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A Software for Causal Modelling

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CAnoVa©: A Software for Causal Modeling

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and Rolf Steyer

CAnoVa©: Causal Analysis of Variance

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Chapter 1

Introduction

1.1 Software for Causal Modeling?

The new impulse given in the last decade to the theory of individual and average causal effects is mostly due to the approach developed by Steyer and others (see e.g. [Steyer et al., 1996], [Steyer et al., 2000b], [Steyer et al., 2000a]) and resulted in valuable theoretical results such as, for example, the link between unconfoundedness and causal unbiasedness. This approach has also allowed for the development of different practical procedures for both testing for confounding and for testing for (average) causal effects (see e.g. Chapters 4 and 5 of [Wuethrich-Martone, 2001]).

When it became clear that testing for confounding and for average causal effects was possible, at least under certain assumptions, the question then arose which software to use for these purposes? Wuethrich-Martone et. al. (see e.g. [Wuethrich-Martone et al., 2000a], [Nachtigall et al., 2000] and [Wuethrich-Martone et al., 2000b]) have particularly focussed on the problem of individuating a software for the two procedures developed for the framework of general linear models with fixed regressors (cf. Sections 4.3 and 4.4 of [Wuethrich-Martone, 2001]). Both these procedures are based on testing a particular general linear hypothesis, i.e. a hypothesis that is linear in the model parameters[1]. By means of an example (see for example Section 5.4 of [Wuethrich-Martone, 2001]) it was proved that the methods implemented in the standard routines for the analysis of variance do not test for causal effects, making them useless for the purposes of causal modeling.

The only means of applying the procedures mentioned above to a specific

[1] A thorough introduction on how to test a general linear hypothesis in the General Linear Model may be found in [Searle, 1987] Section 8.8, or in [Neter et al., 1990] Sections 3.9 and 8.6

design was to use a software that allowed testing of a general linear hypothesis formulated by the user himself.

Only few software offered such a possibility, namely SAS and SYSTAT. Still they required the specification of the coefficient matrix, that is the specification of the matrix of the coefficients of the model parameters appearing in the formulation of a general linear hypothesis. The process of building the coefficient matrix may be quite complicated and definitely time-consuming, especially for designs with a large number of observations or a large number of factor levels. The causal analysis with SAS or SYSTAT of a design with multiple treatment variables and multiple confounder would be even more complicated because of the procedure needed for building the corresponding reduced 2-factor design (see Section 6.2 of [Wuethrich-Martone, 2001]).

Because of all these difficulties, Wuethrich-Martone and others decided to develop a software for testing for confounding and for causal effects and opted for writing a SCRIPT for SPSS. SPSS is a statistical software very broadly used by social scientists and offers the possibility of integrating self-programmed routines in the program itself in form of a SCRIPT. Particularly advantageous is that the SCRIPT uses almost the same interface as SPSS, so that no additional knowledge is required from the user.

1.2 CAnoVa© : a Software for Causal Modeling

CAnoVa© = **C**ausal **An**alysis **o**f **Va**riance is a SCRIPT for SPSS developed by Wuethrich-Martone, Müller and Steyer for performing the causal analysis of a design with fixed regressors, using the procedures outlined in Sections 4.3 and 4.4 of [Wuethrich-Martone, 2001].

To date CAnoVa is available in beta version Release 0.95. The only requirements needed for using CAnoVa are a licensed version of SPSS and a copy of the SCRIPT CAnoVa itself (available from the authors).

CAnoVa may be started directly from the SPSS data file containing the data to analyze. The major advantages of CAnoVa are its user-friendly interface and the possibility of getting as output a standard SPSS output window. It is therefore possible to produce in the same output the results of standard statistical procedures (e.g. analysis of variance) and the results of a causal analysis as well.

CAnoVa automatically performs the test for confounding and the test for causal effects. The distribution of the potential confounder W considered may be given a priori (by appropriately specifying in the data file the

marginal probabilities $P(W = w_j)$) or may be estimated by CAnoVa from the cell frequencies.

In case of a design with multiple treatment variables and multiple confounders, CAnoVa first builds the corresponding reduced 2-factor design (by applying the procedure described in Section 6.2 of [Wuethrich-Martone, 2001]), and it then performs a causal analysis on the reduced design. The reduced design may be automatically saved in a new SPSS data file.

