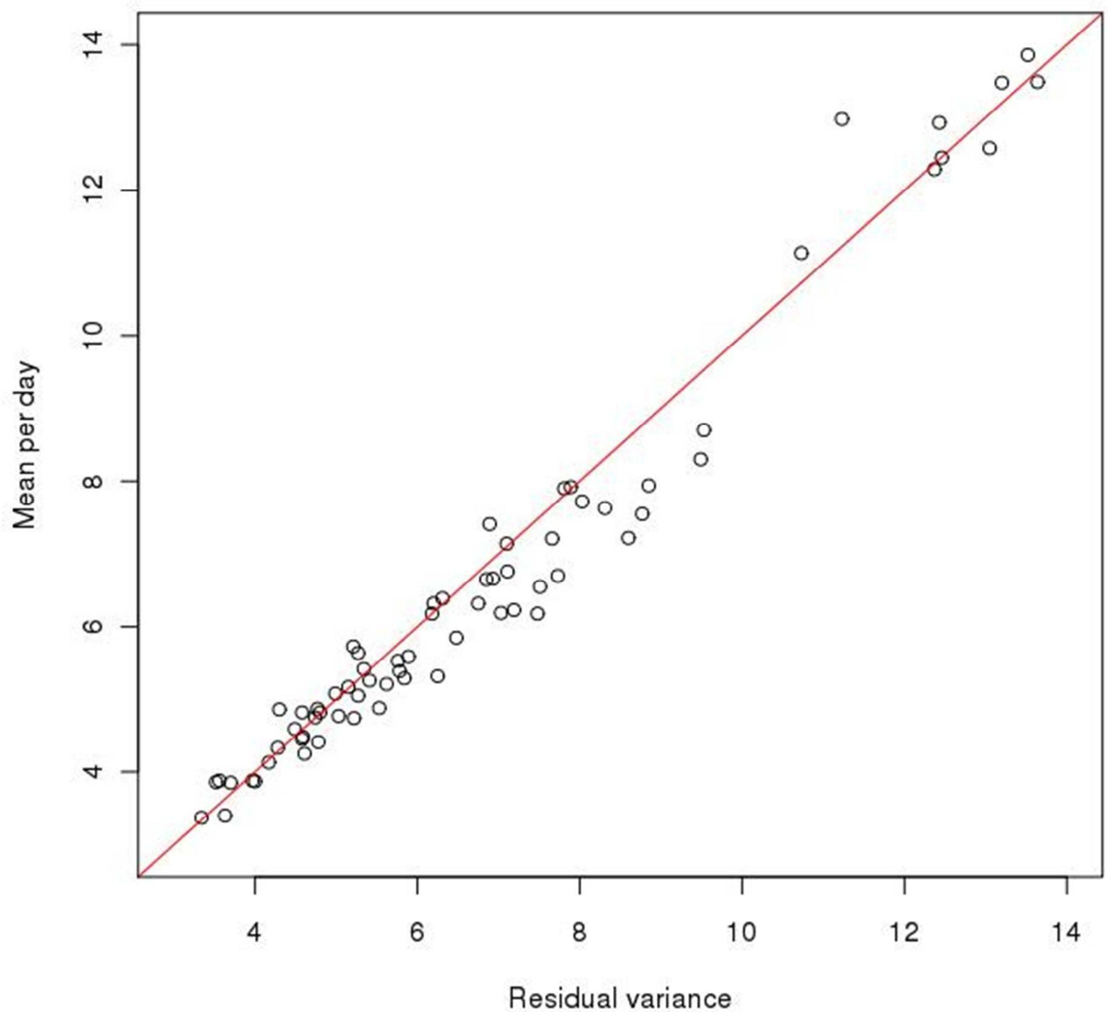
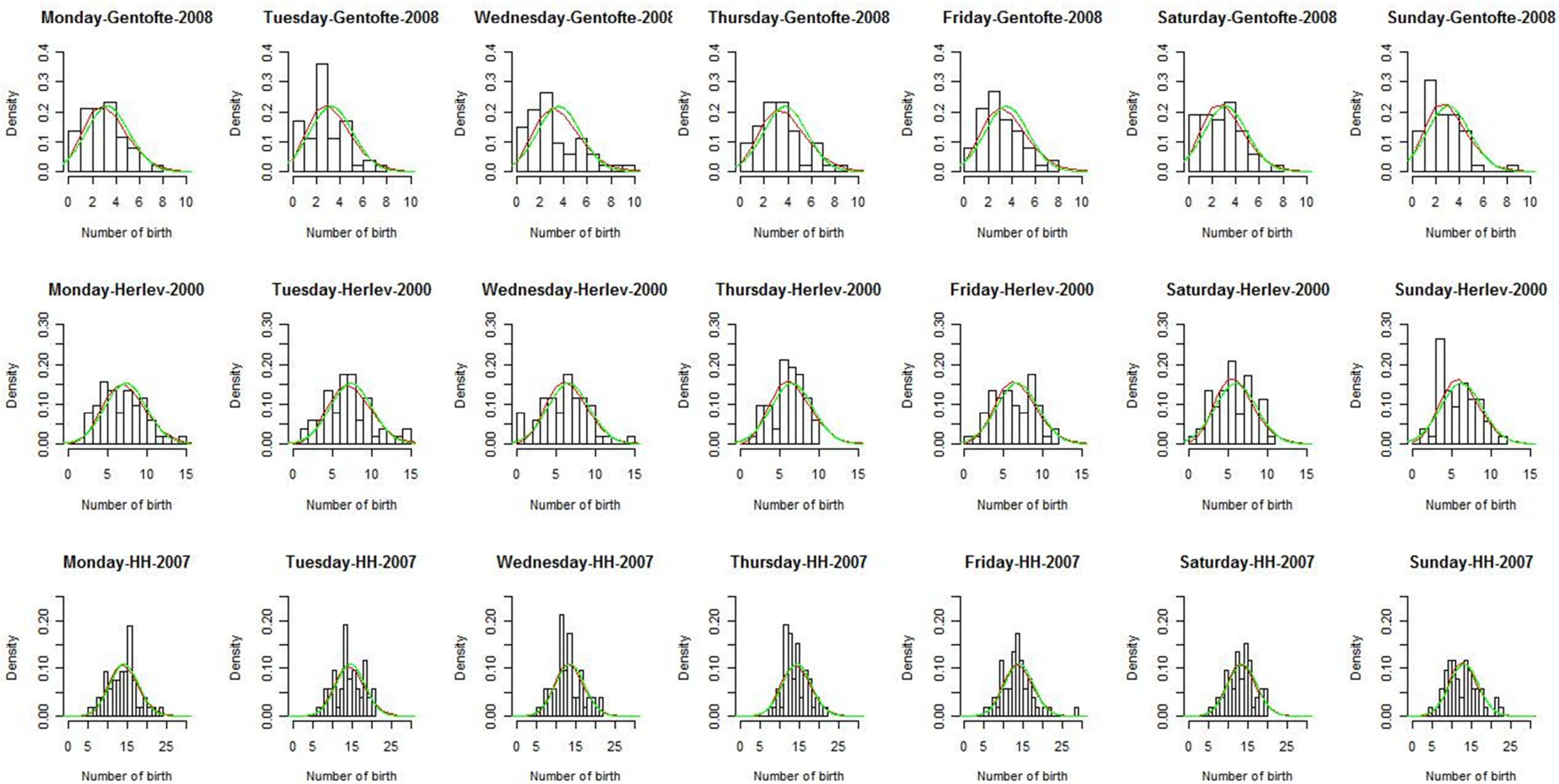


Figure II Examples of a small (Gentofte), medium (Herlev) and large (Hvidovre Hospital(HH)) birthplace with number of births at the x axis and density at the y axis with curves indicating the Poisson distribution (Red) and the normal distribution (Green).



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A MODEL FOR THE DISTRIBUTION OF DAILY NUMBER OF BIRTHS IN OBSTETRIC CLINICS BASED ON A DESCRIPTIVE RETROSPECTIVE STUDY

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Keywords: distribution, births, model, Poisson, manpower, obstetric clinic

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ABSTRACT

Objective: To test whether the relatively unpredictable nature of labour onset can be described by the Poisson distribution.

Design: A descriptive retrospective study.

Setting: From the Danish Birth Registry we identified births from all seven obstetric clinics in the Capital region of Denmark (n=211,290) between 2000 and the end of 2009. On each date the number of births at each department was registered. Births are categorised in whether an elective Caesarean section or induction of labour has been performed and among the remaining 'non-elective births' acute Caesareans were registered.

Methods: After exclusion of elective Caesarean sections and births after induction of labour only 'non-elective' births (n=171,009) were included for the main statistical analysis. Simple descriptive plots and one-way analysis of variance were used to analyse the distribution of 'non-elective' births for each day of the week.

Main outcome measures: **The daily number of 'non-elective' births.**

Results: The number of 'non-elective' births varies considerably over the days of the week and over the year for each obstetric clinic regardless of clinic size. However, for each fixed day of the week the variation over the year is well described by a Poisson distribution, allowing simple prediction of the variability. For births at each fixed day of the week, the Poisson distribution is indistinguishable from a normal distribution.

Conclusion: The number of 'non-elective' births for each day of the week is well-described by a Poisson distribution. Consequently the Poisson model is suitable for estimating the variation in the daily number of 'non-elective' births and could be used for planning of manpower in obstetric clinics. The model can be used in smaller as well as larger clinics.

ARTICLE SUMMARY

Article focus: Does the Poisson distribution correspond precisely to actual random variation in the number of **'non-elective'** births for each fixed day of the week?

Key Message box:

- For each day of the week, the variation of 'non-elective' births over the year is well described by a Poisson distribution.
- The Poisson distribution makes it easy to estimate the variation in the daily number of births and can be used for planning of manpower in obstetric clinics. Standard tables of the normal distribution may be used as exemplified.
- The model is adequate for use in smaller as well as larger clinics and can be used in management of manpower in obstetric clinics.

Strengths and limitations of this study: The main strength is the large dataset of non-selected births. The main limitation is that births are registered only by date, not by time of birth.

INTRODUCTION

There is a structural reorganization of hospitals going on in Denmark implying larger but fewer hospitals. This applies also for the departments of Gynaecology and Obstetrics as smaller departments are being merged resulting in fewer larger departments (1-3). The main motivation for these changes has been that larger departments would **enhance the capacity and quality of patient treatment and additionally reduce the costs for staff at shifts. In Denmark the overall year to year variation in number of births at each department is centrally determined as each department of obstetrics on an administrative level is intended to have a given number of births from a specified geographical region. The manpower required in each obstetric clinic is therefore determined from this figure. The largest part of manpower consists of a daily number of midwifes working eight hours shift during day, evening and night, as well as a varying number of midwifes on 24 hour duty on call from home. Their actual working hours vary considerably. The number of doctors on shift is fixed for each obstetric clinic and depends on the size of the obstetric clinic, as does the number of doctors on call from home.**

An interesting organizational feature in obstetrics is the inherent random variation in onset of spontaneous labour which makes it difficult to precisely plan the necessary number of staff at the obstetric clinics. The planning of manpower in the departments is to our knowledge not based on published methods. Statistics on the number of births on each day for each department every year is available online from Statistics Denmark (4). These numbers indicate considerable day to day variation and week to week variation. The observation of a weekly cycle is in accordance with reports from other countries such as England, Wales, Australia, the United States, Israel and Norway (5-13) and interestingly it has also been shown that the variation depends on whether the Sabbath occurs on a Friday (14), a Saturday (5) or Sunday (6-13). However these former studies included all births regardless of whether or not there had been an elective obstetric intervention, which raises the question whether the variation between the days of the week disappears, when births resulting from an elective obstetric intervention as elective Caesarean or induction of labour are excluded from the data set. There is a long tradition of describing the variation in the daily demand for hospital beds by the Poisson distribution (15-17) sometimes based on queuing theory and with varying efforts at empirical verification. In her well-known textbook Kirkwood (18) used an apparently hypothetical example of manpower planning under uncertainty in the face of merging two obstetrical departments to illustrate the Poisson distribution.

In this study we examine from a broad Danish experience how well the Poisson distribution corresponds to actual random variation in the number of 'non-elective' births for each fixed day of the week. Since the variation in the 'non-elective' births is most obviously random, we exclude in the main analysis 'elective' births (resulting from induction of labour and elective Caesarean sections). However, as a sensitivity analysis we report results on the variation of all births and of acute Caesarean sections.

MATERIAL AND METHODS

Data

The number of births for each date in the period from the 1st of January 2000 until the 31st of December 2009 at all seven obstetric clinics in the capital region of Denmark were extracted from the Danish Birth registry. The obstetric clinics were Rigshospitalet, Frederiksberg, Glostrup, Gentofte, Herlev, Hvidovre and Hillerød, which cover over 99% of all births in the region, as a dwindling number of births takes place at home in Denmark. The data included information on the type of birth: elective Caesarean sections, births after elective induction of labour, acute Caesarean sections and births after spontaneous onset of labour. The labelling of the type of birth has been done by using information from the National Birth registry on operation codes for elective Caesarean sections (KMCA10B and D) and obstetric codes for induction of labour (KMAC00 Amniotomy prior to birth, KMAC96A Mechanical catheter induction, BKHD2 Unspecific medical induction, BKHD20 Induction with prostaglandin, BKHD21 Induction with oxytocin) . The coding of birth information is based on information from midwifes and is generally considered very valid.

Statistical methods

The main concept of these analyses builds on the empirical fact that even for 'non-elective' births there is a non-ignorable variation across the seven days of the week, however for each fixed day of the week the variation across the 52 (53) weeks in a given year may be interpreted as random. We exploit the well-known fact that Poisson distributions are well approximated by normal distributions with the same mean and variance, clearly distinguishable by the Poisson distribution property that the mean equals the variance. In this way the key issue – whether the Poisson distribution is an adequate description – is captured by a one-way analysis of variance comparing the seven days of the week for each of the ten years and each of the seven clinics. The results are illustrated by descriptive graphs and worked examples of possible use in manpower planning. Additional sensitivity analyses are performed including all births and acute Caesareans.

Details of ethics approval

An ethical approval for this study was not required. The data used are available online in an anonymous form.

RESULTS

There were 211,290 births distributed on seven departments in the capital region of Denmark from the 1st of January 2000 until the 31st of December 2009. In order to exclude potential **elective** births, births were subdivided into induced or spontaneous labour and elective and acute Caesareans (Table I). Births where the mode of delivery was an elective Caesarean (n=16,325 (7.73 %)) and births initiated by induction of

labour (n=23,956 (11.34%)) were excluded from the data set for main analyses, thus leaving a total of 171,009 (80.94%) spontaneous births and acute Caesareans, to be denoted 'non-elective' below.

As mentioned in the introduction a main problem in obstetrics management is the variation over days of the week. This variation is to a large degree a result of decisions by the obstetricians on how to distribute elective Caesareans and electively induced labour over the days of the week (6, 12). Preliminary descriptive analyses of the data clearly indicated that such policies varied considerably over the ten years for each department and that the patterns were rather different between departments, however overall a mid-weekly peak in births remained even when 'elective' births were excluded (please see the supplementary file, Figure III-IX). The manpower required for these 'elective' births is a consequence of management decisions, and our focus is here on how to capture the primarily random variation in the 'non-elective' births. Because of the strong heterogeneity in the day-to-day pattern for several of the involved departments over the ten years under study, we performed a set of 70 one-way analyses of variance comparing the number of 'non-elective' births at each day of the week for each fixed combination of department (n=7) and year (n=10). The residual variances from these 70 analyses were compared to the annual mean number of births for each department. Additional sensitivity analyses were performed including all births and acute Caesareans. As seen in Figure I, the residual variances are very close to the means, indicating a Poisson distribution of the variation in number of 'non-elective' births for each day of the week around the yearly average for that day. We also see that the closeness of residual variance to the mean improves when we only look at the 'non-elective' births while for the acute Caesareans only there is a clear trend that the variance is larger than the mean, so-called overdispersion which violates the assumption of Poisson distribution. In view of these findings we focus on the non-elective births in the following.

To illustrate our findings three selected combinations of department and year, a small, medium and large clinic, were chosen. For each day of the week a histogram shows the observed distribution of the 52 (53) numbers of births per day for that year with fitted normal distribution (red) and fitted Poisson distribution was produced (green) (Figure II). It is seen that there is a nice fit throughout of the Poisson distributions, and also that they are very close to the normal distributions with the same variance. This means that calculations of the likely variation in number of 'non-elective' births can be based on the normal distribution with variance given by the average number of 'non-elective' births per day over the year.

For example, if at a particular department in a particular year the mean number of 'non-elective' births is 9, the residual variance is estimated to be 9 and the standard deviation as the square root of 9, that is, 3. Assume that the mean number of 'non-elective' births on Tuesdays for that department for that year is 10.5. In 95% of Tuesdays the actual number of 'non-elective births' at that department will be in the interval between 10.5 – 3 x 1.96 = 4.6 and 10.5 + 3 x 1.96 = 17.4**,** while in 80% of Tuesdays there will be between 10.5 – 3 x 1.28 = 6.7 and 10.5 + 3 x 1.28 = 14.3 non-elective births. This model is suitable for estimating daily number of births and planning of manpower in obstetric clinics and the model is adequate to be used in smaller as well as larger clinics.

Discussion

Management of manpower in obstetric clinics is a difficult task, due to the relatively unpredictable nature of labour onset. Nowadays many births are 'elective' births in the sense that elective Caesarean sections or medically induced labour more or less governs the time of the week where the birth happens. It has been assumed that the day to day variation on numbers of births fits a Poisson distribution (13, 18), but suitable data on live births, including mode of delivery, from a larger population has not previously been studied, thus limiting the means of studying day to day variation (7, 13). Furthermore the impact of elective obstetric intervention on the distribution has not been considered in any of the previous studies addressing birth variation (5-14, 19).

Interestingly we find that even with the exclusion of births resulting from an obstetric intervention as elective caesarean or induction of labour, the remaining data still show significant weekly variation with a mid-weekly peak. As such this variation might not only be ascribed to measurable obstetric interventions, but also less tangible practices, for instance the time of admittance of a woman in early stages of labour might depend on staff numbers which vary during the week. Also traditional non-medical methods of starting labour (hot baths, sexual intercourse, etc.) might be less likely to be tried by mothers in the weekends (7).

However regardless of any obstetric practices or mothers practice, we found that the distribution of the remaining 'non-elective' births for each day of the week, each year, and each department is still well approximated by a Poisson distribution, where the mean equals the variance. For the relevant parameter values, this Poisson distribution is indistinguishable from a normal distribution, where we then may estimate the variance from the mean. This means that calculations of the likely variation in number of non-elective births can be based on the normal distribution with variance given by the average number of non-elective births per day over the year.

This provides us with a useful tool for planning of the manpower necessary to handle all births on a given weekday in an obstetric clinic. Elective Caesarean sections are usually planned to be performed on specific weekdays with staff dedicated to this task. Births after induction of labour will also in most regards be planned. Combining the known number of elective births with the calculation of a 95% or 80% confidence interval of 'non-elective' births on a given week day gives a good possibility to avoid over- or understaffing and utilize the available human resources to their best. For larger clinics where the mean number of non-elective births for a given weekday may vary by more than 1-2 births, the relocation of manpower to 'peak' weekdays has the most to offer, but even smaller clinics can benefit from more concrete calculation, for example on how weekend manpower should be.

The fact that the distribution of 'non-elective' births is indistinguishable from normal distribution provides a simple, but elegant, tool for planning of manpower in obstetric clinics and used wisely may prove a positive adjustment for work efficiency, cost and environment.

Conclusions

We may estimate the variance from the mean, as the Poisson distribution for these parameters is indistinguishable from a normal distribution. This model is suitable for estimating the variation in the daily number of 'non-elective' births and could be used for planning of manpower in obstetric clinics.

Competing interest

All authors have completed the Unified Competing Interest form at http://www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare: no support from any organization for the submitted work, no financial relationships with any organization that might have an interest in the submitted work in the previous three, no other relationships or activities that could appear to have influenced the submitted work.

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Contribution to authorship

CMG, NK, JT and EL have all been involved in the conception of this study. The statistical analysis has been carried out mainly by JT under the guidance of NK, EL and CMG. The writing of this article has been done by CMG, NK, JT and EL. Coordination of the correspondence between authors has been taken care of by CMG.

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Keywords: distribution, births, model, Poisson, manpower, obstetric clinic

Word count: **2375**

ABSTRACT

Objective: **To test whether the relatively unpredictable nature of labour onset can be described by the Poisson distribution.**

Design: A descriptive retrospective study.

