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Using the Poisson Regression Model to Estimate the Frequency Rate of In-Vitro Fertilization (IVF) Procedures

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Abstract : Children are the fundamental cornerstone of the future of nations, hence Poisson regression models were utilized to calculate the frequency rate of successful in vitro fertilization (IVF) treatments. In a significant number of cases, pregnancy does not develop spontaneously, and as a result, doctors turn to in vitro fertilization (IVF) operations. This is the reason why a number of characteristics that have an impact on the success of in vitro fertilization (IVF) treatments were evaluated. This analysis was based on a sample of patients who had successful procedures at Kamal Al-Samara'i Hospital, which included cases from every province in Iraq. Weight increase creates hormonal imbalances, which diminish the chance of success in in vitro fertilization (IVF) treatments, according to the findings of the research. As a result, the mother's weight is one of the most significant elements in determining the success of IVF procedures.

Keywords: *Poisson regression, IVF procedures, maximum likelihood method, In-Vitro Fertilization*

استخدام نموذج انحدار بواسون لتقدير معدل تكرار عمليات الإخصاب خارج الرحم(IVF)

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المستخلص : يُعد الأطفال الركيزة الأساسية لمستقبل الأمم، لذلك تم استخدام نماذج انحدار بواسون لحساب معدل تكرار نجاح عمليات الإخصاب خارج الرحم .(IVF) ففي عدد كبير من الحالات لا يحدث الحمل بصورة طبيعية، مما يدفع الأطباء إلى اللجوء إلى عمليات الإخصاب خارج الرحم. ولهذا السبب تم تقييم مجموعة من العوامل التي تؤثر في نجاح عمليات الإخصاب خارج الرحم .(IVF) استند هذا التحليل إلى عينة من المرضى الذين خضعوا لعمليات ناجحة في مستشفى كمال السامرائي، وشملت الحالات جميع محافظات العراق. وقد أظهرت نتائج الدراسة أن زيادة الوزن تؤدي إلى حدوث اختلالات هرمونية تقلل من فرص نجاح عمليات الإخصاب خارج الرحم (IVF)وبناءً على ذلك، يُعد وزن الأم من أهم العوامل المؤثرة في تحديد نجاح إجراءات الإخصاب خارج الرحم.

الكلمات المفتاحية *: انحدار بواسون، عمليات الإخصاب خارج الرحم(IVF) ، طريقة الإمكان الأعظم، الإخصاب خارج الرح*

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1. Introduction

Poisson regression is a sort of regression analysis that is used in count data models and probability tables. It makes the assumption that the distribution of the response variable (y) follows the Poisson distribution and that the logarithm of its predicted value may be written as a linear combination of variables that are unknown (McGough et al, 2023). The phrase "log-linear model" is often used as a substitute for "Poisson regression," especially when it is used in the context of probability tables (Shi et al, 2022). The subject of attention is regression models in which the response variable is represented by discrete variables rather than continuous ones. This topic is of significant relevance in a wide variety of scientific fields, and it has a wide range of applications in a number of industries and time-related phenomena (Zhou et al, 2021). It is most commonly used to solve problems that involve queuing theory. Examples of these problems include the number of automobiles that are present at a checkpoint on a particular road, the number of automobiles that are present in a service station, the number of telephone calls that are received by a telephone exchange, the number of customers that are present in a sales outlet, and the number of patients that are present in a health center (Solmonovich et al, 2025). The most important elements that determine the effectiveness of in vitro fertilization (IVF) operations were explored by us in the framework of this study. For the aim of this inquiry, we made use of both the stepwise regression and maximum likelihood estimation approaches. Based on the data, the weight of the mother is one of the most significant factors that lead to success in life (George et al, 2024). The purpose of this research project is to explore the factors that have an influence on the success of in vitro fertilization (IVF) operations and to undertake a statistical analysis of these factors via the use of the Poisson regression model. Success in achieving pregnancy by in vitro fertilization will be predicted by the model, which will be used to calculate the number of tries that will be necessary. This research project will focus on the city of Baghdad, which is the capital of Iraq, between the years 2012 and 2020 (Melin et al, 2021;Kong et al, 2022) . We will make use of the Poisson regression model in this investigation to determine the number of efforts at in vitro fertilization (IVF) that are necessary to have a successful pregnancy (Ma et al, 2024). This will be done to compute the frequency rate of IVF attempts (Yirsaw et al, 2024) . Because children are truly the cornerstone of the future of nations and because pregnancy does not occur spontaneously in many conditions, in vitro fertilization (IVF) has emerged as the most often utilized assisted reproductive procedure (Fauque et al, 2021). This approach is usually put into action when other methods of assisted reproduction have failed to provide the desired results. According to the facts that are available as of 2016, in vitro fertilization (IVF) has resulted in the birth of 6.5 million offspring in the United States of America.