In order to show how CAnoVa works, in the next chapter a particular design (described thoroughly in Section 4.5 of [Wuethrich-Martone, 2001]) is analyzed.

Chapter 2

CAnoVa©

2.1 Input

In order to show how CAnoVa works the design described in Section 4.5 of [Wuethrich-Martone, 2001] is analyzed. In this design 500 patients with the same mental disorder are considered. The purpose is to investigate the effects of three different psychotherapies A, B and C on a continuous response variable Y, greater values of which reflect an improvement in the patient's condition. The severity of the disorder is the only potential confounder W considered[1]. Three grades of severity: *high*, *medium* and *low* are distinguished. For each one of the 500 patients, the corresponding severity of the disorder was measured and recorded before treatment. The distribution of W was known and the marginal probabilities $P(W = w_j)$ are

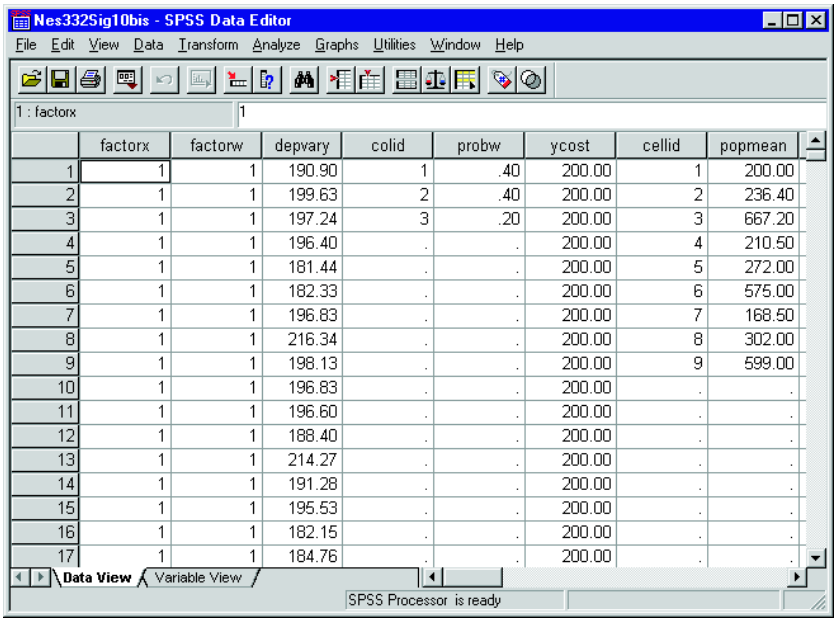
$$P(W = high) = P(W = medium) = 0.4 \quad P(W = low) = 0.2 \qquad (2.1)$$

The response variable Y measures the improvement in the patients' condition and was recorded by all patients at an appropriate time after treatment.

Due to technical limitations (Scripts in SPSS are not very versatile tools), CAnoVa requires that the data are entered in an SPSS data file according to the following requirements (see a snapshot of the data file in Figure 2.1):

(i) the levels of the two factors (treatment variable and potential confounder) must be coded numerically beginning with 1, i.e. therapy A has been coded with 1, therapy B with 2 and therapy C with 3. The severity of the disorder has been coded with 1 for *high*, 2 for

[1]The assignment of patients to therapies has been performed following the procedure of conditional randomization, which guarantees that the effects of any other confounder have been "screened off" (see Section 3.4 of [Wuethrich-Martone, 2001]).



	factorx	factorw	depvary	colid	probw	ycost	cellid	popmean
1	1	1	190.90	1	.40	200.00	1	200.00
2	1	1	199.63	2	.40	200.00	2	236.40
3	1	1	197.24	3	.20	200.00	3	667.20
4	1	1	196.40	.	.	200.00	4	210.50
5	1	1	181.44	.	.	200.00	5	272.00
6	1	1	182.33	.	.	200.00	6	575.00
7	1	1	196.83	.	.	200.00	7	168.50
8	1	1	216.34	.	.	200.00	8	302.00
9	1	1	198.13	.	.	200.00	9	599.00
10	1	1	196.83	.	.	200.00	.	.
11	1	1	196.60	.	.	200.00	.	.
12	1	1	188.40	.	.	200.00	.	.
13	1	1	214.27	.	.	200.00	.	.
14	1	1	191.28	.	.	200.00	.	.
15	1	1	195.53	.	.	200.00	.	.
16	1	1	182.15	.	.	200.00	.	.
17	1	1	184.76	.	.	200.00	.	.