Setting: **From the Danish Birth Registry we identified births from all seven obstetric clinics in the Capital region of Denmark (n=211,290) between 2000 and the end of 2009. On each date the number of births at each department was registered. Births are categorised in whether an elective Caesarean section or induction of labour has been performed and among the remaining 'non-elective births' acute Caesareans were registered.**

Methods: **After exclusion of elective Caesarean sections and births after induction of labour only 'non-elective' births (n=171,009) were included for the main statistical analysis.** Simple descriptive plots and one-way analysis of variance were used to analyse the distribution of **'non-elective'** births for each day of the week.

Main outcome measures: **The daily number of 'non-elective' births.**

Results: The number of 'non-elective' births varies considerably over the days of the week and over the year for each obstetric clinic regardless of clinic size. However, for each fixed day of the week the variation over the year is well described by a Poisson distribution, allowing simple prediction of the variability. For births at each fixed day of the week, the Poisson distribution is indistinguishable from a normal distribution.

Conclusion: **The number of 'non-elective' births for each day of the week is well-described by a Poisson distribution. Consequently the Poisson model is suitable for estimating the variation in the daily number of 'non-elective' births and could be used for planning of manpower in obstetric clinics. The model can be used in smaller as well as larger clinics.**

ARTICLE SUMMARY

Article focus: Does the Poisson distribution correspond precisely to actual random variation in the number of **'non-elective'** births for each fixed day of the week?

Key Message box:

- **For each day of the week, the variation of 'non-elective' births over the year is well described by a Poisson distribution.**
- **The Poisson distribution makes it easy to estimate the variation in the daily number of births and can be used for planning of manpower in obstetric clinics. Standard tables of the normal distribution may be used as exemplified.**
- The model is adequate for use in smaller as well as larger clinics and can be used in management of manpower in obstetric clinics.

Strengths and limitations of this study: **The main strength is the large dataset of non-selected births. The main limitation is that births are registered only by date, not by time of birth.**

INTRODUCTION

There is a structural reorganization of hospitals going on in Denmark implying larger but fewer hospitals. This applies also for the departments of Gynaecology and Obstetrics as smaller departments are being merged resulting in fewer larger departments (1-3). The main motivation for these changes has been that larger departments would enhance the capacity and quality of patient treatment and additionally reduce the costs for staff at shifts. **In Denmark the overall year to year variation in number of births at each department is centrally determined as each department of obstetrics on an administrative level is intended to have a given number of births from a specified geographical region. The manpower required in each obstetric clinic is therefore determined from this figure. The largest part of manpower consists of a daily number of midwifes working eight hours shift during day, evening and night, as well as a varying number of midwifes on 24 hour duty on call from home. Their actual working hours vary considerably. The number of doctors on shift is fixed for each obstetric clinic and depends on the size of the obstetric clinic, as does the number of doctors on call from home.**

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MATERIAL AND METHODS

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The number of births for each date in the period from the 1st of January 2000 until the 31st of December 2009 at **all seven obstetric clinics in the capital region of Denmark were extracted from the Danish Birth registry. The obstetric clinics were Rigshospitalet, Frederiksberg, Glostrup, Gentofte, Herlev, Hvidovre and Hillerød, which cover over 99% of all births in the region,** as a dwindling number of births takes place at home in Denmark. The data included **information on the type of birth: elective Caesarean sections, births after elective induction of labour, acute Caesarean sections and births after spontaneous onset of labour. The labelling of the type of birth has been done by using information from the National Birth registry on operation codes for elective Caesarean sections (KMCA10B and D) and obstetric codes for induction of labour (KMAC00 Amniotomy prior to birth, KMAC96A Mechanical catheter induction, BKHD2 Unspecific medical induction, BKHD20 Induction with prostaglandin, BKHD21 Induction with oxytocin) . The coding of birth information is based on information from midwifes and is generally considered very valid.**

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There were 211,290 births distributed on seven departments in the capital region of Denmark from the 1st of January 2000 until the 31st of December 2009. In order to exclude potential **elective** births, births were subdivided into induced or spontaneous labour and elective and acute Caesareans (Table I). Births where the mode of delivery was an elective Caesarean (n=16,325 (7.73 %)) and births initiated by induction of labour (n=23,956 (11.34%)) were excluded from the data set for main analyses, thus leaving a total of 171,009 (80.94%) spontaneous births and acute Caesareans, to be denoted 'non-elective' below.

As mentioned in the introduction a main problem in obstetrics management is the variation over days of the week. This variation is to a large degree a result of decisions by the obstetricians on how to distribute elective Caesareans and electively induced labour over the days of the week (6, 12). **Preliminary descriptive analyses** of the data clearly indicated that such policies varied considerably over the ten years for each department and that the patterns were rather different between departments, **however overall a mid-weekly peak in births remained even when 'elective' births were excluded (please see the supplementary file, Figure III-IX). The manpower** required for these **'elective' births** is a consequence of management decisions, **and our focus is here on how to capture the primarily random variation in the 'non-elective' births.** Because of the strong heterogeneity in the day-to-day pattern for several of the involved departments over the ten years under study, we performed a set of 70 one-way analyses of variance comparing the number of 'non-elective' births at each day of the week for each fixed combination of department (n=7) and year (n=10). The residual variances from these 70 analyses were compared to the annual mean number of births for each department. **Additional sensitivity analyses were performed including all births and acute Caesareans.** As seen in Figure I, the residual variances are very close to the means, indicating a Poisson distribution of the variation in number of **'non-elective'** births for each day of the week around the yearly average for that day. **We also see that the closeness of residual variance to the mean improves when we only look at the 'non-elective' births while for the acute Caesareans only there is a clear trend that the variance is larger than the mean, so-called overdispersion which violates the assumption of Poisson distribution. In view of these findings we focus on the non-elective births in the following.**

To illustrate our findings three selected combinations of department and year, a small, medium and large clinic, were chosen. **For each day of the week a histogram shows the observed distribution of the 52 (53) numbers of births per day for that year with fitted normal distribution (red) and fitted Poisson distribution was produced (green) (Figure II).** It is seen that there is a nice fit throughout of the Poisson distributions, and also that they are very close to the normal distributions with the same variance. This means that calculations of the likely variation in number **of 'non-elective' births** can be based on the normal distribution with variance given by the average number **of 'non-elective' births** per day over the year.

For example, if at a particular department in a particular year the mean number of **'non-elective'** births is 9, the residual variance is estimated to be 9 and the standard deviation as the square root of 9, that is, 3. Assume that the mean number of **'non-elective'** births on Tuesdays for that department for that year is

10.5. In 95% of Tuesdays the actual number of **'non-elective births'** at that department will be in the interval **between** 10.5 – 3 x 1.96 = 4.6 and 10.5 + 3 x 1.96 = 17.4**,** while in 80% of Tuesdays there will be between 10.5 – 3 x 1.28 = 6.7 and 10.5 + 3 x 1.28 = 14.3 non-elective births. This model is suitable for **estimating daily number of births and planning of manpower in obstetric clinics and the model is adequate to be used in smaller as well as larger clinics.**

Discussion

Management of manpower in obstetric clinics is a difficult task, due to the relatively unpredictable nature of labour onset. Nowadays many births are 'elective' births in the sense that elective Caesarean sections or medically induced labour **more or less** governs the time of the week where the birth happens. It has been assumed that the day to day variation on numbers of births fits a Poisson distribution (13, 18), but suitable data on live births, including mode of delivery, from a larger population has not previously been studied, thus limiting the means of studying day to day variation (7, 13). Furthermore the impact of elective obstetric intervention on the distribution has not been considered in any of the previous studies addressing birth variation (5-14, 19).

Interestingly we find that even with the exclusion of births **resulting from an obstetric intervention as elective caesarean or induction of labour,** the remaining data still show significant weekly variation with a mid-weekly peak. As such this variation might not only be ascribed to measurable obstetric interventions, but also less tangible practices, for instance the time of admittance of a woman in early stages of labour might depend on staff numbers which vary during the week. Also traditional non-medical methods of starting labour (hot baths, sexual intercourse, etc.) might be less likely to be tried by mothers in the weekends (7).

However regardless of any obstetric practices or mothers practice, we found that the distribution of the remaining 'non-elective' births for each day of the week, each year, and each department is still well approximated by a Poisson distribution, where the mean equals the variance. For the relevant parameter values, this Poisson distribution is indistinguishable from a normal distribution, where we then may estimate the variance from the mean. **This means that calculations of the likely variation in number of non-elective births can be based on the normal distribution with variance given by the average number of non-elective births per day over the year.**

This provides us with a useful tool for planning of the manpower necessary to handle all births on a given weekday in an obstetric clinic. Elective Caesarean sections are usually planned to be performed on specific weekdays with staff dedicated to this task. Births after induction of labour will also in most regards be planned. Combining the known number of elective births with the calculation of a 95% or 80% confidence interval of 'non-elective' births on a given week day gives a good possibility to avoid over- or

understaffing and utilize the available human resources to their best. For larger clinics where the mean number of non-elective births for a given weekday may vary by more than 1-2 births, the relocation of manpower to 'peak' weekdays has the most to offer, but even smaller clinics can benefit from more concrete calculation, for example on how weekend manpower should be.

The fact that the distribution of 'non-elective' births is indistinguishable from normal distribution provides a simple, but elegant, tool for planning of manpower in obstetric clinics and used wisely may prove a positive adjustment for work efficiency, cost and environment.

CONCLUSIONS

We may estimate the variance from the mean, as the Poisson distribution for these parameters is indistinguishable from a normal distribution. This model is suitable **for estimating the variation in the daily number of 'non-elective' births and could be used for planning of manpower in obstetric clinics.**

COMPETING INTEREST

All authors have completed the Unified Competing Interest form at http://www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare: no support from any organization for the submitted work, no financial relationships with any organization that might have an interest in the submitted work in the previous three, no other relationships or activities that could appear to have influenced the submitted work.

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CONTRIBUTION TO AUTHORSHIP

CMG, NK, JT and EL have all been involved in the conception of this study. The statistical analysis has been carried out mainly by JT under the guidance of NK, EL and CMG. The writing of this article has been done by CMG, NK, JT and EL. Coordination of the correspondence between authors has been taken care of by CMG.

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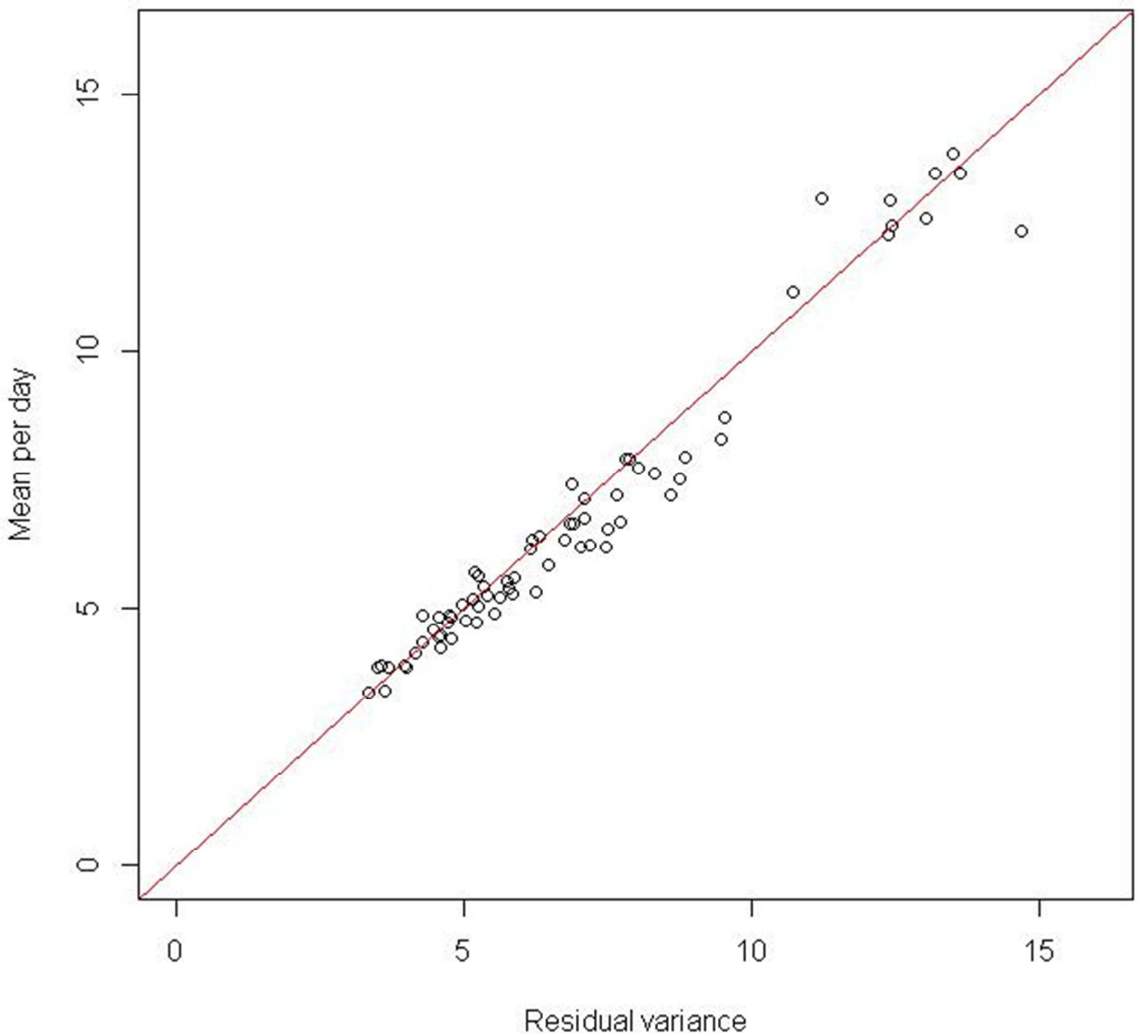
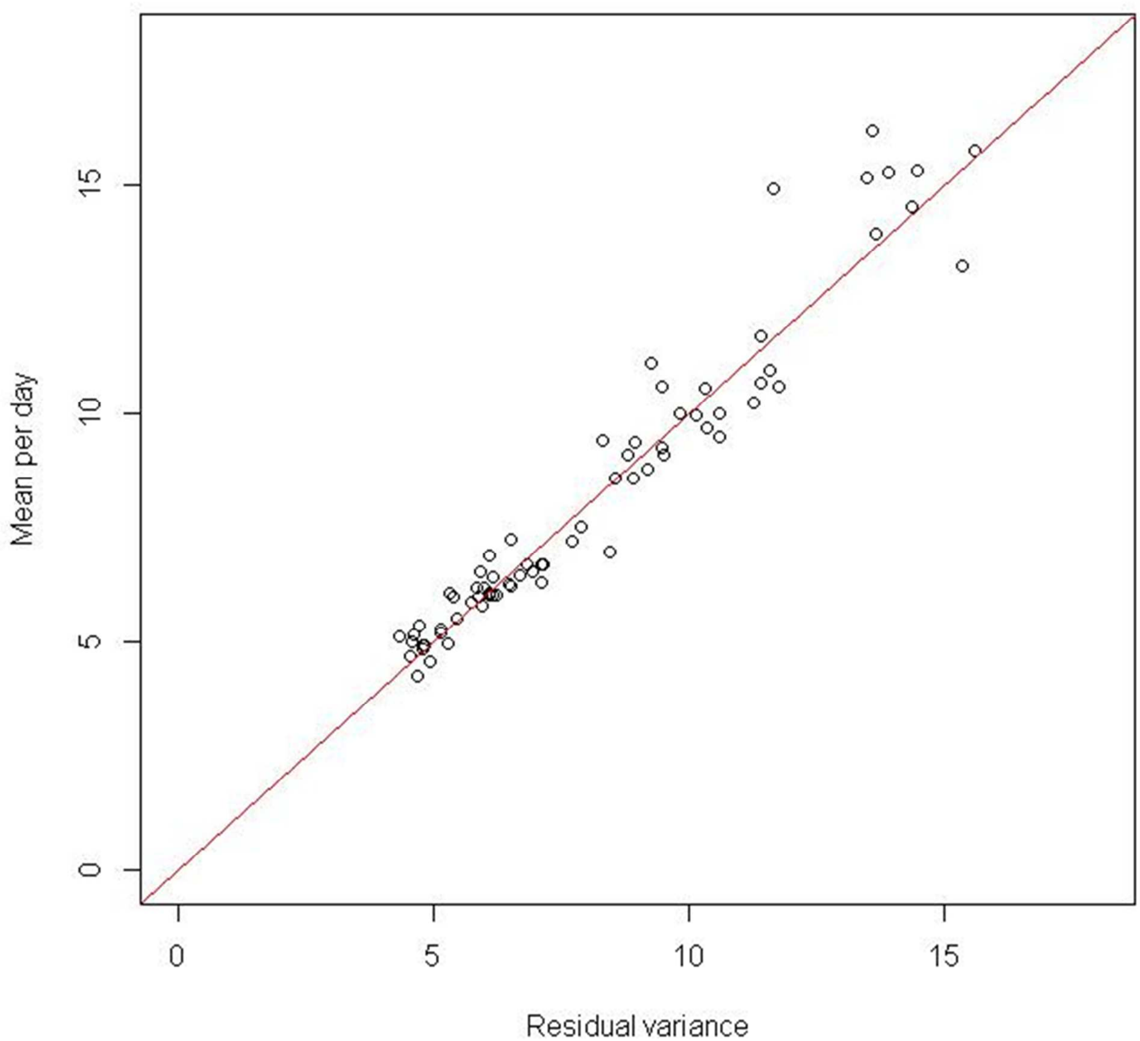
Figure I Residual variance compared to the mean number of births per day for a) 'non-elective' births, b) all births and c) acute Caesarean sections.

a)



b)



c)