2.0 Research methodology

2.1 Poisson Regression Model

The Poisson regression model is a method used to model the response variable when the values of the explanatory variables are countable. It is one of the most important log-linear regression models and one of the tools used in analyzing non-negative data for rare events. This type of regression model assumes that the response variable, as well as the random errors in the model, follow a Poisson distribution with a parameter (λ). The Poisson regression model assumes that the response variable (Y_i) follows a Poisson distribution with a mean and variance of (λ), and that the logarithm of the expected value of the response variable is modeled as a linear combination with the explanatory variables. Therefore, the Poisson regression model is called a log-linear model (Ellington et al, 2025) . The Poisson regression model can be expressed by the probability function shown in the following formula:

$$Y = e(X^T \alpha + \epsilon)$$

Where:

Y: represents the vector of response variables of degree (mx1)
X: represents the matrix of explanatory variables of degree mx (q+1)
α: represents the vector of model parameters of degree (q+1) x 1)
∈: represents the vector of random errors of degree (m x 1)
m: represents the sample size
q: represents the number of explanatory (independent) variables

Assuming that a sample of size m represents the response variable, which follows a Poisson distribution with a distribution parameter (λ), which in turn represents the mean and variance of the values of the response variable, which depend on the vector of explanatory variables X, the mean of the linear regression model used to describe this relationship can be formulated as follows (Matsumoto et al, 2024):

$$E(Y_j) = \lambda_j = \exp(X_j^T \alpha)$$

The formula The linearity mentioned above indicates that the explanatory variables can take any true value of the mean of the response variable (Y). This contradicts the characteristic of the Poisson distribution parameter (λ), which takes non-negative values. To address such a situation, a linear relationship is modeled between the logarithm of the mean parameter (Log λ) and the explanatory variables (X) (Nunes et al, 2024; Zhang et al, 2025). Using the logarithm function as a linking function, the linear-logarithmic model is adopted according to the following formula:

$$\mathrm{Log}\left(E(Y_j)\right) = \mathrm{Log}(\lambda_j) = X_j^T \alpha$$

Where:

α represents the vector of parameters of degree (q+1) x 1) that are being estimated.
X_j is the vector of explanatory variables of degree ((q+1) x 1) plus a constant term.

Formula (5) represents the general formula for the Poisson regression model. The basic idea of this model is to link the probability function of the response variable (Y) to one or more explanatory variables (Xj). The regression vector α mentioned in Model (5) represents the expected amount of change in the logarithm of the mean of the response variable for each unit change in the explanatory variables (Reeder et al, 2025). We then obtain the multiplicative model of the mean of the response variable by taking the exponential function of both sides of the model mentioned . The advantage of using the logarithmic function lies in the fact that the experimental observations are in the form of countable data, so the effect of the explanatory variables is, in most cases, multiplicative rather than cumulative. That is, it can be observed that small countable data are slightly affected, while large countable data are more affected. If the effect is proportional to the countable data, then working with the logarithmic function leads to a simpler model (Fang et al, 2025). Thus, the Poisson regression model assumes three assumptions, as follows:

Assumption 1: The response variable (Y) follows a Poisson distribution with a distribution parameter (λ), and (λ>0)

Assumption 2: The distribution parameter represents both the mean and variance of the values of the response variable (Y). This can be expressed based on the vector of explanatory variables,

Assumption 3: The pairs of observations (yj, xj) must be independent, meaning that each has an independent distribution. The conditional probability function formula for the response variable (Y), given in Formula , can be reformulated based on both the first and second assumptions as follows:

$$f(y_j|x_j) = \frac{e^{-e^{X_j^T\alpha}} e^{yX_j^T\alpha}}{y_j!} \quad , \qquad y = 0,1,2$$