Figure 2.1: SPSS Data file

medium and 3 for *low*. No restrictions apply to the variables names. For the considered design the treatment variable has been entered with the name factorx, the confounder as factorw, and the response variable with the name depvary (for dependent variable y);

(ii) The marginal probabilities $P(W = w_j)$ have been entered as values of a variables called probw, in correspondence of the values of another variable (called colid, for column indicator) used to identify in the design the different columns (which correspond to the different values of W), i.e.

$$\mathsf{colid} = j \;\Leftrightarrow\; \mathsf{probw} = P(W = w_j).$$

If the marginal probabilities are not known, CAnoVa estimates them from the cell frequencies;

(iii) No missing observation in treatment variable, potential confounder or response variable is allowed.

CAnoVa is started (see Figure 2.2) by the menu commands

$$\textit{Utilities} \longrightarrow \textit{Run Script}\ .$$

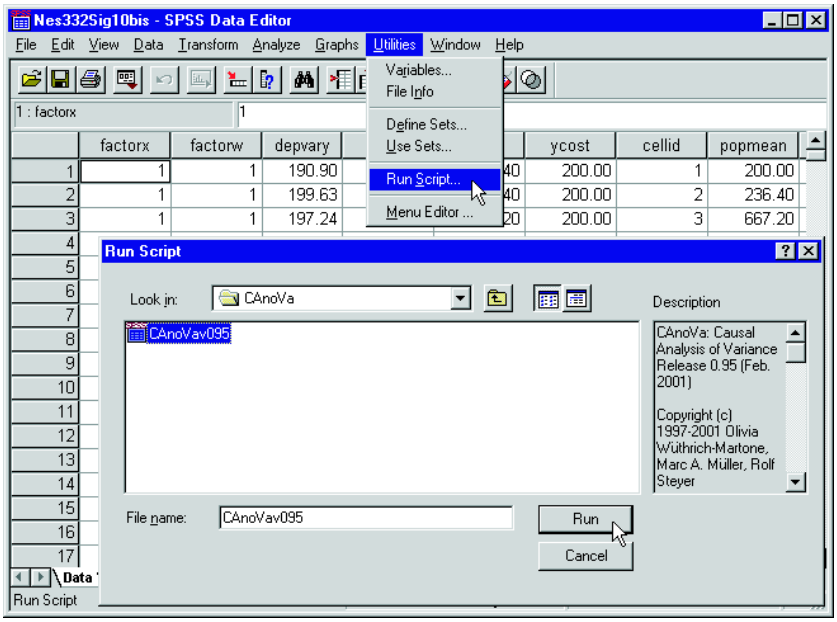


Figure 2.2: How to run CAnoVa

Using the window "Run Script" the CAnoVa Script (in the Figure 2.2 with the name CAnoVav095 that refers to the beta version 0.95) is located and selected and the button Run is activated.

The main window of CAnoVa is shown in Figure 2.3. In this window the variables of the model to analyze are selected. In case of a design with multiple treatment variables and multiple confounders, the variables must be selected in the sequence desired for the analysis, that is $X_1, \ldots, X_p$ for the treatment variables and $W_1, \ldots, W_q$ for the potential confounders. In fact the corresponding reduced 2-factor design is affected by the order by which the variables are considered (see [Wuethrich-Martone, 2001], Section 6.2).

The button Options let the options window of CAnoVa pop up. In this window (see Figure 2.4) the option Confounder Distribution is known has been selected and the variables colid and probw have been entered. CAnoVa will therefore use the marginal probabilities $P(W = w_j)$ specified in probw and will not estimate the probabilities from the cell frequencies.

In the same window CAnoVa may be instructed to use the cell true means and the cell variance[2].

By clicking the button Output in the main window (Figure 2.3), the win-

[2]This option reflects a rather uncommon situation, since in real studies the cell true means are estimated. Since to date CAnoVa is in beta version, a few unnecessary or unusual options are still allowed because they may be of some technical use.