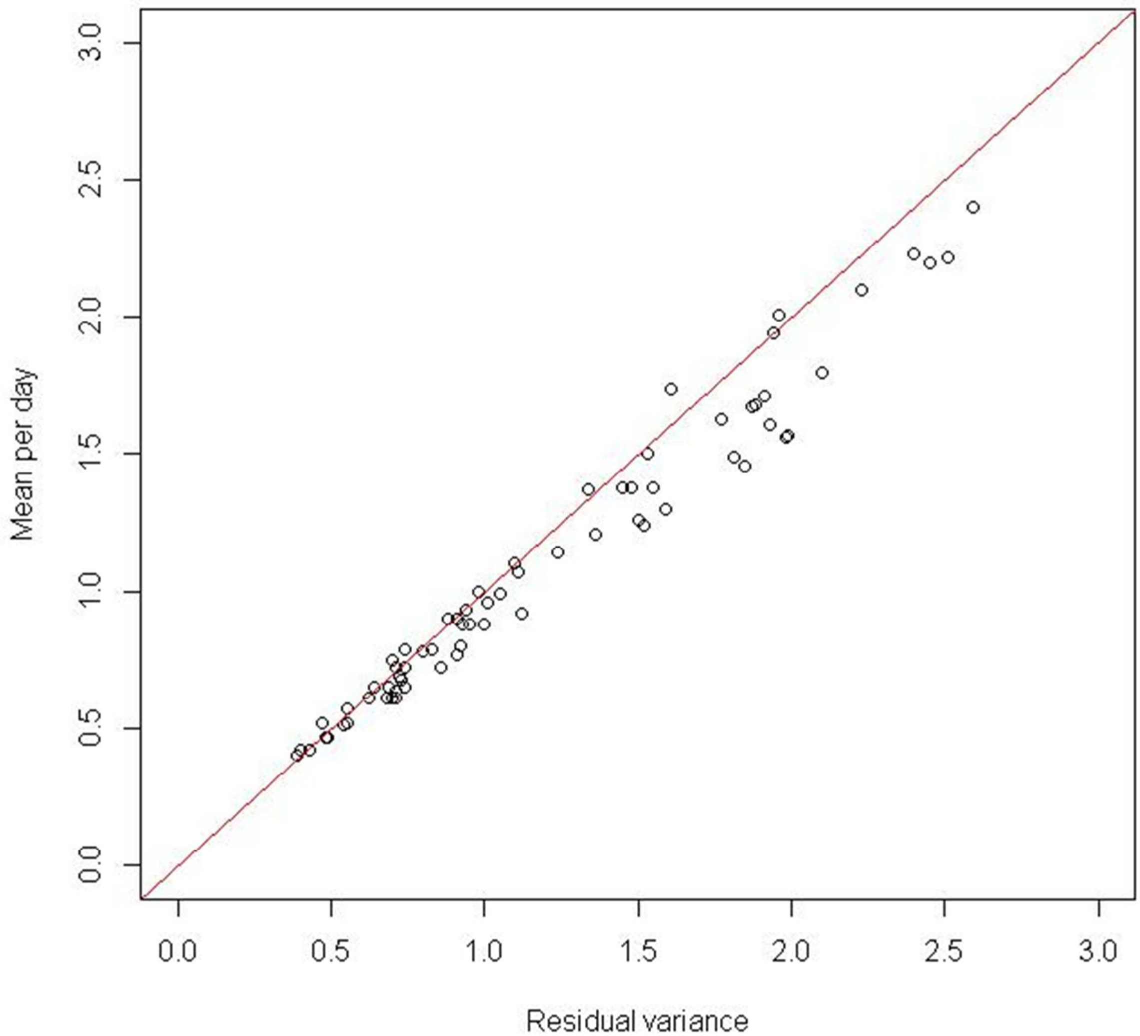
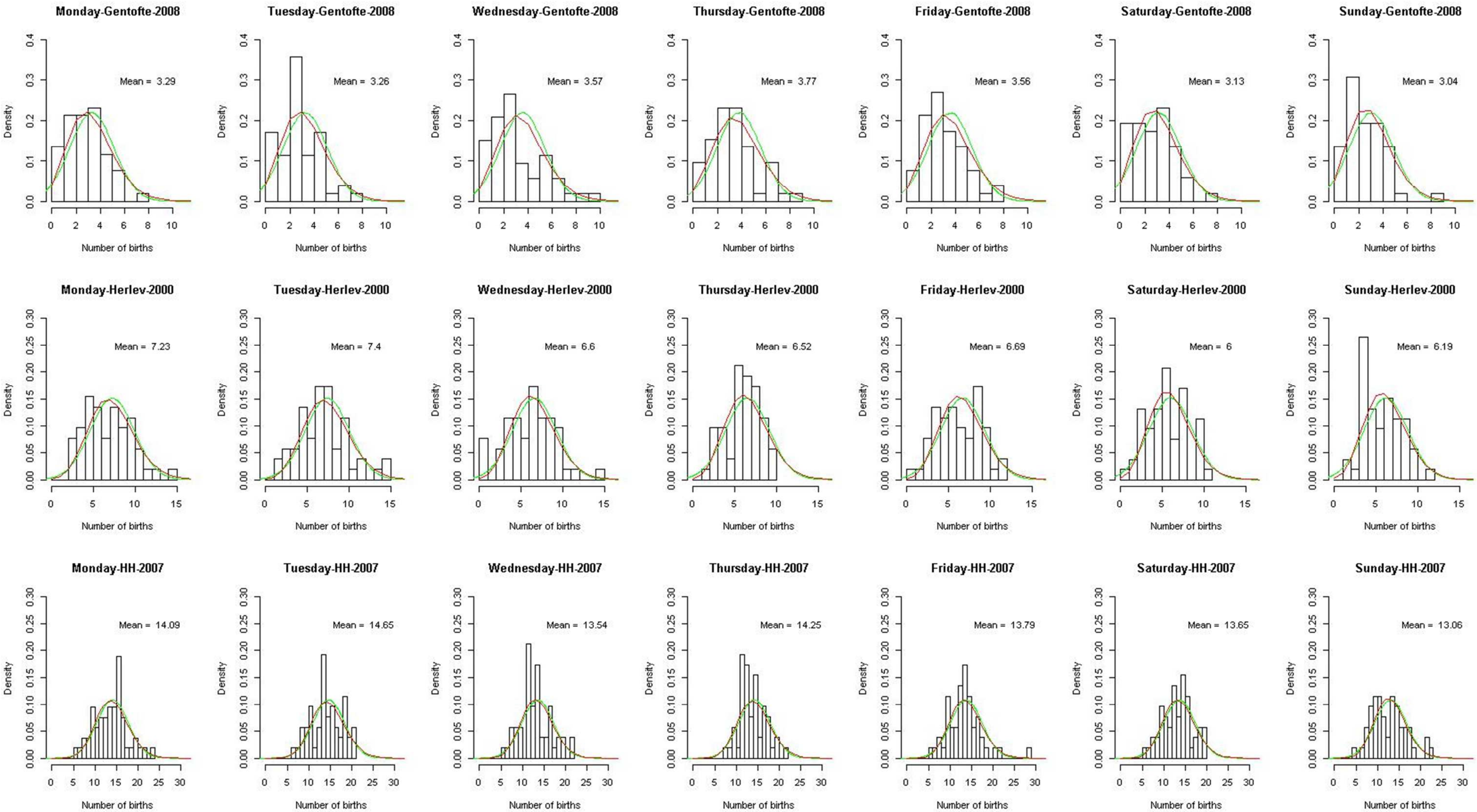

3.0
2.5
2.0
1.5
1.0
0.5
0.0
Mean per day
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Residual variance

Table I Type of births in each obstetric clinic in the Capital region of Denmark during 2000-2009, with number and percentages of spontaneous births, acute Caesarean sections after spontaneous onset of labour, births after induction of labour and elective Caesarean sections.

Obstetric clinic	Births per clinic	Non-elective births (81 %)				Elective births (19 %)			
		Spontaneus birth	%	Acute Caesarean	%	Induced birth	%	Elective Caesarean	%
Rigshospitalet	35.657	19.144	54	5.740	16	6.345	18	4.428	12
Hvidovre	53.300	39.335	74	7.264	14	2.375	4	4.326	8
Frederiksberg	17.751	13.784	78	1.794	10	1.266	7	907	5
Gentofte	21.988	14.216	65	2.863	13	3.349	15	1.560	7
Glostrup	22.737	15.972	70	2.883	13	2.808	12	1.074	5
Herlev	23.967	17.352	72	2.800	12	2.680	11	1.135	5
Hillerød	35.890	23.209	65	4.653	13	5.133	14	2.895	8
All seven clinics	211.290	143.012	68	27.997	13	23.956	11	16.325	8

Figure II Exemplification of a small (Gentofte), medium (Herlev) and large (Hvidovre Hospital, abbreviated HH) obstetric clinic with number of births at the *x* axis and density at the *y* axis with curves indicating the Poisson distribution (Red) and the normal distribution (Green).

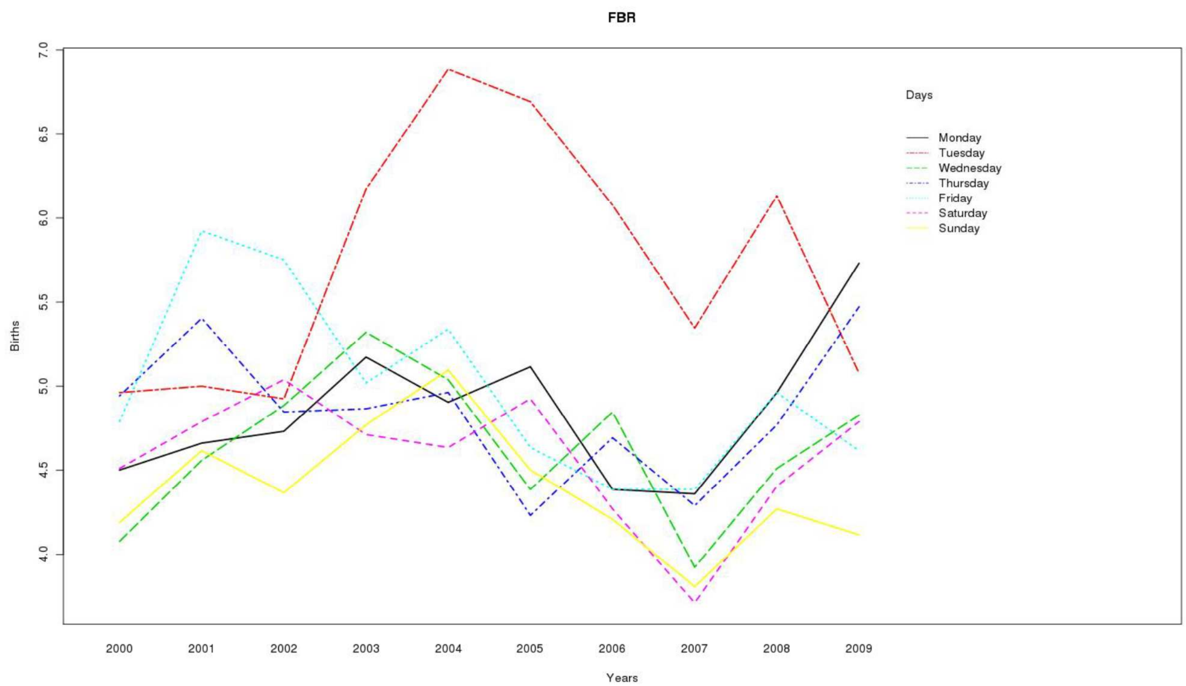


SUPPLEMENTARY FILE

Preliminary descriptive analyses of the data clearly indicated that policies concerning planning of elective Caesarean sections and electively induced labour varied considerably over the ten years for each department and that the patterns were rather different between departments, however overall a mid-weekly peak in births remained even when 'elective' births were excluded. The following figures (Figure III-IX) illustrate this finding.

Figure III Number of births on each day of the week for each year in the obstetric clinic of Frederiksberg a) for all births and b) for 'non-elective' births

a)



b)

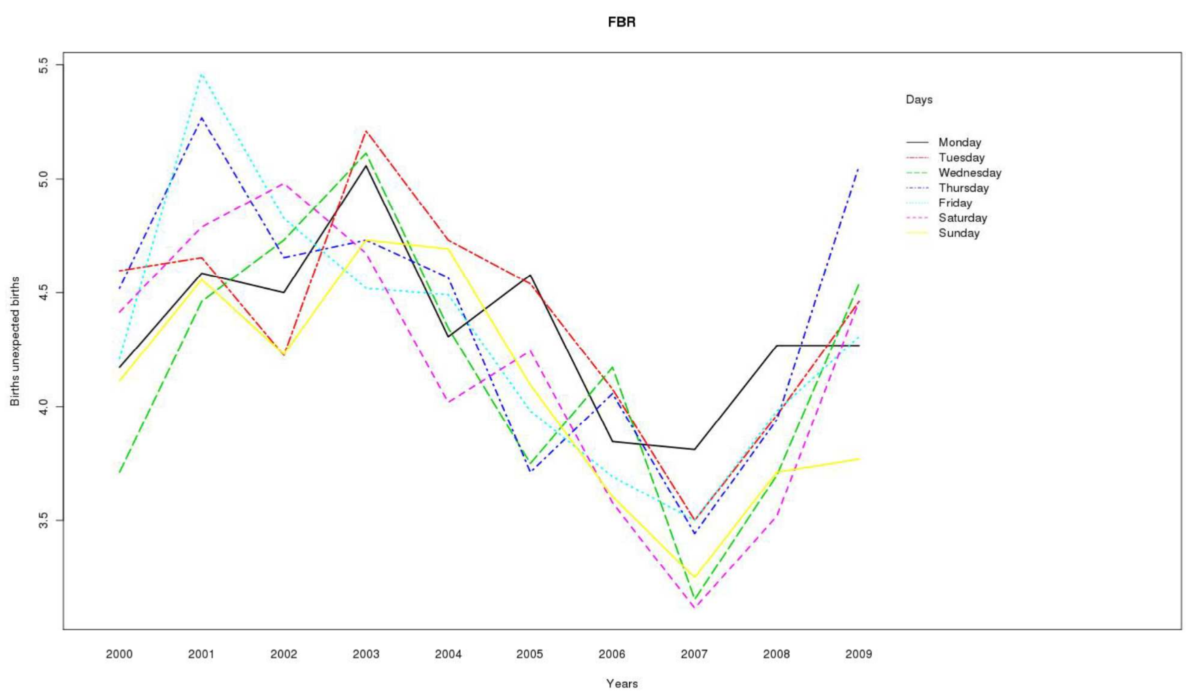
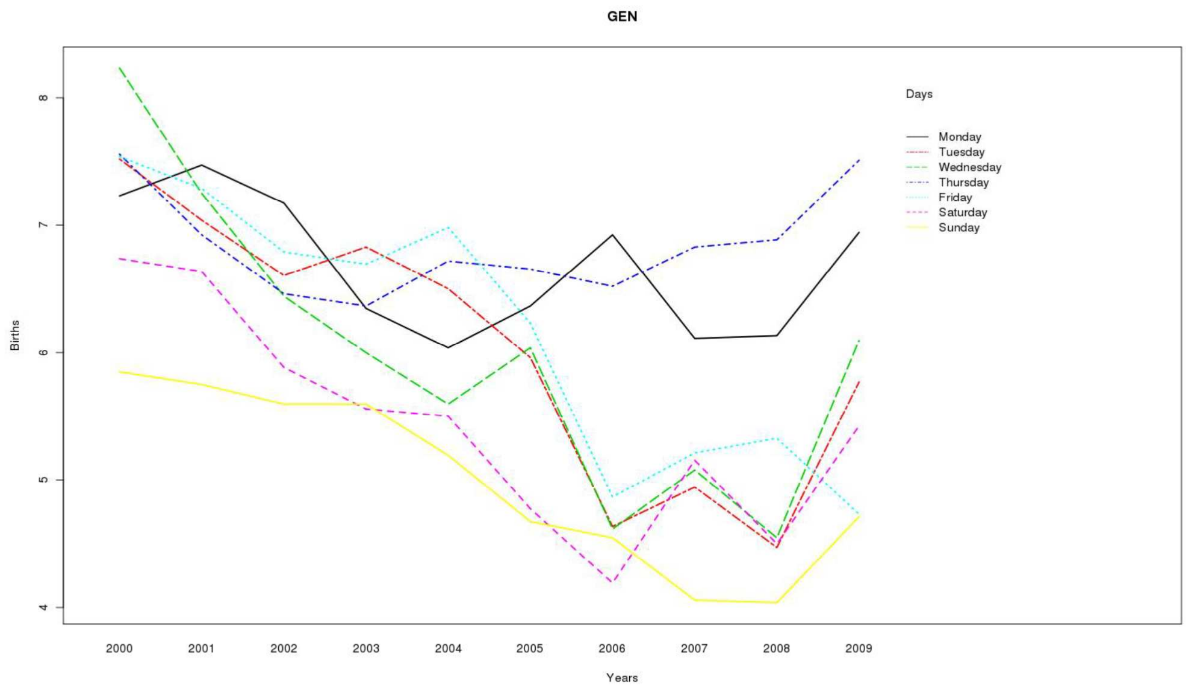


Figure IV Number of births on each day of the week for each year in the obstetric clinic of Gentofte a) for all births and b) for 'non-elective' births

a)



b)

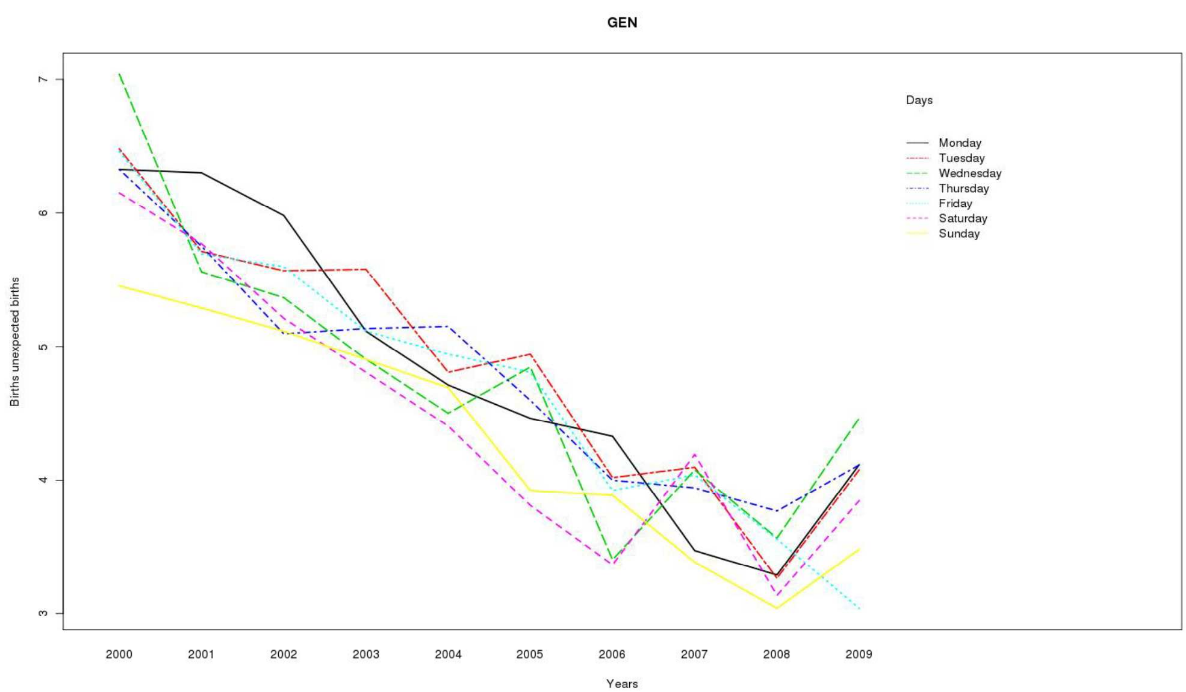
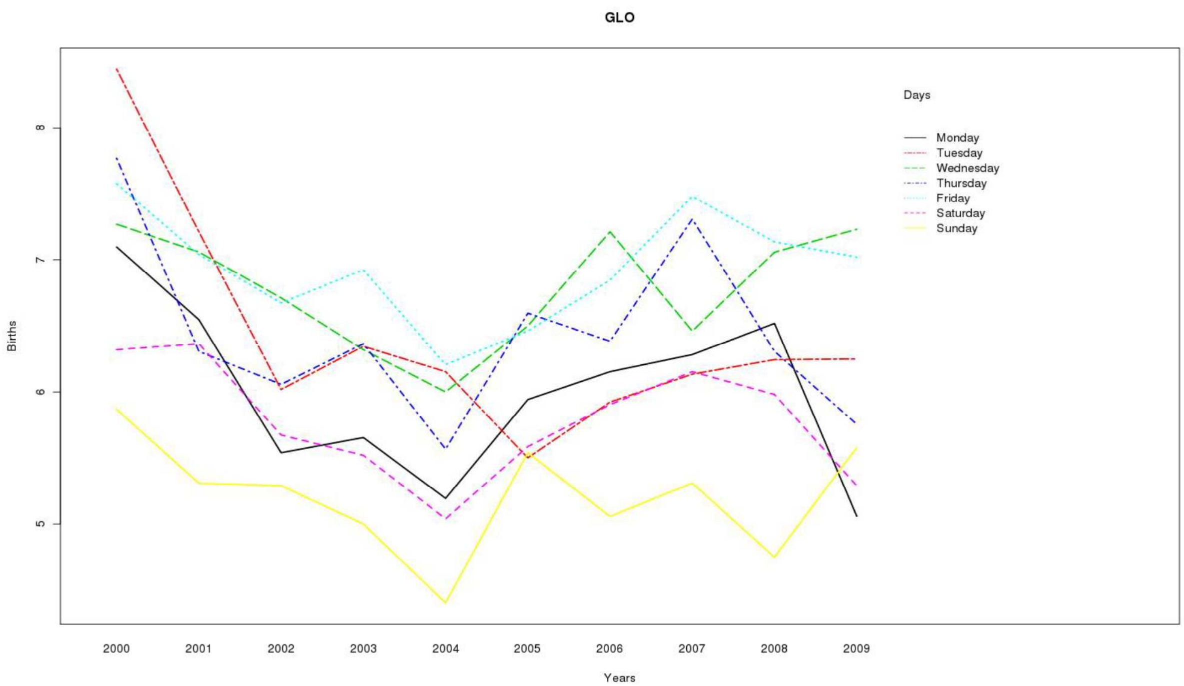


Figure V Number of births on each day of the week for each year in the obstetric clinic of Glostrup a) for all births and b) for 'non-elective' births

a)



b)