Therefore, in light of the three aforementioned assumptions specific to the model Poisson regression: This model yields an exponential mean function (or log-linear mean function) and an exponential conditional variance function (linear-logarithmic), which can be represented by the following two formulas:

$$Var(Y|X) = \lambda = exp(X^T\alpha)$$

2.2 Poisson Regression Model Parameters Estimation

Several methods can be used to estimate the parameters of the Poisson regression model, including parametric and nonparametric methods. The most common parametric method for estimating countable data models is the maximum likelihood method. As for nonparametric estimation methods, the most commonly used are the kernel method and the penalized spline method. Since the current research relies on parametric methods in Estimating Model Parameters: The maximum likelihood method will be used in the estimation process (Mainguy et al, 2025).

2.3 Maximum Likelihood Method

To begin estimating the parameters of the Poisson regression model using the maximum likelihood method, we will assume a sample size of m of independent observations (yj, xj). Therefore, the maximum likelihood function is the product of all conditional probability mass functions for each observation of the response variable Y . The Poisson distribution, shown above in formula , can be formulated as follows:

$$L(\alpha; y_1, y_2, \dots, y_m, x_1, x_2, \dots, x_m) = \prod_{j=1}^{m} d\, f(y_j | x_j, \alpha)$$

Since the parameter estimator for the mentioned model is the one that maximizes the possibility function, i.e.:

$$\hat{\alpha} = argL(\alpha; y_1, y_2, \dots, y_m, x_1, x_2, \dots, x_m)$$

To simplify the calculations, we will work with the logarithm of the possibility function instead of the function itself, since the logarithmic transformation is a monotonic transformation, and Maximizing the logarithm of the possibility function is equivalent to maximizing that function. Therefore, the logarithm of the possibility function for a Poisson regression model is shown in the following formula:

$$l(\underline{\alpha}, \underline{Y}, \underline{X}) = Log \prod_{j=1}^{m} r\, f(y_j | x_j, \alpha) = \sum_{j=1}^{m} r\, Log f(y_j | x_j, \alpha)$$

By extracting the first derivative of the logarithm of the maximum likelihood function of the model parameter vector (α), we obtain (q+1) from the derivatives. The vector containing these derivatives is called the score vector. The following formula illustrates this. That is:

$$S_m(\underline{\alpha}, \underline{Y}, \underline{X}) = \frac{\partial l(\underline{\alpha}, \underline{Y}, \underline{X})}{\partial \underline{\alpha}} = \sum_{j=1}^{m} r\, [y_j - exp(\underline{X}_j^T \underline{\alpha})] x_j$$

By setting these derivatives equal to zero, the maximum likelihood estimators of the vector of coefficients of the Poisson regression model (α̂) represent the values of the coefficients (α) that achieve the following:

$$S\_m(\alpha\hat{}\_j; y, x) = 0$$

The previous formula represents the conditions for the process of maximizing the necessary likelihood function, in addition to calculating the second derivative matrix, which is called the

Hessian matrix, which represents the second-order partial derivative of a multivariable numerical function, which in turn must be a negative definite matrix for all values of the parameters The β model represents the maximum likelihood estimate. The Hessian matrix for the Poisson regression model is formulated as follows:

$$H_m(\underline{\alpha}, \underline{Y}, \underline{X}) = \frac{\partial^2 l(\underline{\alpha}, \underline{Y}, \underline{X})}{\partial \underline{\alpha} \partial \underline{\alpha}^T}$$

$$= -\sum_{j=1}^{m} y\, exp(\underline{X}_j^T \underline{\alpha}) X_j^T X_j$$

From the above formula, we find that the matrix Hm is a definite, negative matrix. Therefore, the shape of the logarithm of the Poisson regression model is generally concave. Therefore, the coefficients $\hat{\alpha}$ that solve the set of equations mentioned in formula below are the unique maximum likelihood estimators. Formula below is nonlinear and can be solved using one of the iterative methods, one of which is the Newton-Raphson method, which is a suitable choice for concave functions. This method is summarized as follows: giving initial estimated values for the parameters of the regression model α ̂_0, through which a second-order approximation of the logarithm of the maximum likelihood function L(α) can be obtained around the initial values α ̂_o, as follows:

$$L^*(\alpha) = l(\hat{\alpha}_o) + S_m(\hat{\alpha}_o)^T(\alpha - \hat{\alpha}_o) + \frac{1}{2}(\alpha - \hat{\alpha}_o)^T H_m(\hat{\alpha}_o)(\alpha - \hat{\alpha}_0)$$