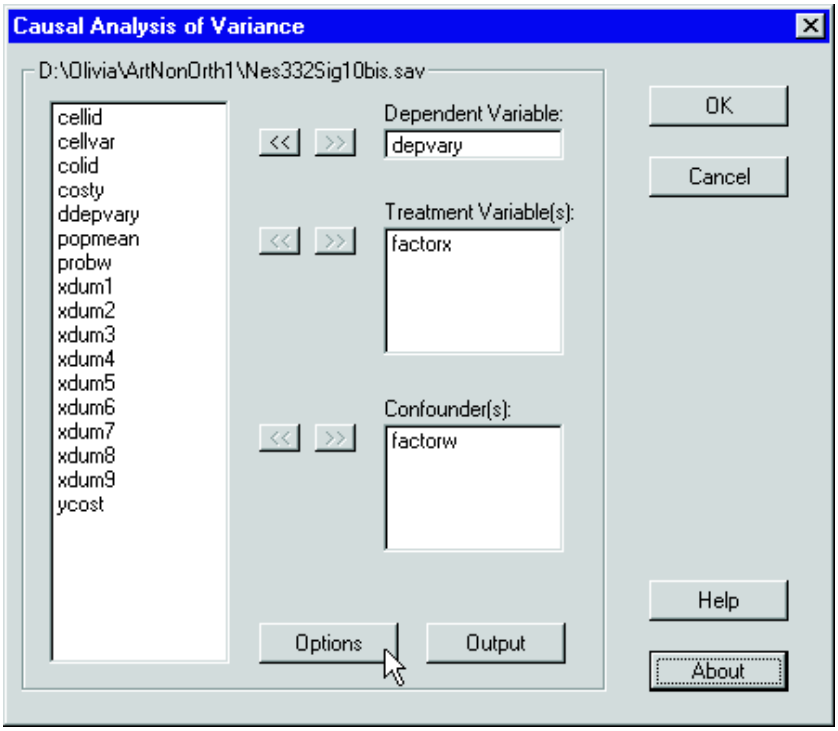


Figure 2.3: CAnoVa: Main window

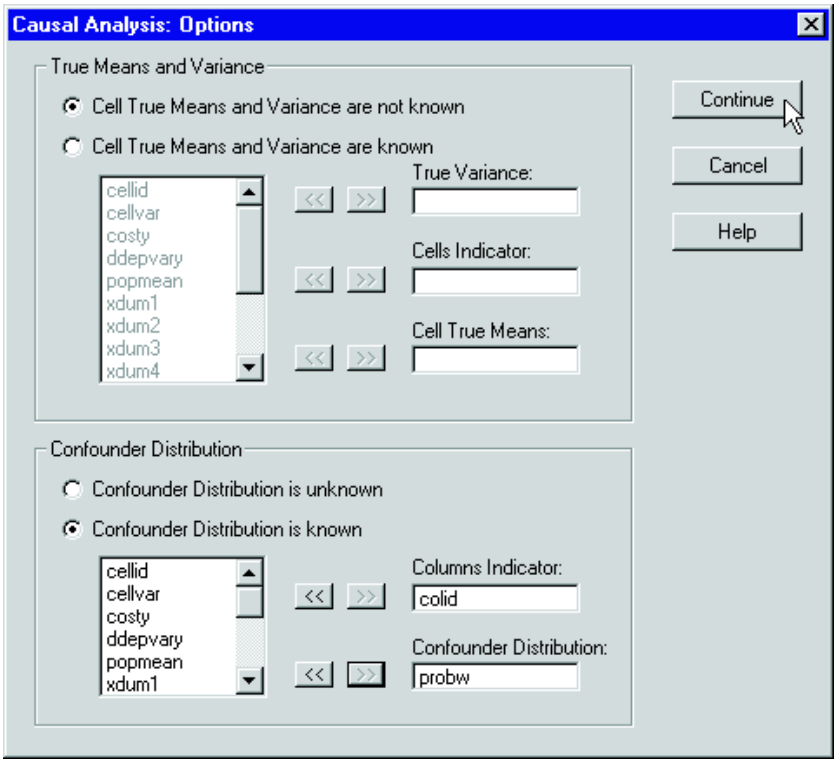


Figure 2.4: CAnoVa: Options window

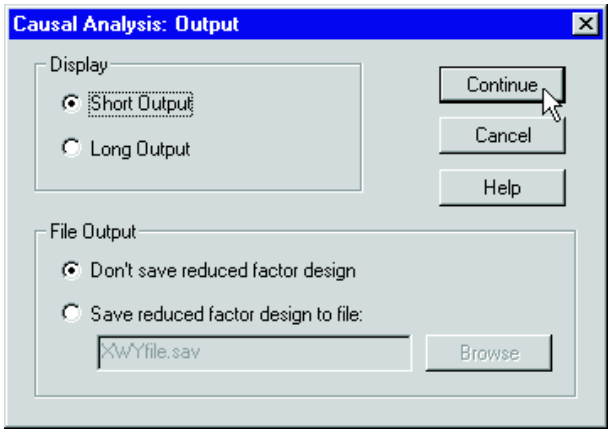


Figure 2.5: CAnoVa: Instructions for the output

dow for the output instructions is activated. This window is shown in Figure 2.5. Two output versions are available, a long one and a short one (a thorough description of the two versions is given in Section 2.2).

In the case of a design with multiple treatment variables and multiple confounders, CAnoVa may be instructed (see Figure 2.5) to save the corresponding reduced 2-factor design in a new SPSS data file. Be aware that no attempt at all should be done to save the reduced design in the original data file, since this could lead to a partial or even to a complete loss of the original data.

By clicking on the Help button a concise list of formulas used by CAnoVa is made available (cf. Figure 2.6).

2.2 Output

Figure 2.7, Figure 2.8 and Figure 2.9 show the output short version produced by CAnoVA for the psychotherapies example (see also Section 4.5 of [Wuethrich-Martone, 2001]). The short version of the output consists of a table with information concerning the data file considered and the options specified (Figure 2.7, top), of various summary tables (Figure 2.7, bottom and Figure 2.8) and of the results of the causal analysis of variance (Figure 2.8), i.e. the estimated treatment means (adjusted for confounding and not) and the tests for confounding and for causal effects.

The summary tables listed in the output show respectively: the cell frequencies (Figure 2.7, bottom), the cell means, the cell probabilities $P(X = x, W = w)$ and the cell conditional probabilities $P(W = w \,|\, X = x)$ (Figure 2.8). The most important part of the output is shown in Figure 2.9. In