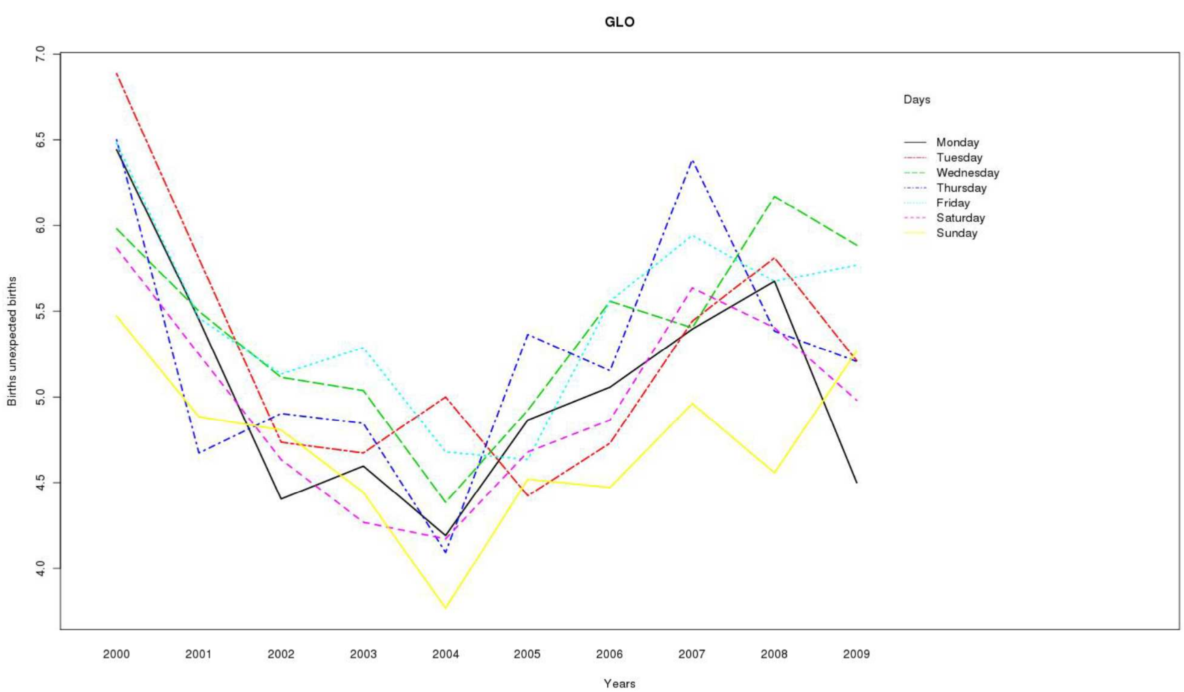
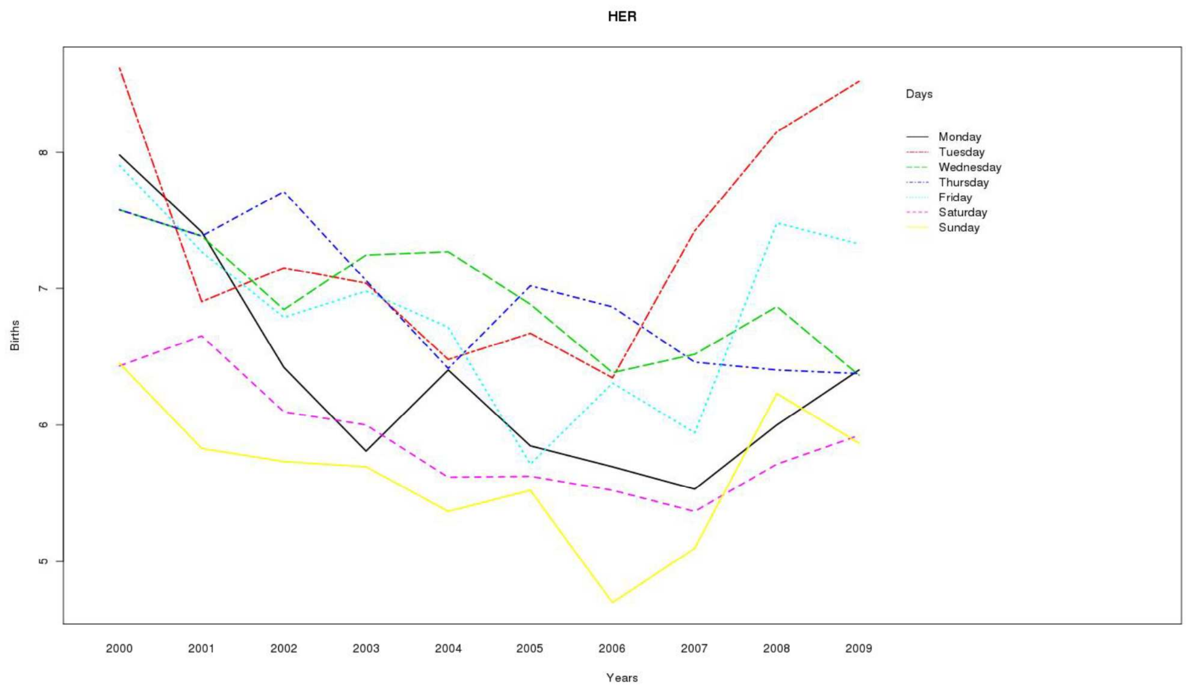


Figure VI Number of births on each day of the week for each year in the obstetric clinic of Herlev a) for all births and b) for 'non-elective' births

a)



b)

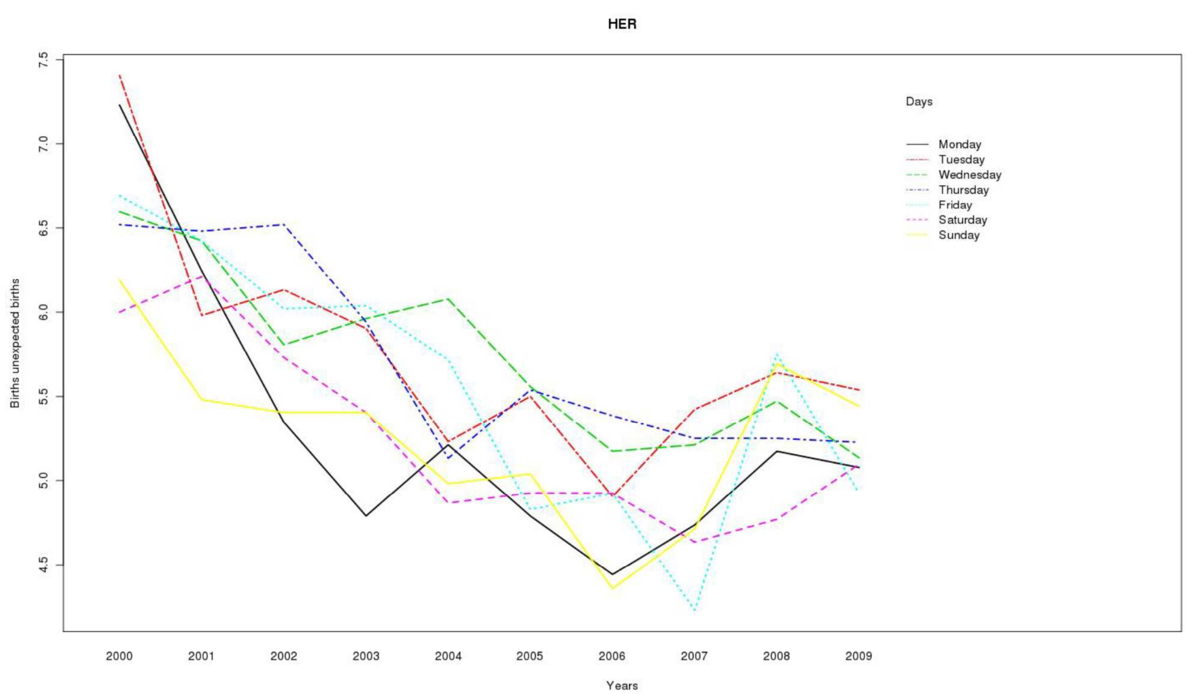
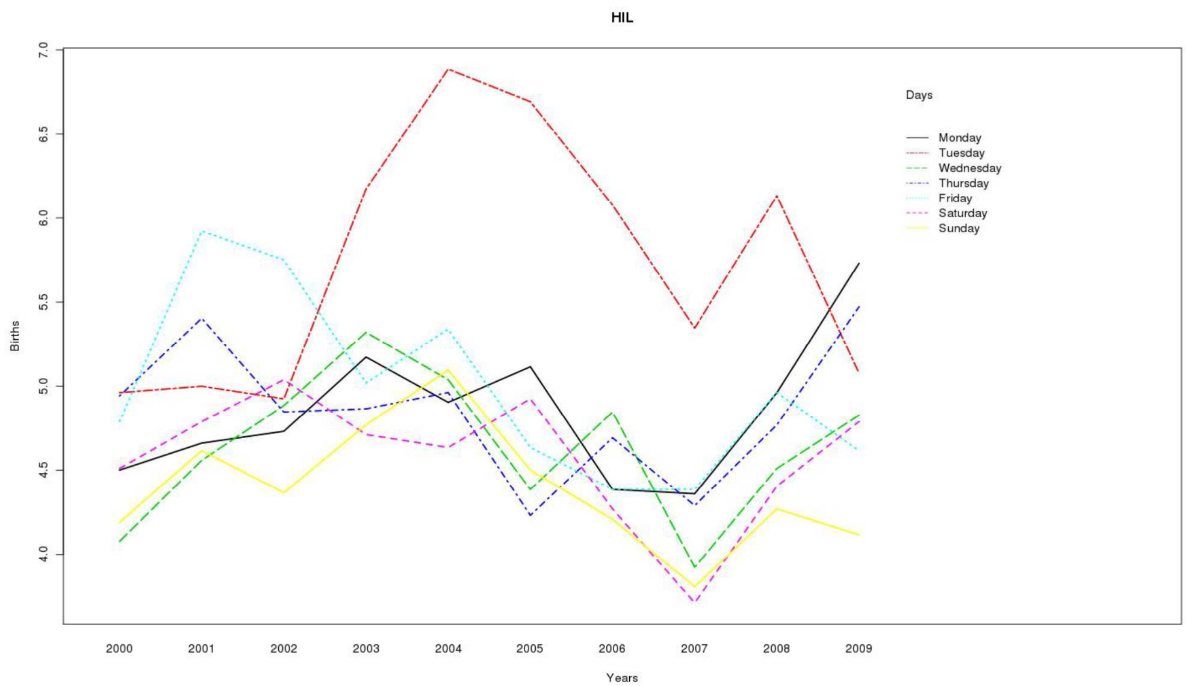


Figure VII Number of births on each day of the week for each year in the obstetric clinic of Hillerød a) for all births and b) for 'non-elective' births

a)



b)

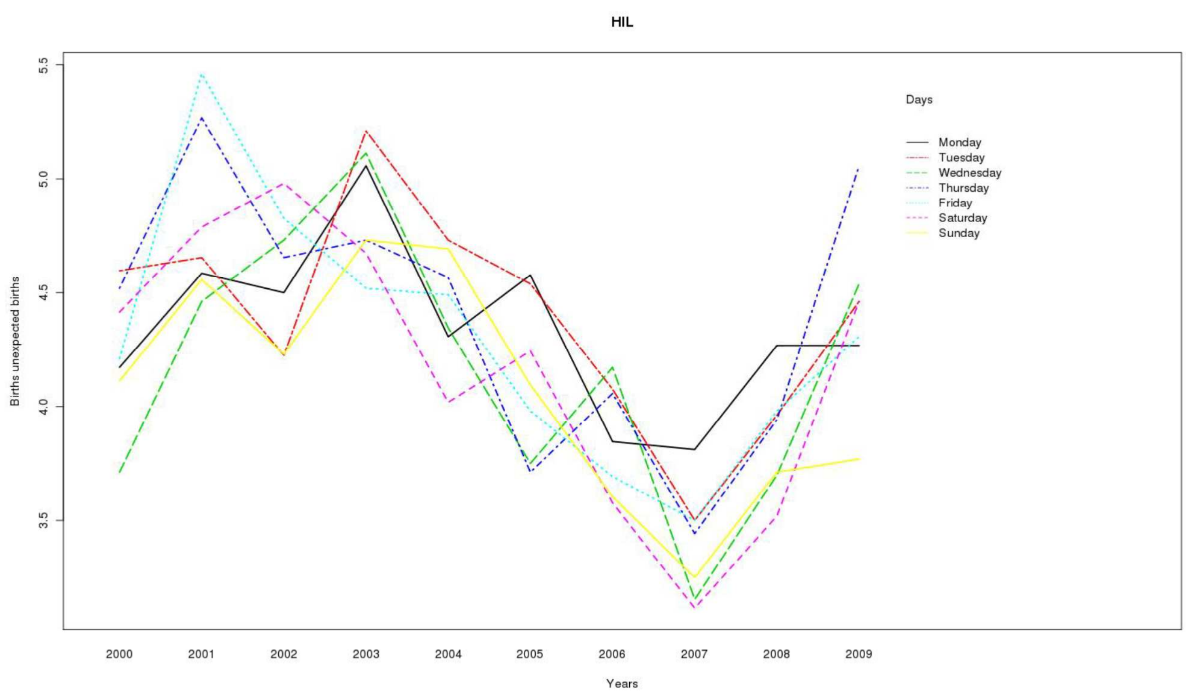
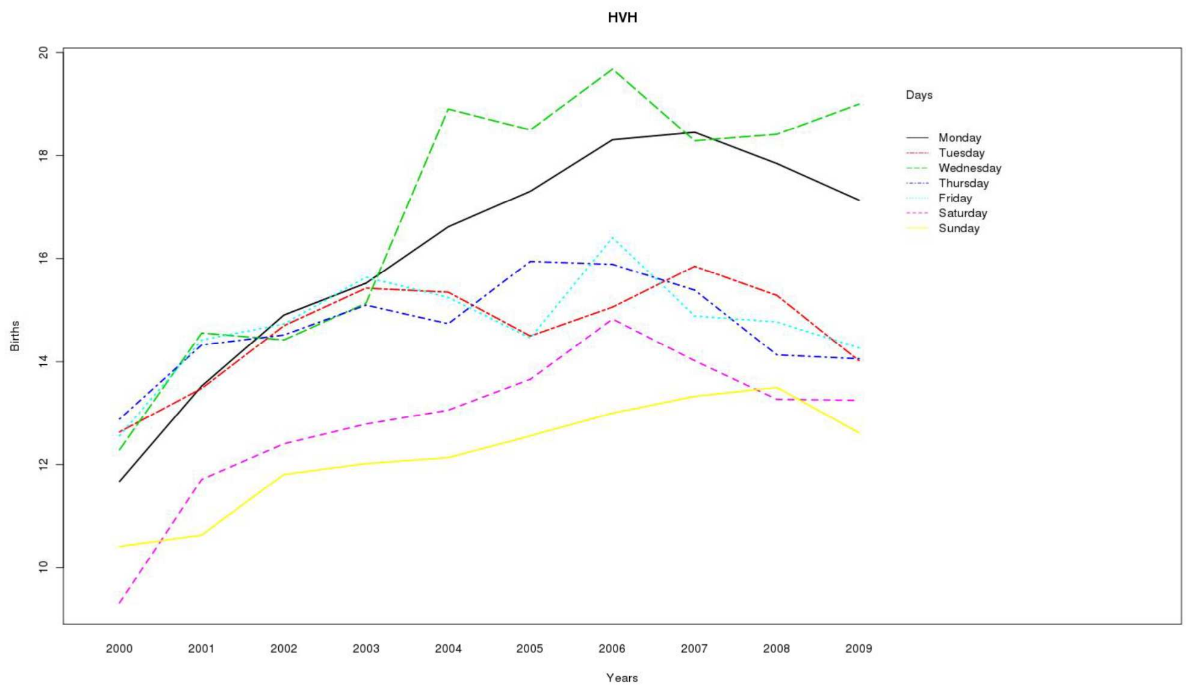


Figure VIII Number of births on each day of the week for each year in the obstetric clinic of Hvidovre a) for all births and b) for 'non-elective' births

a)



b)

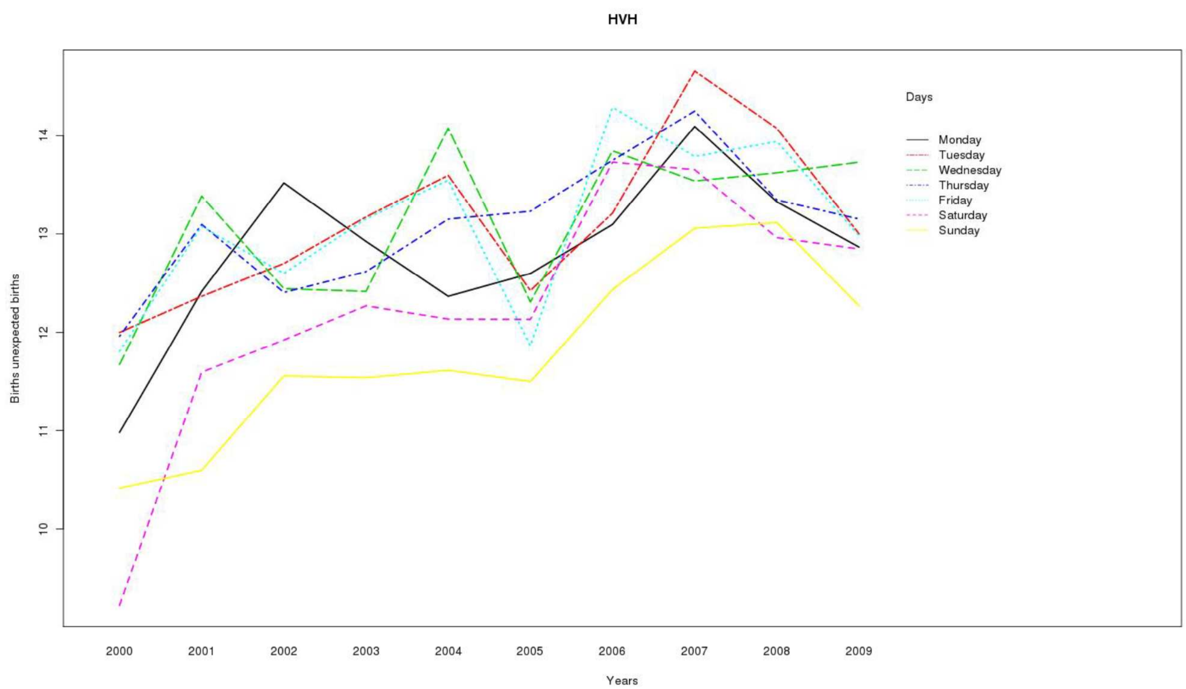
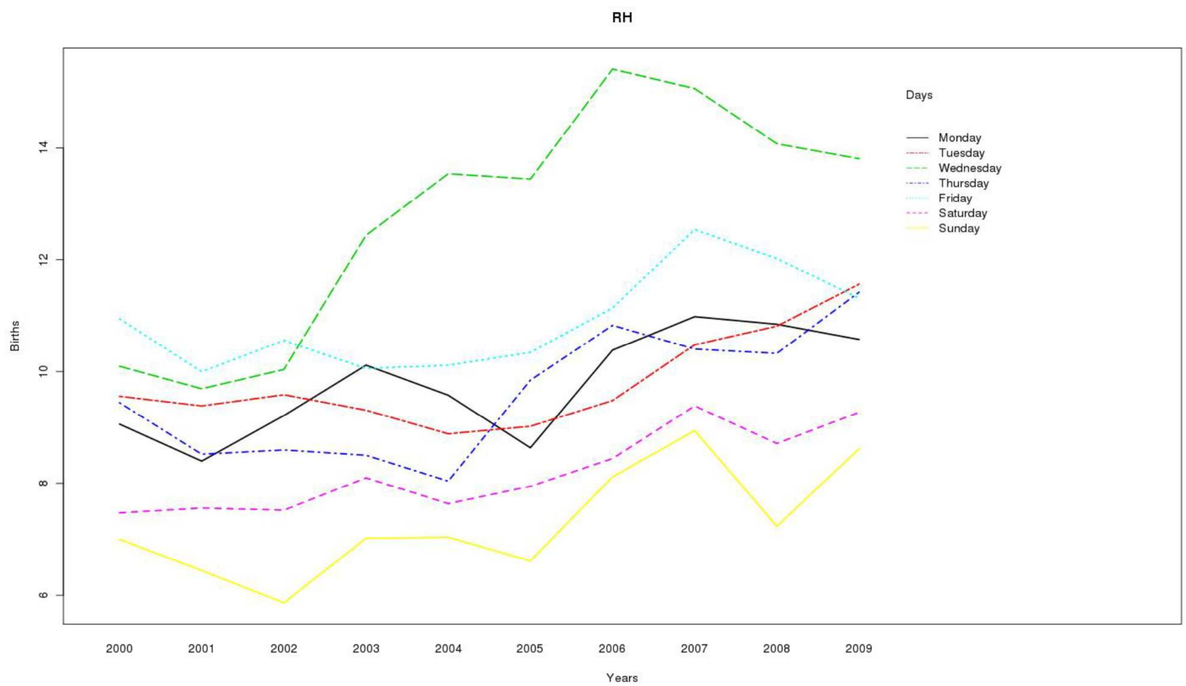
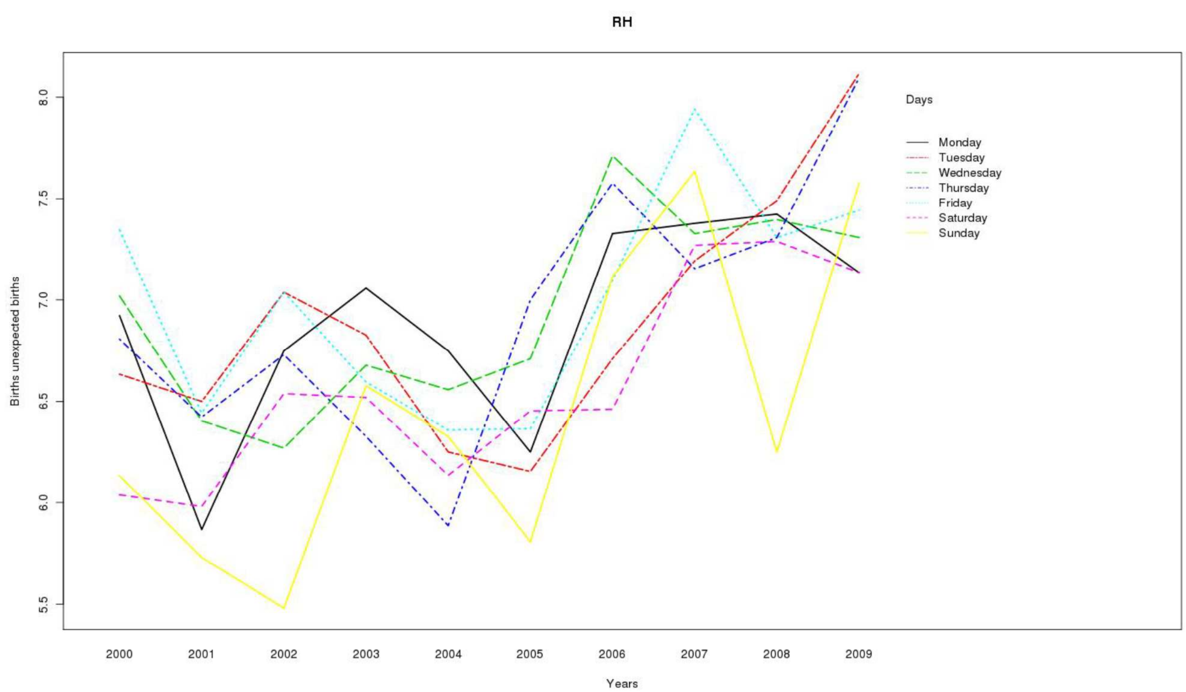