By maximizing the value of L^* (α), instead of L(α), then for (α) We obtain a new estimate for the parameters, let it be α ̂^T, noting that the necessary condition for the first-order maximization process is shown in the following formula:

$$\hat{\alpha}^T = \hat{\alpha}_o - [H_m(\hat{\alpha}_o)]^{-1} S_m(\hat{\alpha}_o)$$

2.3 Study sample

The study was conducted on a sample of married couples who underwent IVF at Kamal Al-Samarrai Hospital in Baghdad, numbering 60 cases, as shown in Table (1). The goal was to model the number of cases of repeating the IVF procedure until pregnancy was achieved, with the response variable (y) being considered, while the explanatory variables were the wife's age (x1), the husband's age (x2), the wife's weight (x3), the wife's smoking status (x4), and chronic diseases (x5). The following is an explanation of the variables included in the model:

Wife's age: This is one of the most important factors controlling the success of IVF. Many doctors warn against performing the procedure on women of advanced age. Doctors have also confirmed that there is a high risk of fetal abnormalities due to the mother's advanced age, and that the success rate of IVF is more assured the younger the woman. A woman's peak fertility period ranges from 21-28 years, then begins to gradually decline after the age of 35 until she reaches the age of 45. This period is called menopause.

Husband's age: Researchers have confirmed that the husband's age affects fertility, pregnancy, and the health of the child. They found that men aged 45 and older suffered from decreased fertility and were at risk due to pregnancy complications. They also found that children born to older fathers were more at risk of premature birth, low birth weight, and birth defects such as heart disease. Smoking: Smoking is a factor influencing delayed pregnancy due to the toxic substances it contains that play an indirect role in fertility. Statistical studies have proven that women who smoke reach menopause earlier than non-smokers, and that the chances of IVF success for smokers are half those of non-smokers. Studies have also shown that toxic substances affect the egg's ability to be fertilized, reducing it. On the other hand, they lead to an increase in the FSH hormone, which, if elevated before the IVF stimulation program begins, leads to the failure of the procedure. Smoking here pertains to the wife, as 0 represents a non-smoker and 1 represents a smoker. Chronic diseases: Chronic diseases and health problems can cause male infertility. Infertility can be caused by poor sperm production, sperm morphology, blockages preventing sperm from reaching the cervix, or certain genetic conditions or disorders. The diseases are ranked as follows: 0 - Normal 1 - Sperm abnormalities 2 - Low sperm count 3 - Varicocele 4 - Low egg production in the woman 5 - Husband abuses alcohol 6 - Diabetes 7 - Hormonal problems in the woman 8 - Uterine problems Wife's weight: Being overweight affects the IVF process, as it can lead to ovulation disorders. The risk of IVF or IVF failure increases with weight gain, as excess weight can lead to difficulty in retrieval of the egg due to the fat accumulating around it during the egg retrieval process.

2.4 Poisson Distribution

The Poisson distribution is one of the discrete distributions that expresses the probability of a certain number of events occurring within a fixed period of time, assuming that the events occur at a known and constant average rate, independently of the time since the last event. If we assume that a specific event occurs within a certain time period, then this event is considered a random Variables.

3.0 Results and discussion

3.1. Applying the Poisson Regression Model

Minitab was used to analyze and apply the Poisson regression model. Minitab provides three correlation functions that allow fitting Poisson models. Natural log was chosen as the correlation function to estimate the model parameters. The parameter estimation process required four iterations. The table below shows the deviation values for the variables and parameters as shown in table 1.

Table 1. shows the goodness-of-fit test.