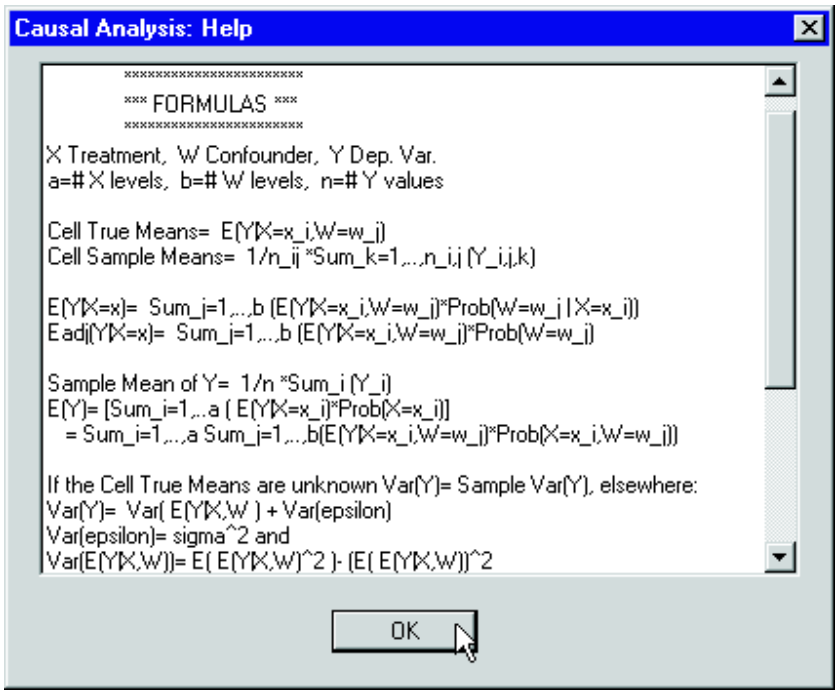


Figure 2.6: CAnoVa: Help window

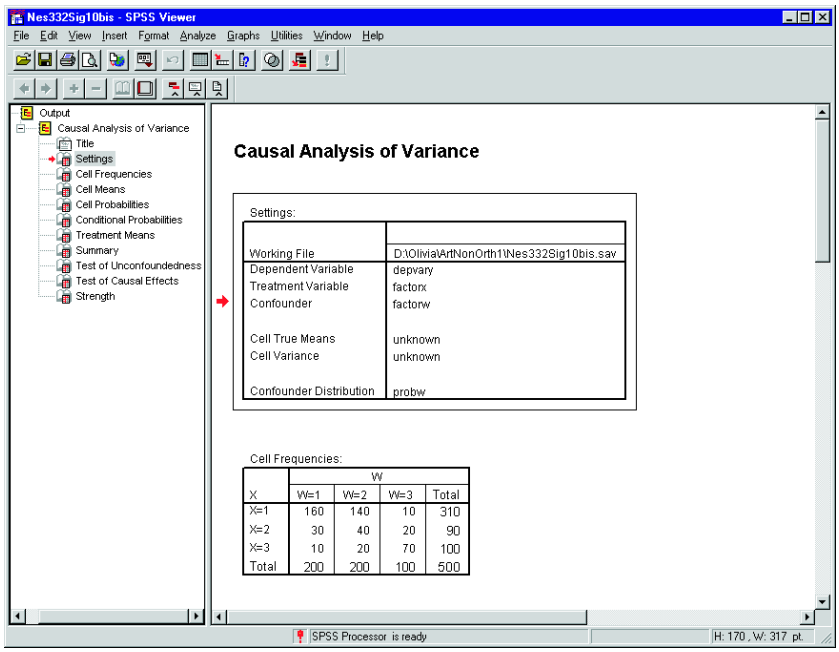


Figure 2.7: CAnoVa: Output (short version) Part 1

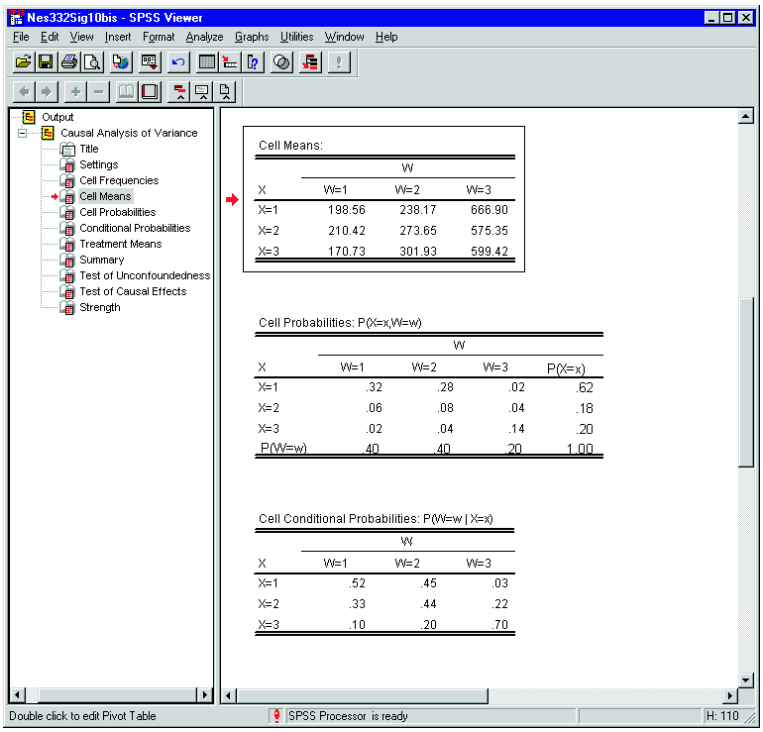


Figure 2.8: CAnoVa: Output (short version) Part 2

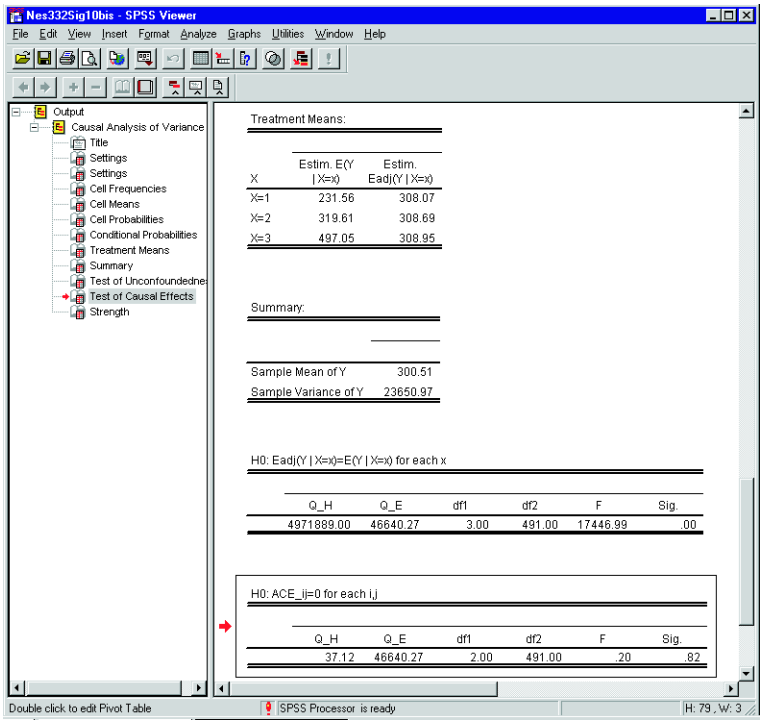


Figure 2.9: CAnoVa: Output (short version) Part 3

the first table the estimates of the treatment means (Estim. $\mathrm{E}(Y|X = x)$) and the estimates of the treatment means adjusted for confounding (Estim. $\mathrm{Eadj}(Y|X = x)$) are listed. The last two tables present, in the order, the results of the test for confounding w.r.t. W and of the test for average causal effects[3].

The test for confounding w.r.t. W tests whether the considered confounder (the severity of the disorder) does actually confound the treatment regression considered (that is in our example the treatment regression of patients' improvement on therapies). The test statistics F is the quotient of the two sums of squares Q_H and Q_E (the analytical expressions