Figure IX Number of births on each day of the week for each year in the obstetric clinic of Rigshospitalet a) for all births and b) for 'non-elective' births

a)



b)



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A MODEL FOR THE DISTRIBUTION OF DAILY NUMBER OF BIRTHS IN OBSTETRIC CLINICS BASED ON A DESCRIPTIVE RETROSPECTIVE STUDY

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A MODEL FOR THE DISTRIBUTION OF DAILY NUMBER OF BIRTHS IN OBSTETRIC CLINICS BASED ON A DESCRIPTIVE RETROSPECTIVE STUDY

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ABSTRACT

Objective: To test whether the relatively unpredictable nature of labour onset can be described by the Poisson distribution.

Design: A descriptive retrospective study.

Setting: From the Danish Birth Registry we identified births from all seven obstetric clinics in the Capital region of Denmark (n=211,290) between 2000 and the end of 2009. On each date the number of births at each department was registered. Births are categorised in whether an elective Caesarean section or induction of labour has been performed and among the remaining 'non-elective births' acute Caesareans were registered.

Methods: After exclusion of elective Caesarean sections and births after induction of labour only 'non-elective' births (n=171,009) were included for the main statistical analysis. Simple descriptive plots and one-way analysis of variance were used to analyse the distribution of 'non-elective' births for each day of the week.

Main outcome measures: The daily number of 'non-elective' births.

Results: The number of 'non-elective' births varies considerably over the days of the week and over the year for each obstetric clinic regardless of clinic size. However, for each fixed day of the week the variation over the year is well described by a Poisson distribution, allowing simple prediction of the variability. For births at each fixed day of the week, the Poisson distribution is indistinguishable from a normal distribution.

Conclusion: The number of 'non-elective' births for each day of the week is well-described by a Poisson distribution. Consequently the Poisson model is suitable for estimating the variation in the daily number of 'non-elective' births and could be used for planning of staffing in obstetric clinics. The model can be used in smaller as well as larger clinics.

ARTICLE SUMMARY

Article focus: Does the Poisson distribution correspond precisely to actual random variation in the number of 'non-elective' births for each fixed day of the week?

Key Message box:

- For each day of the week, the variation of 'non-elective' births over the year is well described by a Poisson distribution.
- The Poisson distribution makes it easy to estimate the variation in the daily number of births and can be used for planning of staffing in obstetric clinics. Standard tables of the normal distribution may be used as exemplified.
- The model is adequate for use in smaller as well as larger clinics and can be used in management of staffing in obstetric clinics.

Strengths and limitations of this study: The main strength is the large dataset of non-selected births. The main limitation is that births are registered only by date, not by time of birth.

INTRODUCTION

There is a structural reorganization of hospitals going on in Denmark implying larger but fewer hospitals. This applies also for the departments of Gynaecology and Obstetrics as smaller departments are being merged resulting in fewer larger departments (1-3). The main motivation for these changes has been that larger departments would enhance the capacity and quality of patient treatment and additionally reduce the costs for staff at shifts. In Denmark the overall year to year variation in number of births at each department is centrally determined as each department of Gynaecology and Obstetrics on an administrative level is intended to have a given number of births from a specified geographical region and therefore the staffing required in each obstetric clinic in each department is determined from this figure. The largest part of staffing consists of a daily number of midwifes working eight hours shift during day, evening and night, as well as a varying number of midwifes on 24 hour duty on call from home. Their actual working hours vary considerably. The number of doctors on shift is fixed for each obstetric clinic and depends on the size of the obstetric clinic, as does the number of doctors on call from home.

An interesting organizational feature in obstetrics is the inherent random variation in onset of spontaneous labour which makes it difficult to precisely plan the necessary number of staff at the obstetric clinics. The planning of staffing in the departments is to our knowledge not based on published methods. Statistics on the number of births on each day for each department every year is available online from Statistics Denmark (4). These numbers indicate considerable day to day variation and week to week variation. The observation of a weekly cycle is in accordance with reports from other countries such as England, Wales, Australia, the United States, Israel and Norway (5-13) and interestingly it has also been shown that the variation depends on whether the Sabbath occurs on a Friday (14), a Saturday (5) or Sunday (6-13). However these former studies included all births regardless of whether or not there had been an elective obstetric intervention, which raises the question whether the variation between the days of the week disappears, when births resulting from an elective obstetric intervention as elective Caesarean or induction of labour are excluded from the data set. There is a long tradition of describing the variation in the daily demand for hospital beds by the Poisson distribution (15-17) sometimes based on queuing theory and with varying efforts at empirical verification. In her well-known textbook Kirkwood (18) used an apparently hypothetical example of staffing planning in the face of merging two obstetrical departments to illustrate the Poisson distribution.

In this study we examine from a broad Danish experience how well the Poisson distribution corresponds to actual random variation in the number of 'non-elective' births for each fixed day of the week. Since the variation in the 'non-elective' births is most obviously random, we exclude in the main analysis 'elective' births (resulting from induction of labour and elective Caesarean sections). However, as a sensitivity analysis we report results on the variation of all births and of acute Caesarean sections.

MATERIAL AND METHODS

Data

The number of births for each date in the period from the 1st of January 2000 until the 31st of December 2009 at all seven obstetric clinics in the capital region of Denmark were extracted from the Danish Birth registry. The obstetric clinics were Rigshospitalet, Frederiksberg, Glostrup, Gentofte, Herlev, Hvidovre and Hillerød, which cover over 99% of all births in the region, as a dwindling number of births takes place at home in Denmark. The data included information on the type of birth: elective Caesarean sections, births after elective induction of labour, acute Caesarean sections and births after spontaneous onset of labour. The labelling of the type of birth has been done by using information from the National Birth registry on operation codes for elective Caesarean sections (KMCA10B and D) and obstetric codes for induction of labour (KMAC00 Amniotomy prior to birth, KMAC96A Mechanical catheter induction, BKHD2 Unspecific medical induction, BKHD20 Induction with prostaglandin, BKHD21 Induction with oxytocin) . The coding of birth information is based on information from midwifes and is generally considered very valid.

Statistical methods

The main concept of these analyses builds on the empirical fact that even for 'non-elective' births there is a non-ignorable variation across the seven days of the week, however for each fixed day of the week the variation across the 52 (53) weeks in a given year may be interpreted as random. We exploit the well-known fact that Poisson distributions are well approximated by normal distributions with the same mean and variance, clearly distinguishable by the Poisson distribution property that the mean equals the variance. In this way the key issue – whether the Poisson distribution is an adequate description – is captured by a one-way analysis of variance comparing the seven days of the week for each of the ten years and each of the seven clinics. The results are illustrated by descriptive graphs and worked examples of possible use in staffing planning. Additional sensitivity analyses are performed including all births and acute Caesareans.

Details of ethics approval

An ethical approval for this study was not required. The data used are available online in an anonymous form.

RESULTS

There were 211,290 births distributed on seven departments in the capital region of Denmark from the 1st of January 2000 until the 31st of December 2009. In order to exclude potential elective births, births were subdivided into induced or spontaneous labour and elective and acute Caesareans (Table I). Births where the mode of delivery was an elective Caesarean (n=16,325 (7.73 %)) and births initiated by induction of

labour (n=23,956 (11.34%)) were excluded from the data set for main analyses, thus leaving a total of 171,009 (80.94%) spontaneous births and acute Caesareans, to be denoted 'non-elective' below.

As mentioned in the introduction a main problem in obstetrics management is the variation over days of the week. This variation is to a large degree a result of decisions by the obstetricians on how to distribute elective Caesareans and electively induced labour over the days of the week (6, 12). Preliminary descriptive analyses of the data clearly indicated that such policies varied considerably over the ten years for each department and that the patterns were rather different between departments, however overall a mid-weekly peak in births remained even when 'elective' births were excluded (please see the supplementary file, Figure III-IX). The staffing required for these 'elective' births is a consequence of management decisions, and our focus is here on how to capture the primarily random variation in the 'non-elective' births. Because of the strong heterogeneity in the day-to-day pattern for several of the involved departments over the ten years under study, we performed a set of 70 one-way analyses of variance comparing the number of 'non-elective' births at each day of the week for each fixed combination of department (n=7) and year (n=10). The residual variances from these 70 analyses were compared to the annual mean number of births for each department. Additional sensitivity analyses were performed including all births and acute Caesareans. As seen in Figure I, the residual variances are very close to the means, indicating a Poisson distribution of the variation in number of 'non-elective' births for each day of the week around the yearly average for that day. We also see that the closeness of residual variance to the mean improves when we only look at the 'non-elective' births while for the acute Caesareans only there is a clear trend that the variance is larger than the mean, so-called overdispersion which violates the assumption of Poisson distribution. In view of these findings we focus on the non-elective births in the following.

To illustrate our findings three selected combinations of department and year, a small, medium and large clinic, were chosen. For each day of the week a histogram shows the observed distribution of the 52 (53) numbers of births per day for that year with fitted normal distribution (red) and fitted Poisson distribution was produced (green) (Figure II). It is seen that there is a nice fit throughout of the Poisson distributions, and also that they are very close to the normal distributions with the same variance. This means that calculations of the likely variation in number of 'non-elective' births can be based on the normal distribution with variance given by the average number of 'non-elective' births per day over the year.

For example, if at a particular department in a particular year the mean number of 'non-elective' births is 9, the residual variance is estimated to be 9 and the standard deviation as the square root of 9, that is, 3. Assume that the mean number of 'non-elective' births on Tuesdays for that department for that year is 10.5. In 95% of Tuesdays the actual number of 'non-elective births' at that department will be in the interval between 10.5 – 3 x 1.96 = 4.6 and 10.5 + 3 x 1.96 = 17.4, while in 80% of Tuesdays there will be between 10.5 – 3 x 1.28 = 6.7 and 10.5 + 3 x 1.28 = 14.3 non-elective births. This model is suitable for estimating daily number of births and planning of staffing in obstetric clinics and the model is adequate to be used in smaller as well as larger clinics.

Discussion

Management of staffing in obstetric clinics is a difficult task, due to the relatively unpredictable nature of labour onset. Nowadays many births are 'elective' births in the sense that elective Caesarean sections or medically induced labour more or less governs the time of the week where the birth happens. It has been assumed that the day to day variation on numbers of births fits a Poisson distribution (13, 18), but suitable data on live births, including mode of delivery, from a larger population has not previously been studied, thus limiting the means of studying day to day variation (7, 13). Furthermore the impact of elective obstetric intervention on the distribution has not been considered in any of the previous studies addressing birth variation (5-14, 19).

Interestingly we find that even with the exclusion of births resulting from an obstetric intervention as elective caesarean or induction of labour, the remaining data still show significant weekly variation with a mid-weekly peak. As such this variation might not only be ascribed to measurable obstetric interventions, but also less tangible practices, for instance the time of admittance of a woman in early stages of labour might depend on staff numbers which vary during the week. Also traditional non-medical methods of starting labour (hot baths, sexual intercourse, etc.) might be less likely to be tried by mothers in the weekends (7).

However regardless of any obstetric practices or mothers practice, we found that the distribution of the remaining 'non-elective' births for each day of the week, each year, and each department is still well approximated by a Poisson distribution, where the mean equals the variance. For the relevant parameter values, this Poisson distribution is indistinguishable from a normal distribution, where we then may estimate the variance from the mean. This means that calculations of the likely variation in number of non-elective births can be based on the normal distribution with variance given by the average number of non-elective births per day over the year.

This provides us with a useful tool for planning of the staffing necessary to handle all births on a given weekday in an obstetric clinic. Elective Caesarean sections are usually planned to be performed on specific weekdays with staff dedicated to this task. Births after induction of labour will also in most regards be planned. Combining the known number of elective births with the calculation of a 95% or 80% confidence interval of 'non-elective' births on a given week day gives a good possibility to avoid over- or understaffing and utilize the available human resources to their best. For larger clinics where the mean number of non-elective births for a given weekday may vary by more than 1-2 births, the relocation of staffing to 'peak' weekdays has the most to offer, but even smaller clinics can benefit from more concrete calculation, for example on how weekend staffing should be.

The fact that the distribution of ‘non-elective’ births is indistinguishable from normal distribution provides a simple, but elegant, tool for planning of staffing in obstetric clinics and used wisely may prove a positive adjustment for work efficiency, cost and environment.

Conclusions

We may estimate the variance from the mean, as the Poisson distribution for these parameters is indistinguishable from a normal distribution. This model is suitable for estimating the variation in the daily number of ‘non-elective’ births and could be used for planning of staffing in obstetric clinics.

Competing interest

All authors have completed the Unified Competing Interest form at http://www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare: no support from any organization for the submitted work, no financial relationships with any organization that might have an interest in the submitted work in the previous three, no other relationships or activities that could appear to have influenced the submitted work.

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Contribution to authorship

CMG, NK, JT and EL have all been involved in the conception of this study. The statistical analysis has been carried out mainly by JT under the guidance of NK, EL and CMG. The writing of this article has been done by CMG, NK, JT and EL. Coordination of the correspondence between authors has been taken care of by CMG.

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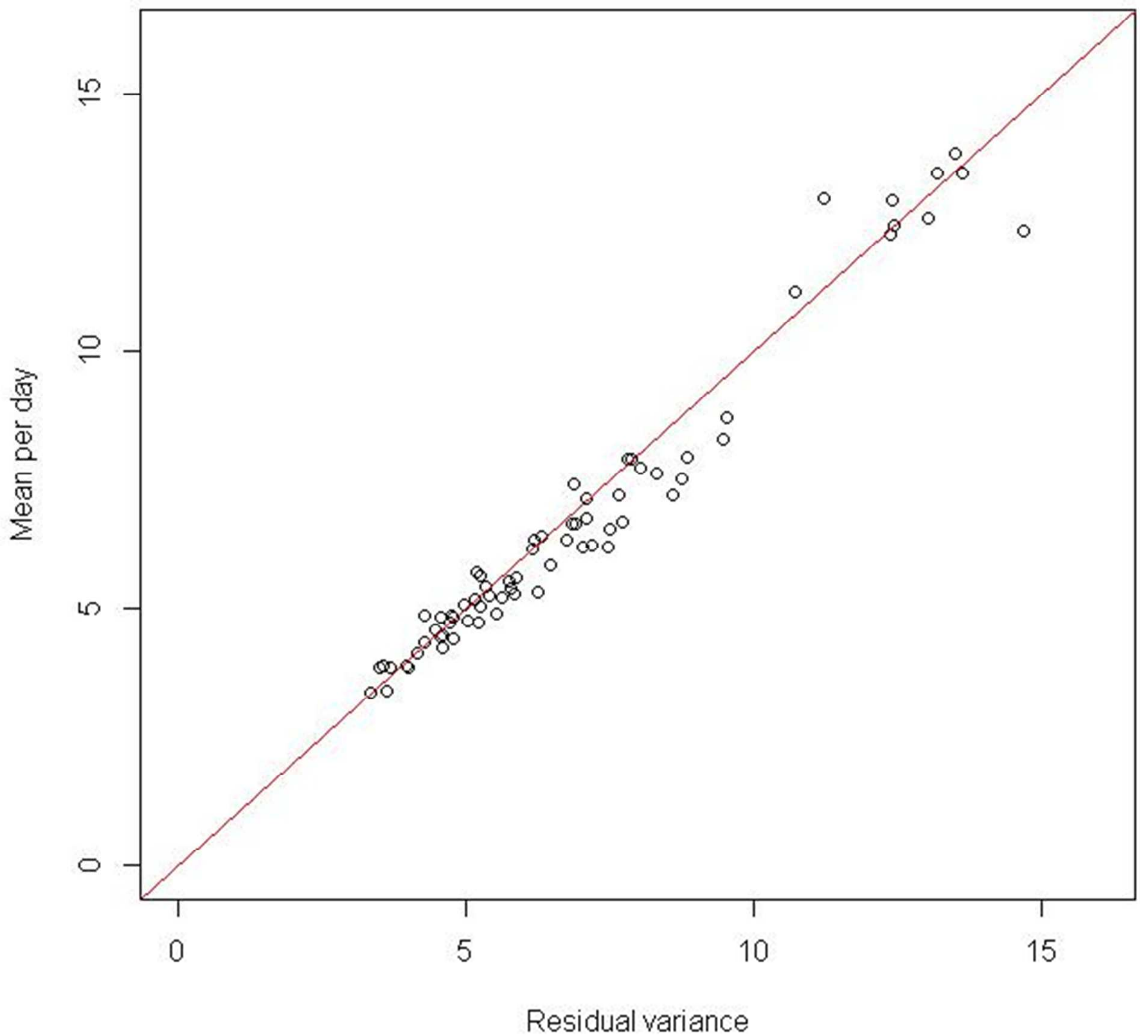
Table I Type of births in each obstetric clinic in the Capital region of Denmark during 2000-2009, with number and percentages of spontaneous births, acute Caesarean sections after spontaneous onset of labour, births after induction of labour and elective Caesarean sections.