Test	DF	Estimate	Mean	Chi-Square	P-Value
Deviance	52	23.41370	0.45026	23.41	1.000
Pearson	52	20.70650	0.39820	20.71	1.000

Use goodness-of-fit tests to determine whether the predicted values of the cases deviate from the observed values in a way that would not be expected by a Poisson distribution. Note that the significance level is 0.05, so we accept the null hypothesis that the Poisson model provides a good fit to the data under study as shown in table 2.

Table 2. Shows the deviations of the explanatory variables and the chi-square values.

Source	DF	Seq Dev	Contribution	Adj Dev	Adj Mean	Chi-Square	P-Value
Regression	8	54.9077	%70.11	54.9077	6.86346	54.91	0.000
Wife’s age	1	43.5828	%55.65	2.0361	2.03613	2.04	0.154
Husband’s age	1	1.5972	%2.04	0.4624	0.46242	0.46	0.496
Wife’s weight	1	2.4616	%3.14	3.3474	3.34740	3.35	0.043
Smoking	1	0.0044	%0.01	0.0099	0.00995	0.01	0.921
Diseases	4	7.2617	%9.27	7.2617	1.81543	7.26	0.123
Error	52	23.4137	%29.89	23.4137	0.45026		
Total	60	78.3214	%100.00				

Table (3) shows the degree of freedom, which indicates the amount of information contained in the data. It also shows the deviation values and the extent of contribution for each explanatory variable. We note the overall significance of the regression model, as the significance value (0.00) appeared less than the significance level (0.05). The significance also included the explanatory variable, mother's weight, as its significance value was (0.04), which is also less than the significance level as shown in table 3.

Table 3. The values of the coefficient of determination.

R-Sq	(R-Sq(adj	AIC
%70.11	%61.17	186.95

The Akaike AIC value is approximately 186, a measure of the relative quality of the model compared to other models. The table above shows that the corrected coefficient of determination value is appropriate and explains more than 60% of the deviation in the response variable. The model fits the data under study.

Table 5. Shows the estimated parameter values.

Term		SE Coef	CI %95	Z-Value	P-Value
Wife’s age	0.0431-	0.0300	(0.0156 ;0.1018-)	1.44-	0.150
Husband’s age	0.0143	0.0209	(0.0553 ;0.0267-)	0.69	0.493
Wife’s weight	0.0266	0.0141	(0.0541 ;0.0010-)	1.89	0.049

Smoking					
1	0.020-	0.205	(0.382 ;423.0-)	0.10-	0.921
Diseases					
1	0.437-	0.267	(0.088 ;0.961-)	1.63-	0.103
2	0.190	0.353	(0.882 ;0.501-)	0.54	0.590
3	0.168	0.295	(0.746 ;0.410-)	0.57	0.569
4	0.030	0.302	(0.621 ;0.561-)	0.10	0.921

4.0 Conclusions

The Poisson regression model, estimated using the maximum likelihood method and used to model the number of successful IVF cases, was generally significant. Significance also included the explanatory variable (maternal weight), with a probability value of 0.04 and a significance level of 0.05, indicating a significant effect of the aforementioned variable on the frequency of IVF procedures. The use of goodness-of-fit tests is necessary to determine whether the predicted values of the studied cases deviate from the observed values in a way not expected by the Poisson distribution. We note that the p-value for the goodness-of-fit test is greater than the significance level of 0.05, and therefore the null hypothesis that the Poisson model provides a good fit to the data under study is accepted. The quality of the estimated model is relatively high, based on the value of the coefficient of determination (R2), which explains the percentage of deviation in the response variable by 61.17%. The relationship between maternal age and the response variable was negative, meaning that the effect of this variable was inverse. As for both the husband's age and mother's weight, their effects were positively correlated with the response variable. The smoking variable had an inversely negative effect. We note that the chronic disease variable had an inverse effect at one time and a direct effect at another time, meaning that its effect fluctuated at all levels. Conduct future research that takes into account the influence of other factors on the number of IVF repetitions, in addition to the variables of husband and wife's age and maternal weight. The Poisson regression model should be used in fields other than health care if the data is countable, due to the model's efficiency, regardless of whether the model estimation process is parametric or nonparametric. Conduct future research that addresses other estimation methods, such as the generalized maximum likelihood method, for parametric estimation methods, or the penalty spline method, for nonparametric estimation methods, to estimate the Poisson regression model and conduct a comparison between these methods.

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