of Q_H and Q_E may be found in Section 4.3 of [Wuethrich-Martone, 2001]). Since the distribution of the confounder was known, the test statistics follows under the null hypothesis of unconfoundedness an $F_{[3,491]}$ distribution[4]. The p-value

[3]A thorough description of the two tests is given in Sections 4.3 and 4.4 of [Wuethrich-Martone, 2001] respectively.

[4]To date there is no ultimate information (simulations studies are being performed) on the distribution of the tests statistics if the joint distribution of the treatment variable X, the potential confounder W and the response variable Y is unknown. For a more detailed account on this problem, see Sections 4.2 and 9.2 of [Wuethrich-Martone, 2001].

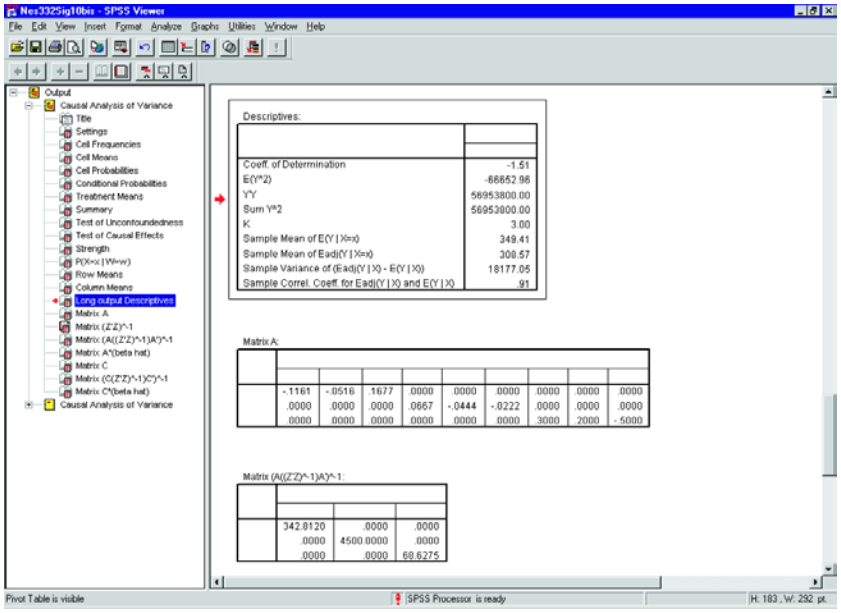


Figure 2.10: CAnoVa: Output (long version) Part 1

corresponding to the test statistics is almost zero, which leads to the rejection of the null hypothesis. It may therefore be concluded that the Severity of the Disorder is an actual confounder for the treatment regression considered.