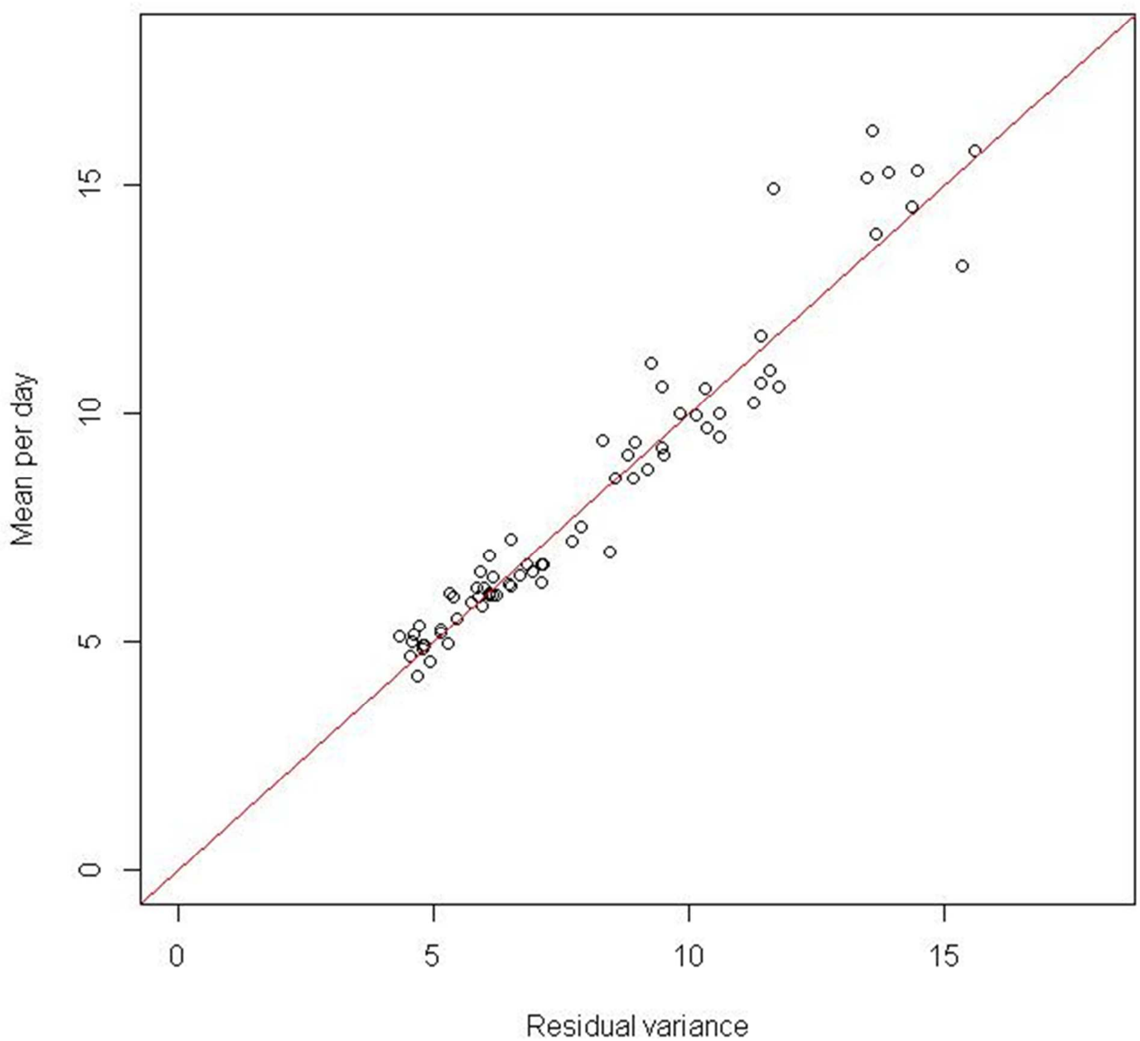
Obstetric clinic	Births per clinic	Non-elective births (81 %)				Elective births (19 %)			
		Spontaneus birth	%	Acute Caesarean	%	Induced birth	%	Elective Caesarean	%
Rigshospitalet	35.657	19.144	54	5.740	16	6.345	18	4.428	12
Hvidovre	53.300	39.335	74	7.264	14	2.375	4	4.326	8
Frederiksberg	17.751	13.784	78	1.794	10	1.266	7	907	5
Gentofte	21.988	14.216	65	2.863	13	3.349	15	1.560	7
Glostrup	22.737	15.972	70	2.883	13	2.808	12	1.074	5
Herlev	23.967	17.352	72	2.800	12	2.680	11	1.135	5
Hillerød	35.890	23.209	65	4.653	13	5.133	14	2.895	8
All seven clinics	211.290	143.012	68	27.997	13	23.956	11	16.325	8

Figure I Residual variance compared to the mean number of births per day for a) 'non-elective' births, b) all births and c) acute Caesarean sections.

a)



b)



c)

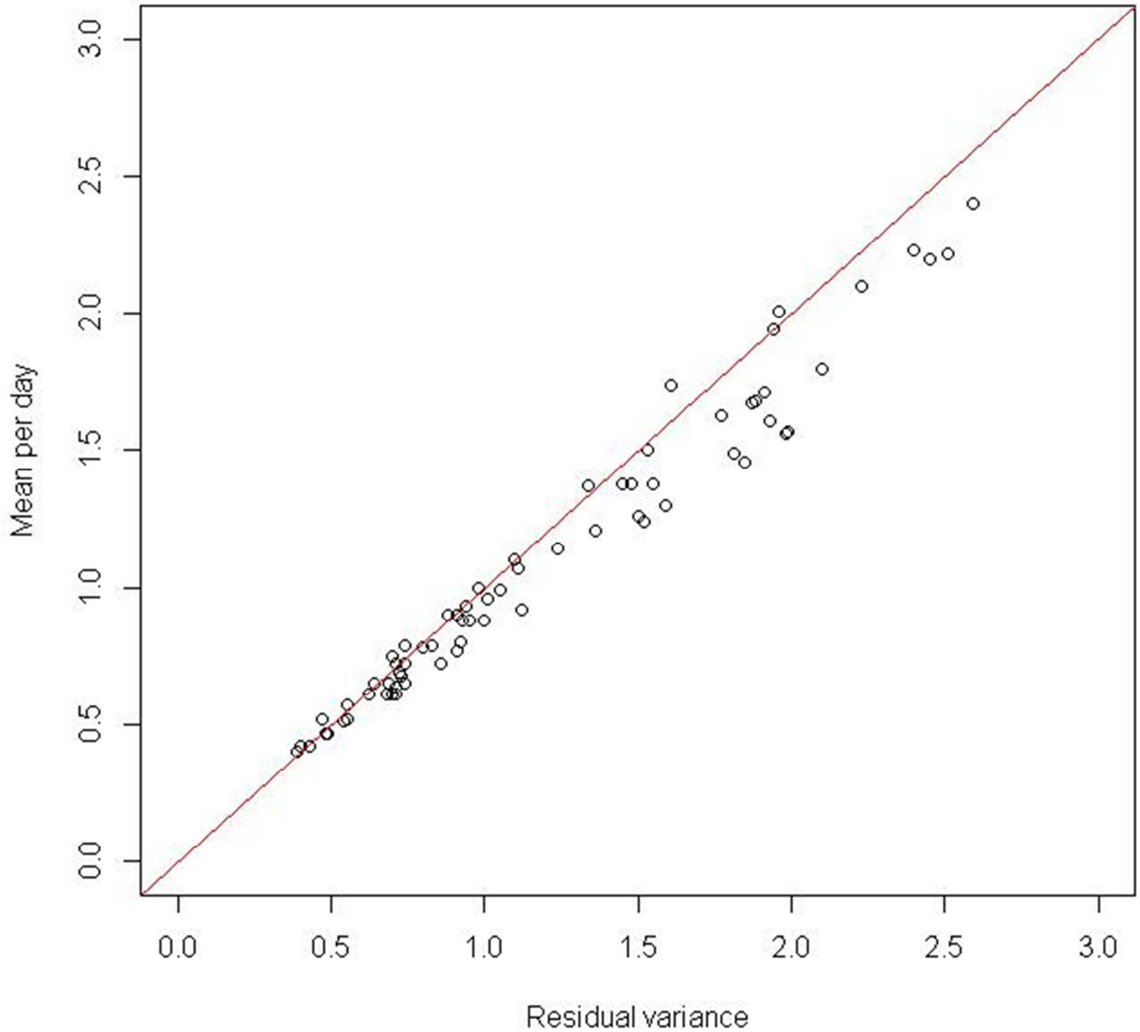
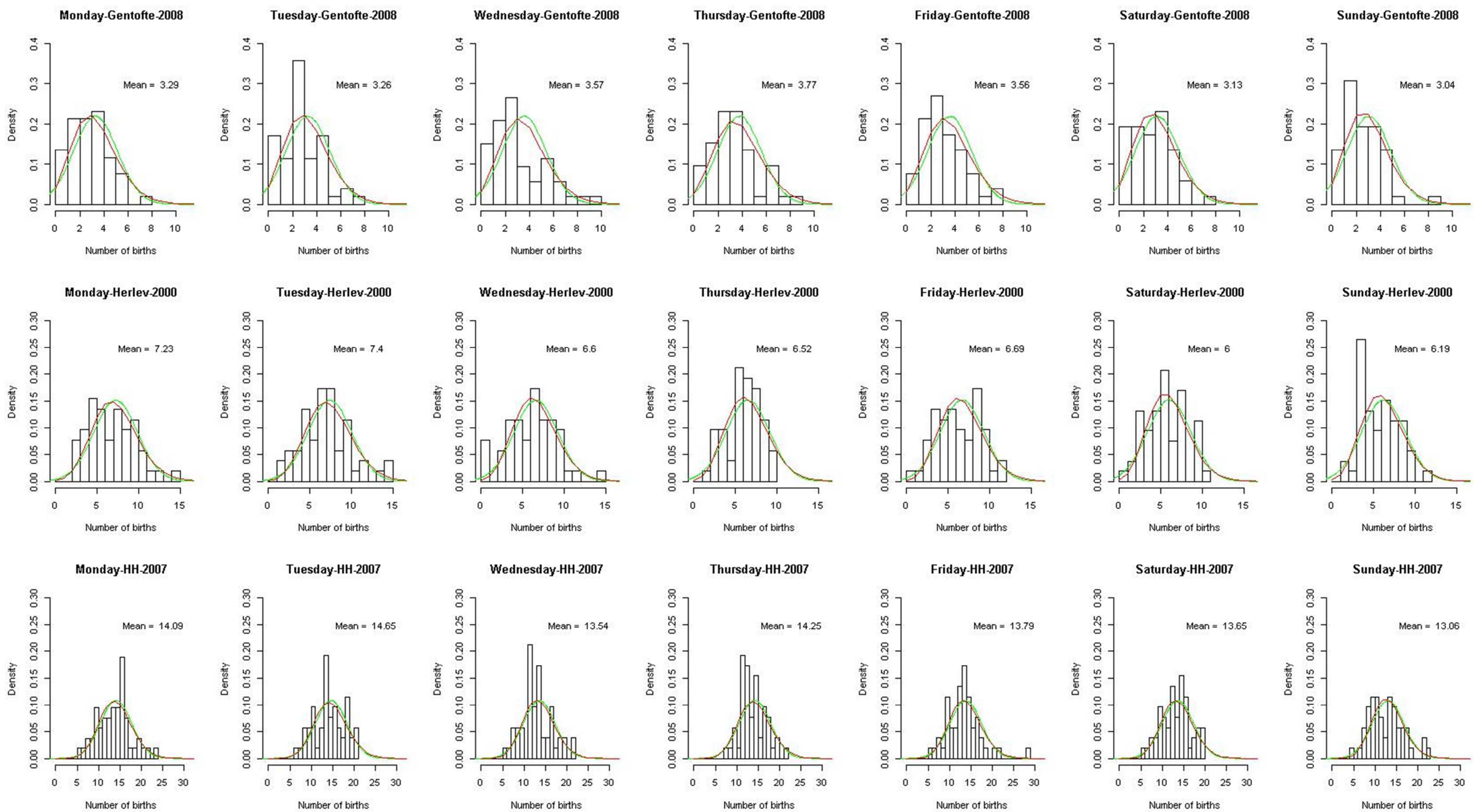


Figure II Exemplification of a small (Gentofte), medium (Herlev) and large (Hvidovre Hospital, abbreviated HH) obstetric clinic with number of births at the *x* axis and density at the *y* axis with curves indicating the Poisson distribution (Red) and the normal distribution (Green).

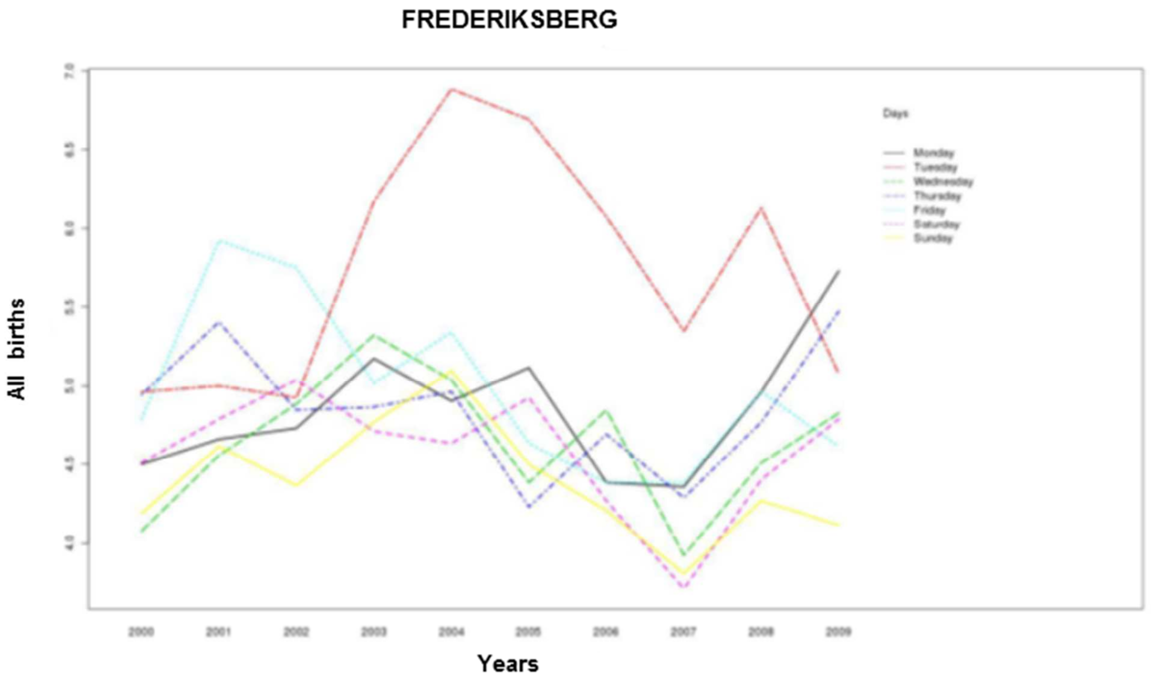


SUPPLEMENTARY FILE

Preliminary descriptive analyses of the data clearly indicated that policies concerning planning of elective Caesarean sections and electively induced labour varied considerably over the ten years for each department and that the patterns were rather different between departments, however overall a mid-weekly peak in births remained even when 'elective' births were excluded. The following figures (Figure III-IX) illustrate this finding.

Figure III Number of births on each day of the week for each year in the obstetric clinic of Frederiksberg a) for all births and b) for 'non-elective' births

a)



b)

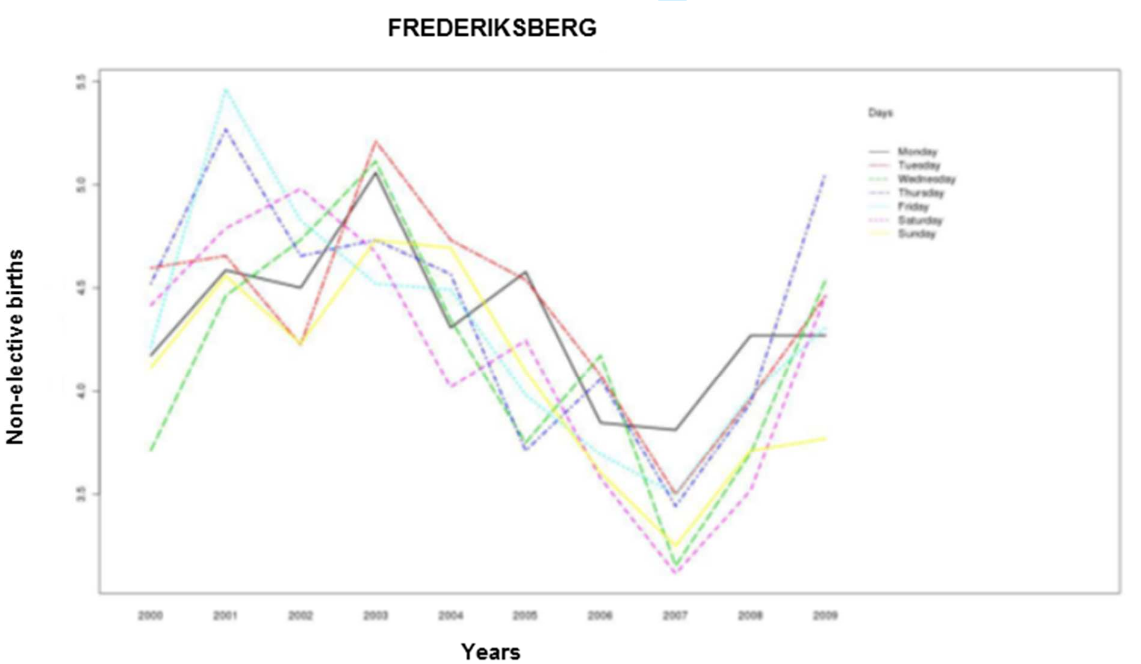
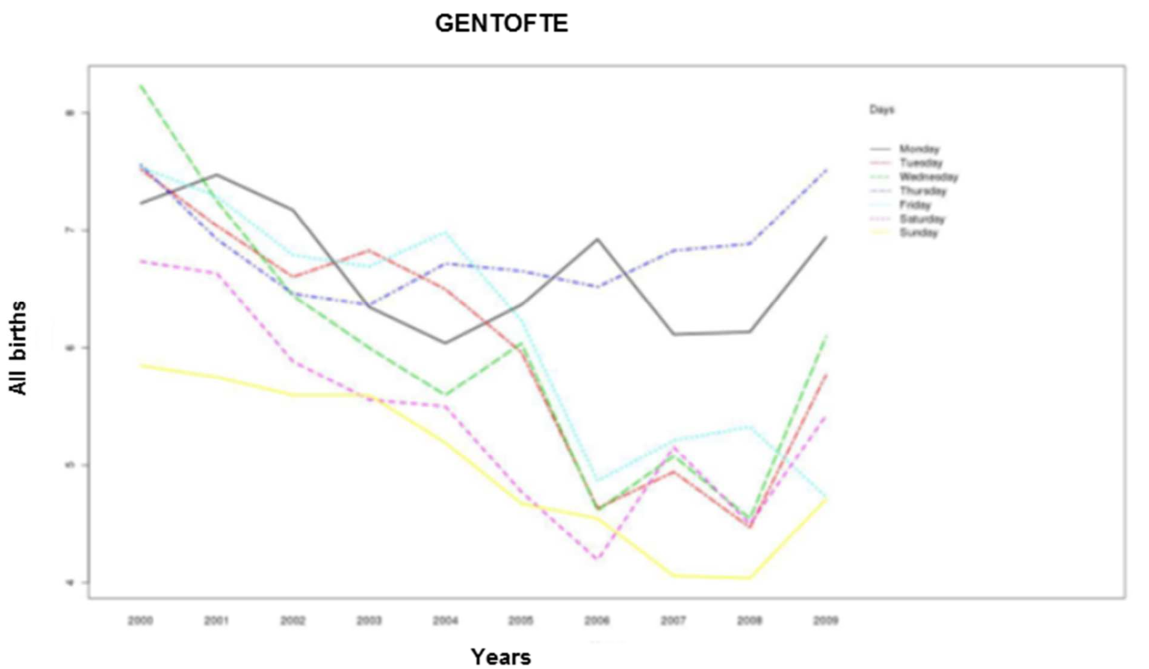


Figure IV Number of births on each day of the week for each year in the obstetric clinic of Gentofte a) for all births and b) for 'non-elective' births

a)



b)

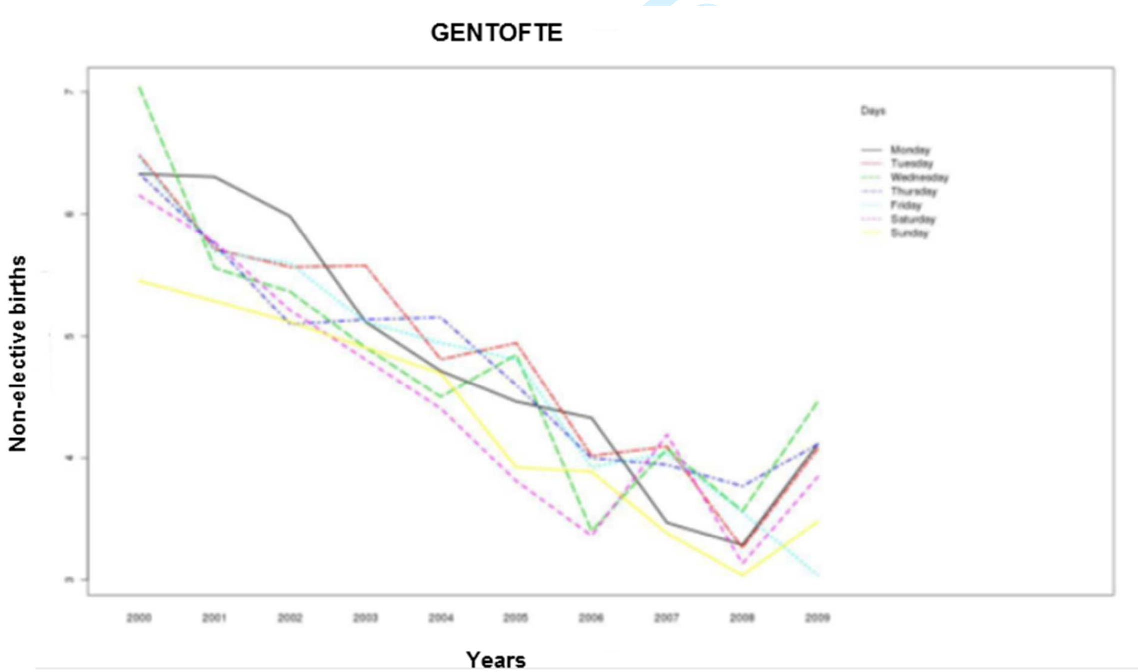
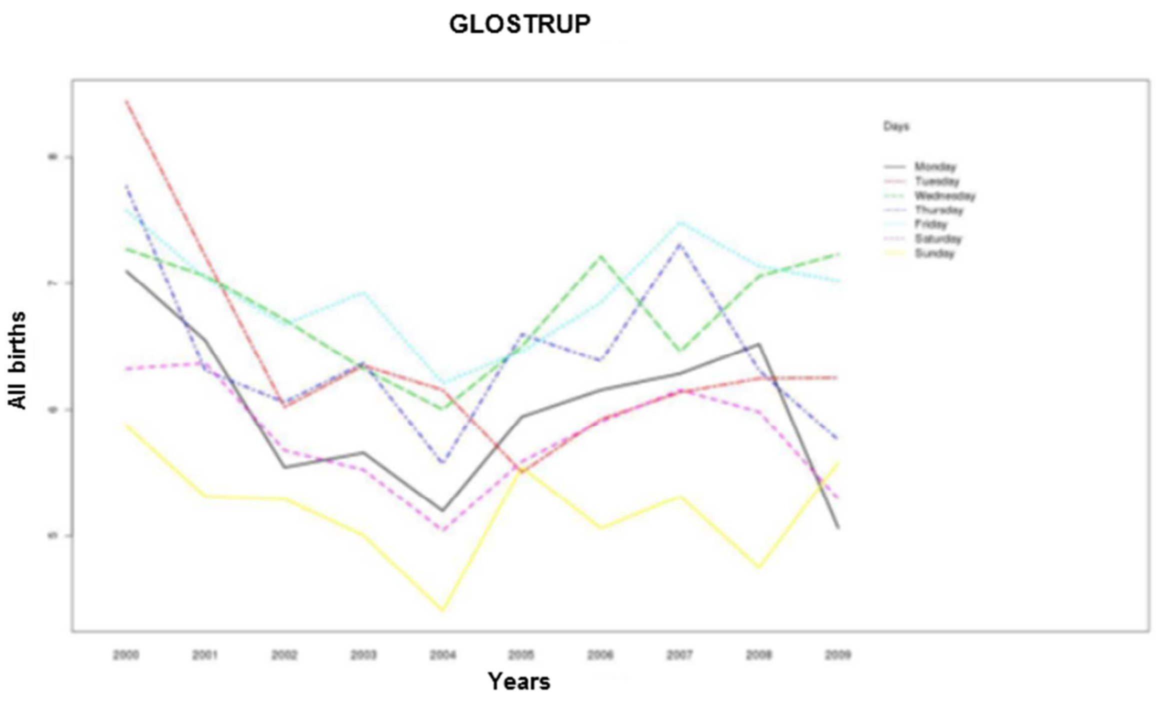


Figure V Number of births on each day of the week for each year in the obstetric clinic of Glostrup a) for all births and b) for 'non-elective' births

a)



b)

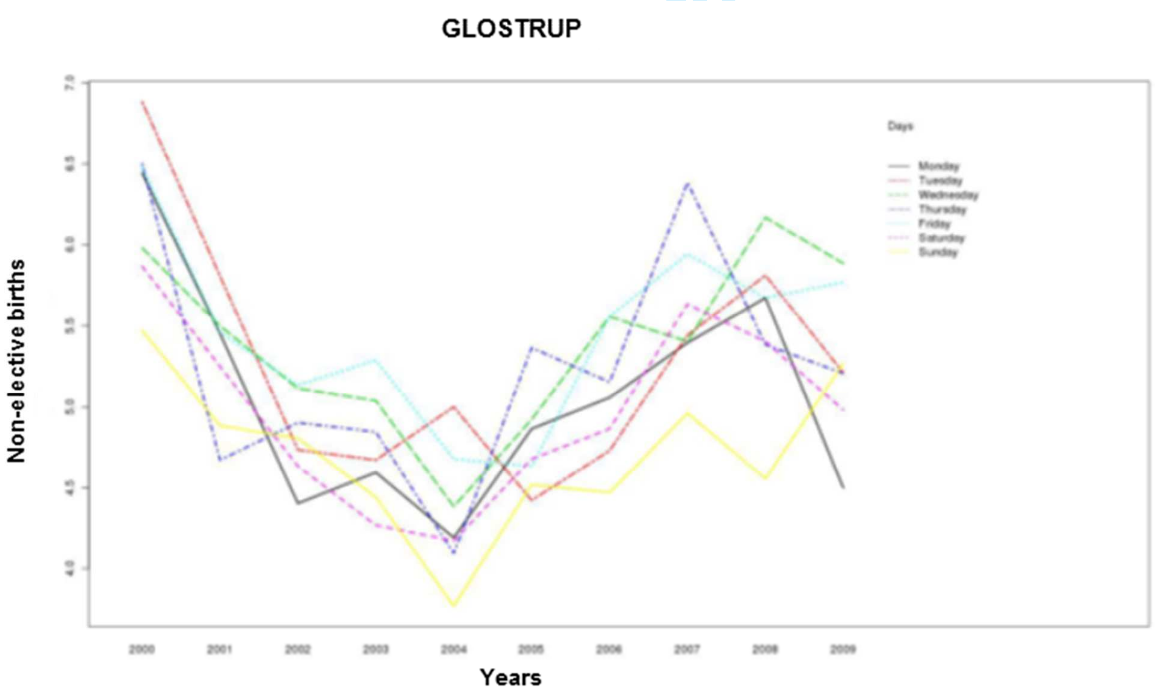
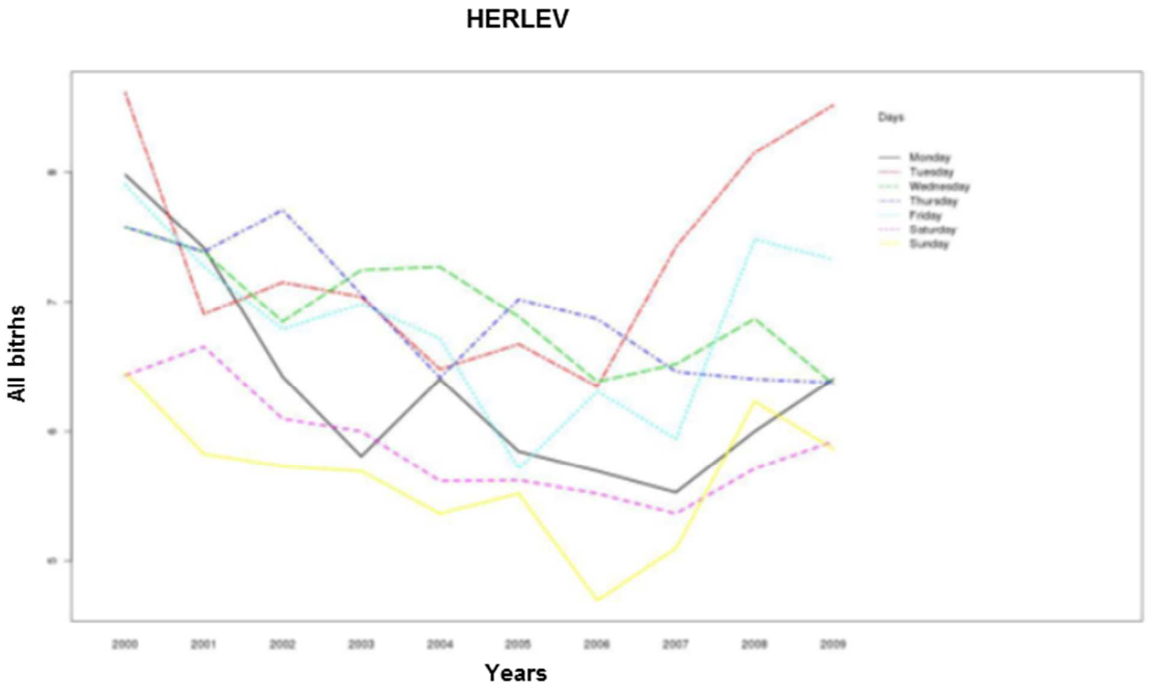


Figure VI Number of births on each day of the week for each year in the obstetric clinic of Herlev a) for all births and b) for ‘non-elective’ births

a)



b)

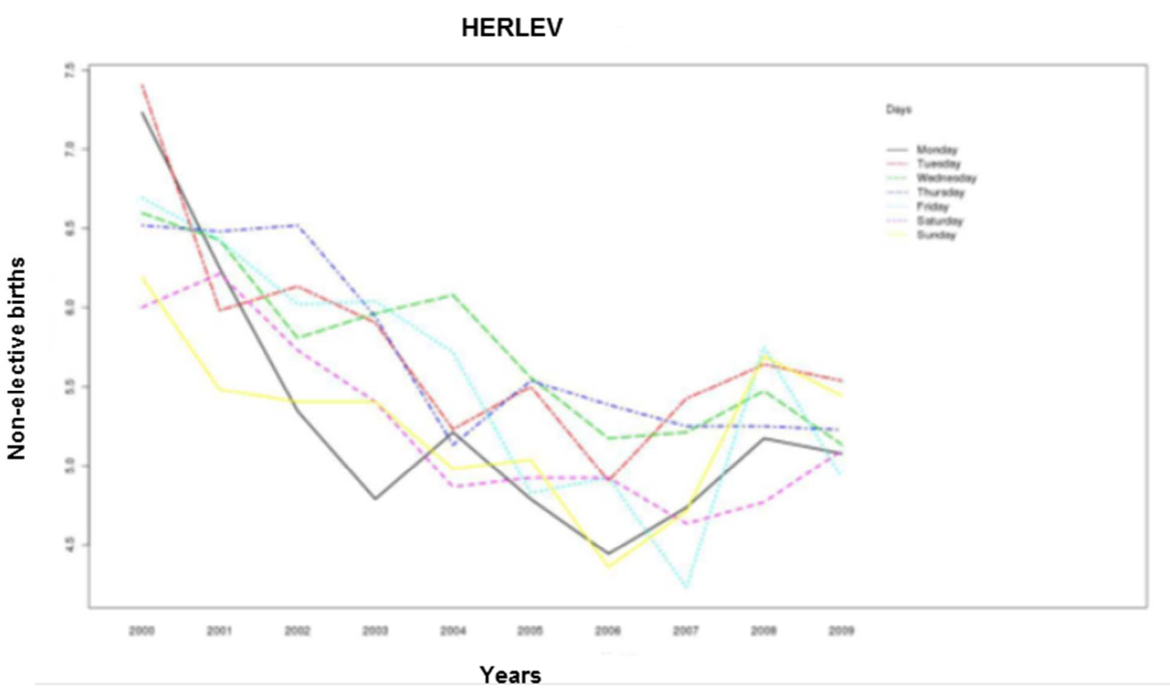
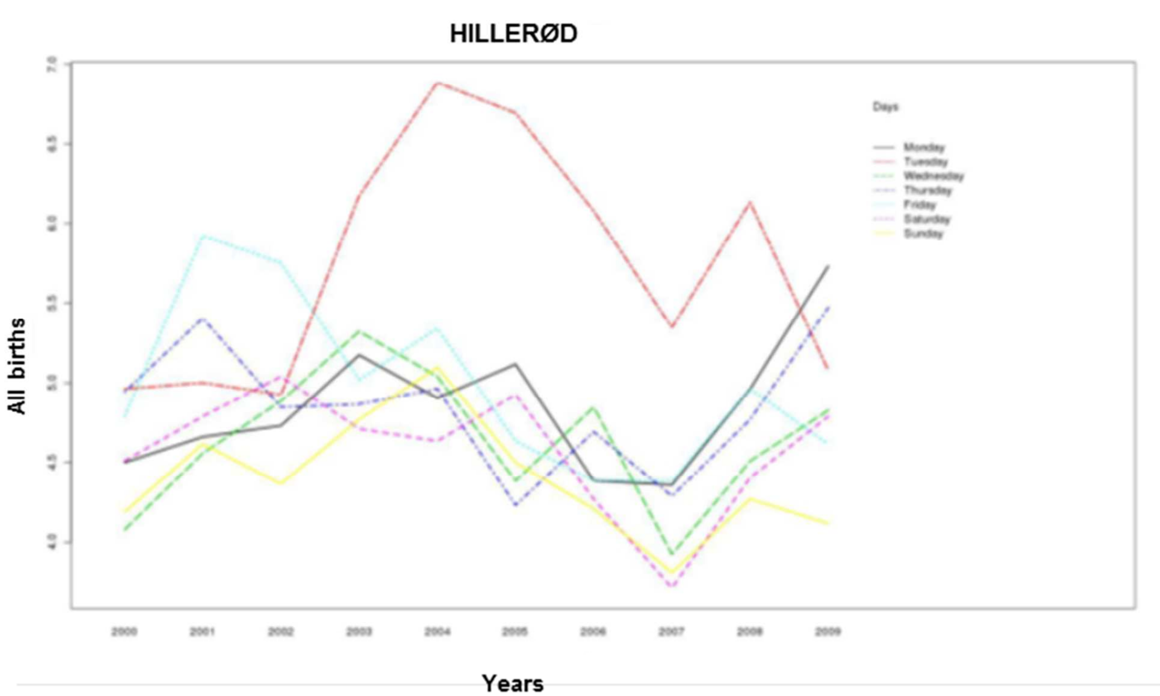


Figure VII Number of births on each day of the week for each year in the obstetric clinic of Hillerød a) for all births and b) for 'non-elective' births

a)



b)

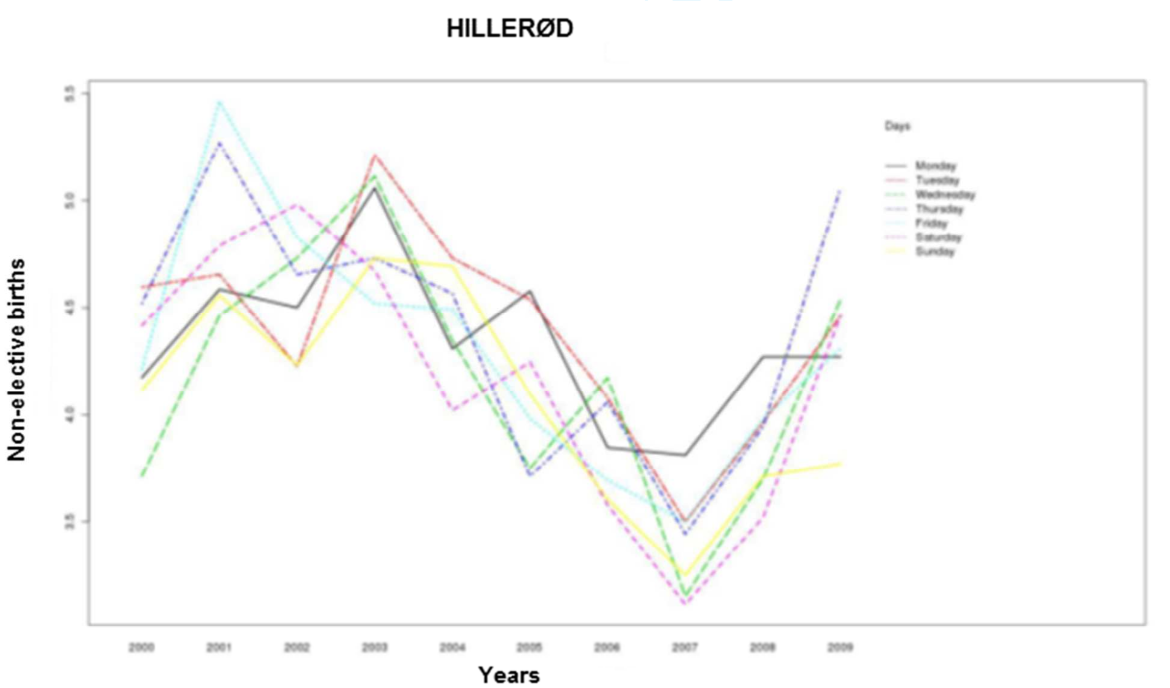
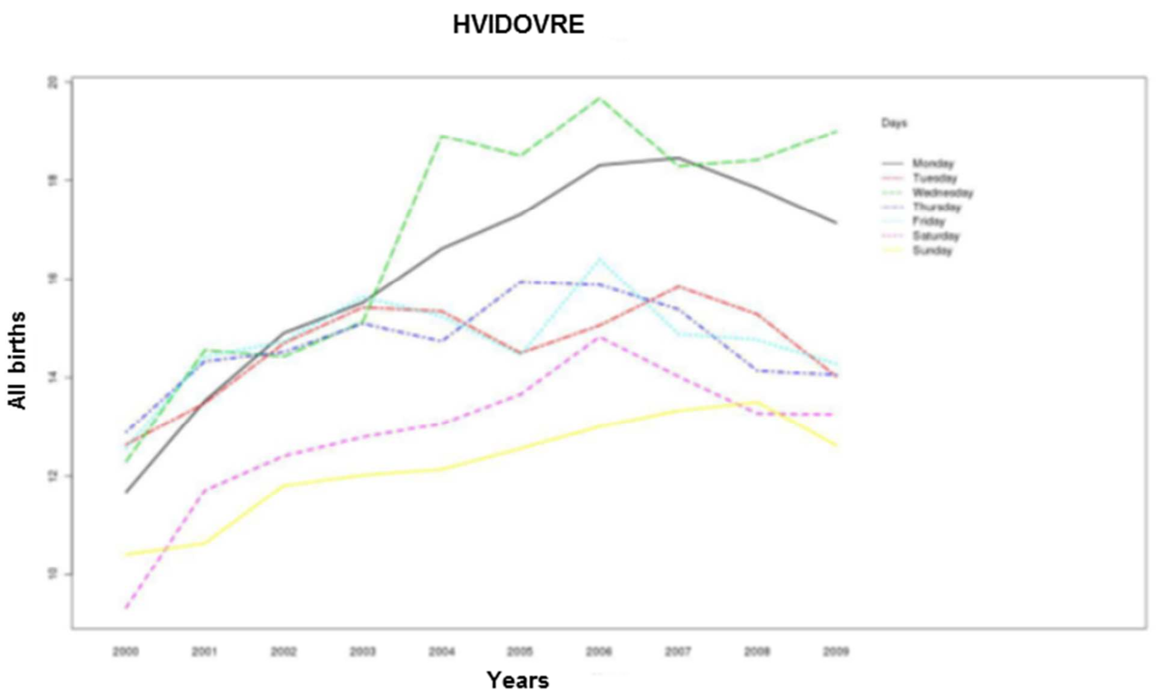


Figure VIII Number of births on each day of the week for each year in the obstetric clinic of Hvidovre a) for all births and b) for 'non-elective' births

a)



b)