The last table (the one indicated by an arrow) in Figure 2.9 presents the result of testing the causal hypothesis

$$H_0 : \ ACE(i, i') = 0 \quad \forall i \ \forall i' \tag{2.2}$$

that states that the three therapies do not differ from each other with respect to their (average) causal effects. The test statistics F is the quotient of the two sums of squares Q_H and Q_E (the analytical expressions of Q_H and Q_E may be found in Section 4.4 of [Wuethrich-Martone, 2001]). Since the distribution of the confounder was known, the test statistics follows under the null hypothesis of unconfoundedness an $F_{[2,491]}$ distribution[5]. The p-value corresponding to the test statistics is 0.82, which leads to accept the null hypothesis. The three psychotherapies considered do not differ significantly one from each other concerning their average causal effects. The long version of the output produced by CAnoVa consists of the short version of the output and of the following additional features (see for the psychotherapies example Figure 2.10 and Figure 2.11):

[5]As well as for the test of unconfoundedness, simulations studies are being performed to investigate the distribution of the tests statistics when the joint distribution of the treatment variable X, the potential confounder W and the response variable Y is unknown.

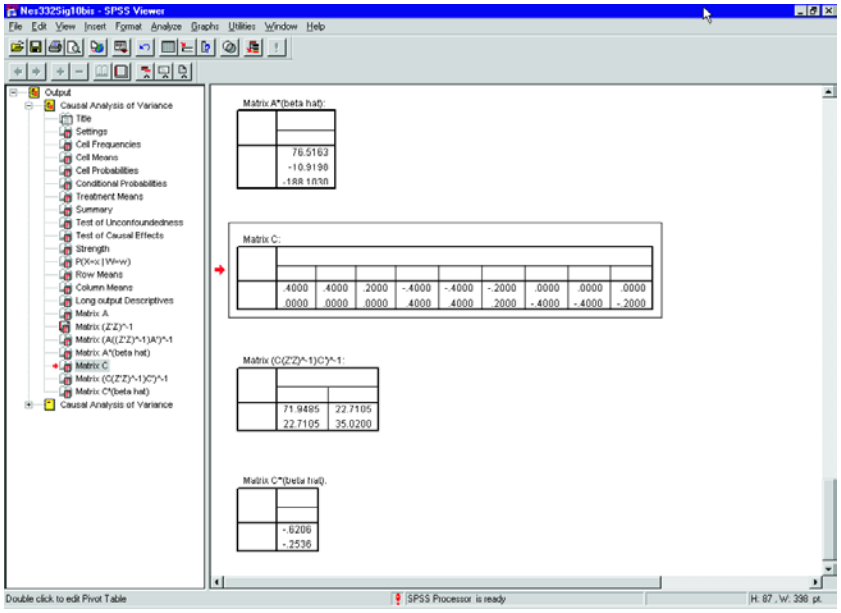


Figure 2.11: CAnoVa: Output (long version) Part 2

(i) three tables (not shown in figure), the first listing the conditional probabilities $P(X = x \,|\, W = w)$, the second listing the row means, and the third one listing the column means;

(ii) a summary table with various descriptive statistics (Figure 2.10, top);

(iii) the coefficient matrix[6] A for the null hypothesis of unconfoundedness (Figure 2.10, top), the matrix[7] $(Z'Z)^{-1}$ (not shown in figure), the matrix $(A(Z'Z)^{-1}A')^{-1}$ (Figure 2.10, bottom) and the matrix $A\hat{\beta}$ (Figure 2.11, top);

(iv) the coefficient matrix[8] C for the causal null hypothesis, the matrix $(C(Z'Z)^{-1}C')^{-1}$ and the matrix $C\hat{\beta}$ (the three matrices are shown in Figure 2.11).

CAnoVa, even in the beta version, is still a practical tool for the experimenter interested in causal modeling and in the analysis of confounding

[6] The null hypothesis of unconfoundedness is formulated as a particular general linear hypothesis $A\beta = 0$, where β is the vector of the true cell means. For more detail, see Section 4.3 of [Wuethrich-Martone, 2001].

[7] Z indicates the design matrix.

[8] The causal null hypothesis is formulated as a particular general linear hypothesis $C\beta = 0$. For more detail, see Section 4.4 of [Wuethrich-Martone, 2001].

variables. CAnoVa was also presented to the 14th Conference of the International Association for Statistical Computing, in Utrecht, the Netherlands, August 21-25, 2000.

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