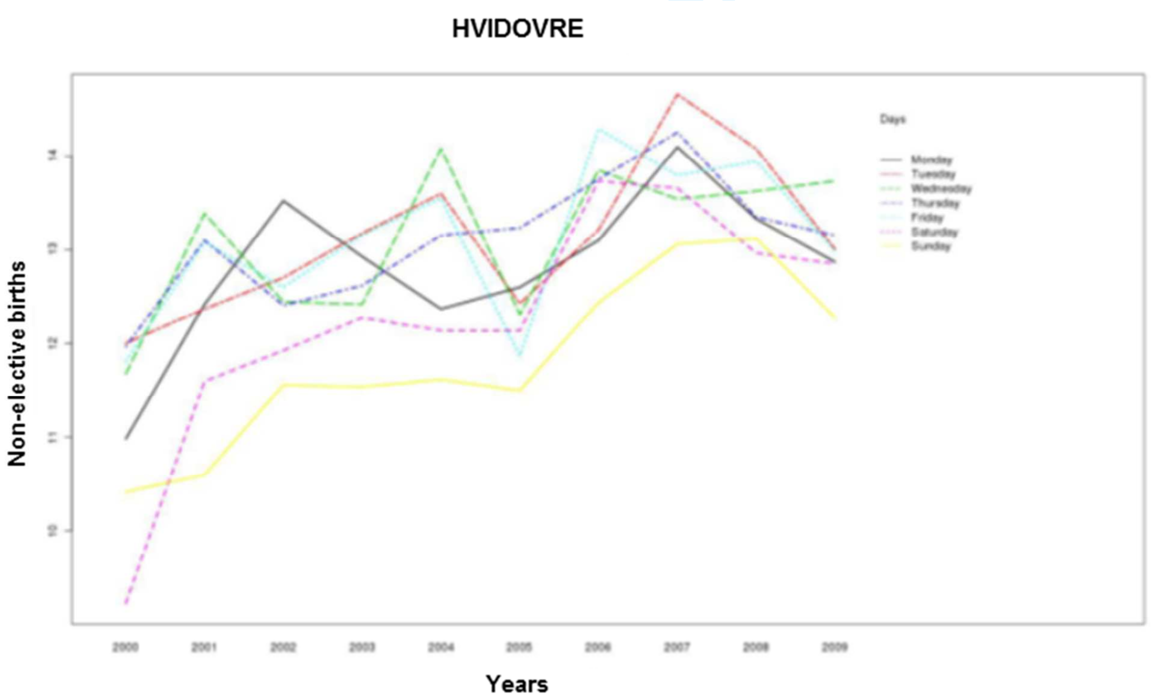
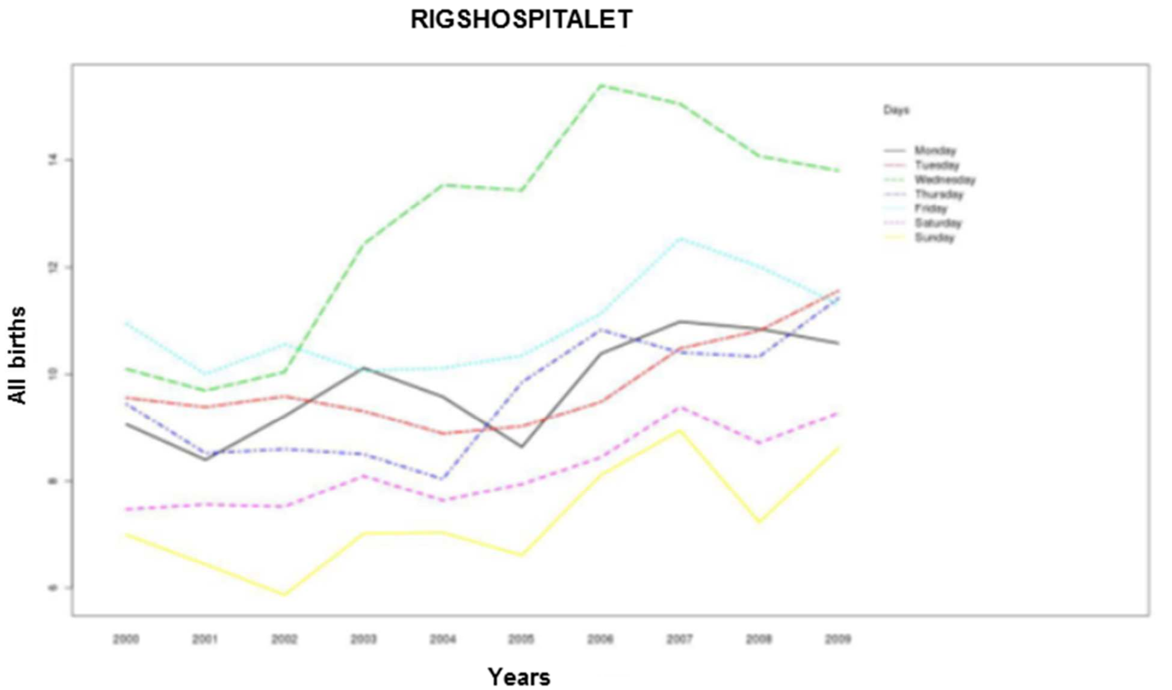
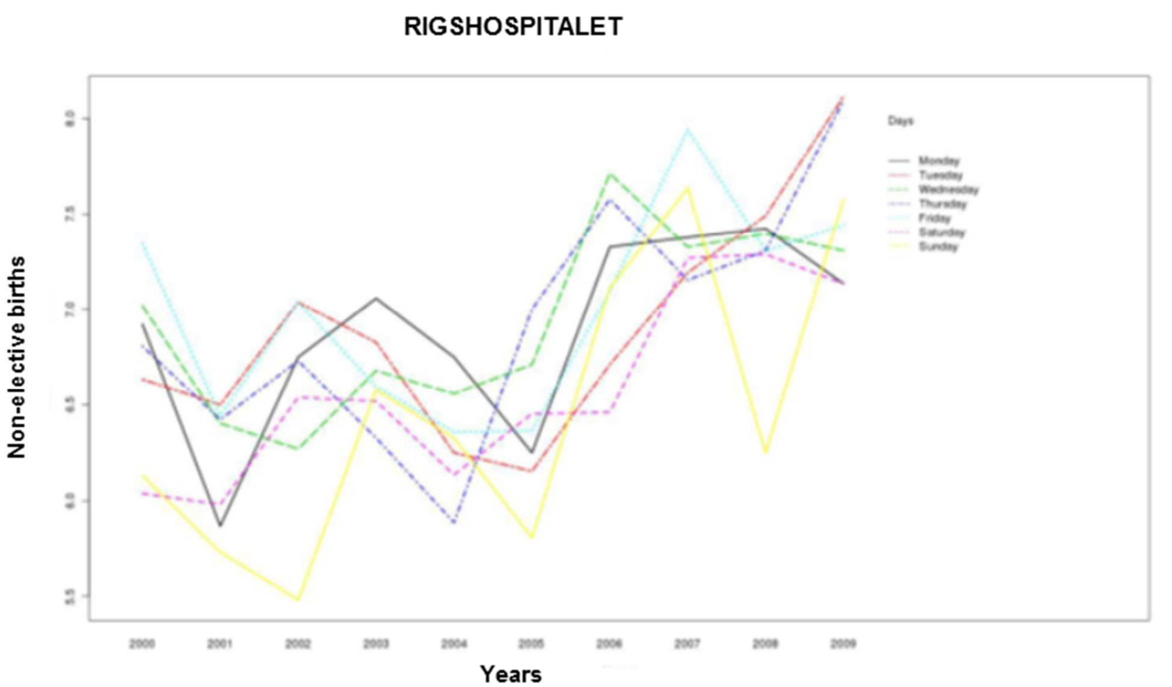


Figure IX Number of births on each day of the week for each year in the obstetric clinic of Rigshospitalet a) for all births and b) for 'non-elective' births

a)



b)



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A MODEL FOR THE DISTRIBUTION OF DAILY NUMBER OF BIRTHS IN OBSTETRIC CLINICS BASED ON A DESCRIPTIVE RETROSPECTIVE STUDY

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Abstract

Objective: To test whether the relatively unpredictable nature of labour onset can be described by the Poisson distribution.

Design: A descriptive retrospective study.

Setting: From the Danish Birth Registry we identified births from all seven obstetric clinics in the Capital region of Denmark (n=211,290) between 2000 and the end of 2009. On each date the number of births at each department was registered. Births are categorised in whether an elective Caesarean section or induction of labour has been performed and among the remaining 'non-elective births' acute Caesareans were registered.

Methods: After exclusion of elective Caesarean sections and births after induction of labour only 'non-elective' births (n=171,009) were included for the main statistical analysis. Simple descriptive plots and one-way analysis of variance were used to analyse the distribution of 'non-elective' births for each day of the week.

Main outcome measures: The daily number of 'non-elective' births.

Results: The number of 'non-elective' births varies considerably over the days of the week and over the year for each obstetric clinic regardless of clinic size. However, for each fixed day of the week the variation over the year is well described by a Poisson distribution, allowing simple prediction of the variability. For births at each fixed day of the week, the Poisson distribution is indistinguishable from a normal distribution.

Conclusion: The number of 'non-elective' births for each day of the week is well-described by a Poisson distribution. Consequently the Poisson model is suitable for estimating the variation in the daily number of 'non-elective' births and could be used for planning of **staffing** in obstetric clinics. The model can be used in smaller as well as larger clinics.

ARTICLE SUMMARY

Article focus: Does the Poisson distribution correspond precisely to actual random variation in the number of 'non-elective' births for each fixed day of the week?

Key Message box:

- For each day of the week, the variation of 'non-elective' births over the year is well described by a Poisson distribution.
- The Poisson distribution makes it easy to estimate the variation in the daily number of births and can be used for planning of **staffing** in obstetric clinics. Standard tables of the normal distribution may be used as exemplified.
- The model is adequate for use in smaller as well as larger clinics and can be used in management of **staffing** in obstetric clinics.

Strengths and limitations of this study: The main strength is the large dataset of non-selected births. The main limitation is that births are registered only by date, not by time of birth.

INTRODUCTION

There is a structural reorganization of hospitals going on in Denmark implying larger but fewer hospitals. This applies also for the departments of Gynaecology and Obstetrics as smaller departments are being merged resulting in fewer larger departments (1-3). The main motivation for these changes has been that larger departments would enhance the capacity and quality of patient treatment and additionally reduce the costs for staff at shifts. In Denmark the overall year to year variation in number of births at each department is centrally determined as each department of **Gynaecology and Obstetrics** on an administrative level is intended to have a given number of births from a specified geographical region **and therefore the staffing required in each obstetric clinic in each department is determined from this figure.** The largest part of **staffing** consists of a daily number of midwifes working eight hours shift during day, evening and night, as well as a varying number of midwifes on 24 hour duty on call from home. Their actual working hours vary considerably. The number of doctors on shift is fixed for each obstetric clinic and depends on the size of the obstetric clinic, as does the number of doctors on call from home.

An interesting organizational feature in obstetrics is the inherent random variation in onset of spontaneous labour which makes it difficult to precisely plan the necessary number of staff at the obstetric clinics. The planning of **staffing** in the departments is to our knowledge not based on published methods. Statistics on the number of births on each day for each department every year is available online from Statistics Denmark (4). These numbers indicate considerable day to day variation and week to week variation. The observation of a weekly cycle is in accordance with reports from other countries such as England, Wales, Australia, the United States, Israel and Norway (5-13) and interestingly it has also been shown that the variation depends on whether the Sabbath occurs on a Friday (14), a Saturday (5) or Sunday (6-13). However these former studies included all births regardless of whether or not there had been an elective obstetric intervention, which raises the question whether the variation between the days of the week disappears, when births resulting from an elective obstetric intervention as elective Caesarean or induction of labour are excluded from the data set. There is a long tradition of describing the variation in the daily demand for hospital beds by the Poisson distribution (15-17) sometimes based on queuing theory and with varying efforts at empirical verification. In her well-known textbook Kirkwood (18) used an apparently hypothetical example of **staffing** planning in the face of merging two obstetrical departments to illustrate the Poisson distribution.

In this study we examine from a broad Danish experience how well the Poisson distribution corresponds to actual random variation in the number of 'non-elective' births for each fixed day of the week. Since the variation in the 'non-elective' births is most obviously random, we exclude in the main analysis 'elective' births (resulting from induction of labour and elective Caesarean sections). However, as a sensitivity analysis we report results on the variation of all births and of acute Caesarean sections.

MATERIAL AND METHODS

Data

The number of births for each date in the period from the 1st of January 2000 until the 31st of December 2009 at all seven obstetric clinics in the capital region of Denmark were extracted from the Danish Birth registry. The obstetric clinics were Rigshospitalet, Frederiksberg, Glostrup, Gentofte, Herlev, Hvidovre and Hillerød, which cover over 99% of all births in the region, as a dwindling number of births takes place at home in Denmark. The data included information on the type of birth: elective Caesarean sections, births after elective induction of labour, acute Caesarean sections and births after spontaneous onset of labour. The labelling of the type of birth has been done by using information from the National Birth registry on operation codes for elective Caesarean sections (KMCA10B and D) and obstetric codes for induction of labour (KMAC00 Amniotomy prior to birth, KMAC96A Mechanical catheter induction, BKHD2 Unspecific medical induction, BKHD20 Induction with prostaglandin, BKHD21 Induction with oxytocin) . The coding of birth information is based on information from midwifes and is generally considered very valid.

Statistical methods

The main concept of these analyses builds on the empirical fact that even for 'non-elective' births there is a non-ignorable variation across the seven days of the week, however for each fixed day of the week the variation across the 52 (53) weeks in a given year may be interpreted as random. We exploit the well-known fact that Poisson distributions are well approximated by normal distributions with the same mean and variance, clearly distinguishable by the Poisson distribution property that the mean equals the variance. In this way the key issue – whether the Poisson distribution is an adequate description – is captured by a one-way analysis of variance comparing the seven days of the week for each of the ten years and each of the seven clinics. The results are illustrated by descriptive graphs and worked examples of possible use in **staffing** planning. Additional sensitivity analyses are performed including all births and acute Caesareans.

Details of ethics approval

An ethical approval for this study was not required. The data used are available online in an anonymous form.

RESULTS

There were 211,290 births distributed on seven departments in the capital region of Denmark from the 1st of January 2000 until the 31st of December 2009. In order to exclude potential elective births, births were subdivided into induced or spontaneous labour and elective and acute Caesareans (Table I). Births where the mode of delivery was an elective Caesarean (n=16,325 (7.73 %)) and births initiated by induction of

labour (n=23,956 (11.34%)) were excluded from the data set for main analyses, thus leaving a total of 171,009 (80.94%) spontaneous births and acute Caesareans, to be denoted 'non-elective' below.

As mentioned in the introduction a main problem in obstetrics management is the variation over days of the week. This variation is to a large degree a result of decisions by the obstetricians on how to distribute elective Caesareans and electively induced labour over the days of the week (6, 12). Preliminary descriptive analyses of the data clearly indicated that such policies varied considerably over the ten years for each department and that the patterns were rather different between departments, however overall a mid-weekly peak in births remained even when 'elective' births were excluded (please see the supplementary file, Figure III-IX). The **staffing** required for these 'elective' births is a consequence of management decisions, and our focus is here on how to capture the primarily random variation in the 'non-elective' births. Because of the strong heterogeneity in the day-to-day pattern for several of the involved departments over the ten years under study, we performed a set of 70 one-way analyses of variance comparing the number of 'non-elective' births at each day of the week for each fixed combination of department (n=7) and year (n=10). The residual variances from these 70 analyses were compared to the annual mean number of births for each department. Additional sensitivity analyses were performed including all births and acute Caesareans. As seen in Figure I, the residual variances are very close to the means, indicating a Poisson distribution of the variation in number of 'non-elective' births for each day of the week around the yearly average for that day. We also see that the closeness of residual variance to the mean improves when we only look at the 'non-elective' births while for the acute Caesareans only there is a clear trend that the variance is larger than the mean, so-called overdispersion which violates the assumption of Poisson distribution. In view of these findings we focus on the non-elective births in the following.

To illustrate our findings three selected combinations of department and year, a small, medium and large clinic, were chosen. For each day of the week a histogram shows the observed distribution of the 52 (53) numbers of births per day for that year with fitted normal distribution (red) and fitted Poisson distribution was produced (green) (Figure II). It is seen that there is a nice fit throughout of the Poisson distributions, and also that they are very close to the normal distributions with the same variance. This means that calculations of the likely variation in number of 'non-elective' births can be based on the normal distribution with variance given by the average number of 'non-elective' births per day over the year.

For example, if at a particular department in a particular year the mean number of 'non-elective' births is 9, the residual variance is estimated to be 9 and the standard deviation as the square root of 9, that is, 3. Assume that the mean number of 'non-elective' births on Tuesdays for that department for that year is 10.5. In 95% of Tuesdays the actual number of 'non-elective births' at that department will be in the interval between 10.5 – 3 x 1.96 = 4.6 and 10.5 + 3 x 1.96 = 17.4, while in 80% of Tuesdays there will be between 10.5 – 3 x 1.28 = 6.7 and 10.5 + 3 x 1.28 = 14.3 non-elective births. This model is suitable for estimating daily number of births and planning of **staffing** in obstetric clinics and the model is adequate to be used in smaller as well as larger clinics.

Discussion

Management of **staffing** in obstetric clinics is a difficult task, due to the relatively unpredictable nature of labour onset. Nowadays many births are 'elective' births in the sense that elective Caesarean sections or medically induced labour more or less governs the time of the week where the birth happens. It has been assumed that the day to day variation on numbers of births fits a Poisson distribution (13, 18), but suitable data on live births, including mode of delivery, from a larger population has not previously been studied, thus limiting the means of studying day to day variation (7, 13). Furthermore the impact of elective obstetric intervention on the distribution has not been considered in any of the previous studies addressing birth variation (5-14, 19).

Interestingly we find that even with the exclusion of births resulting from an obstetric intervention as elective caesarean or induction of labour, the remaining data still show significant weekly variation with a mid-weekly peak. As such this variation might not only be ascribed to measurable obstetric interventions, but also less tangible practices, for instance the time of admittance of a woman in early stages of labour might depend on staff numbers which vary during the week. Also traditional non-medical methods of starting labour (hot baths, sexual intercourse, etc.) might be less likely to be tried by mothers in the weekends (7).

However regardless of any obstetric practices or mothers practice, we found that the distribution of the remaining 'non-elective' births for each day of the week, each year, and each department is still well approximated by a Poisson distribution, where the mean equals the variance. For the relevant parameter values, this Poisson distribution is indistinguishable from a normal distribution, where we then may estimate the variance from the mean. This means that calculations of the likely variation in number of non-elective births can be based on the normal distribution with variance given by the average number of non-elective births per day over the year.

This provides us with a useful tool for planning of the **staffing** necessary to handle all births on a given weekday in an obstetric clinic. Elective Caesarean sections are usually planned to be performed on specific weekdays with staff dedicated to this task. Births after induction of labour will also in most regards be planned. Combining the known number of elective births with the calculation of a 95% or 80% confidence interval of 'non-elective' births on a given week day gives a good possibility to avoid **over- or understaffing** and utilize the available human resources to their best. For larger clinics where the mean number of non-elective births for a given weekday may vary by more than 1-2 births, the relocation of staffing to 'peak' weekdays has the most to offer, but even smaller clinics can benefit from more concrete calculation, for example on how weekend **staffing** should be.

The fact that the distribution of 'non-elective' births is indistinguishable from normal distribution provides a simple, but elegant, tool for planning of staffing in obstetric clinics and used wisely may prove a positive adjustment for work efficiency, cost and environment.

Conclusions

We may estimate the variance from the mean, as the Poisson distribution for these parameters is indistinguishable from a normal distribution. This model is suitable for estimating the variation in the daily number of 'non-elective' births and could be used for planning of **staffing** in obstetric clinics.

Competing interest

All authors have completed the Unified Competing Interest form at http://www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare: no support from any organization for the submitted work, no financial relationships with any organization that might have an interest in the submitted work in the previous three, no other relationships or activities that could appear to have influenced the submitted work.

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Contribution to authorship

CMG, NK, JT and EL have all been involved in the conception of this study. The statistical analysis has been carried out mainly by JT under the guidance of NK, EL and CMG. The writing of this article has been done by CMG, NK, JT and EL. Coordination of the correspondence between authors has been taken care of by CMG.

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