IDENTIFICATION AND SYSTEM PARAMETER ESTIMATION

Edited by
R. ISERMANN

Volume 1

IFAC

IDENTIFICATION AND SYSTEM PARAMETER ESTIMATION

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Edited by

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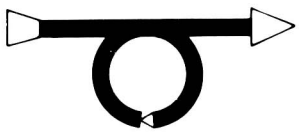

IFAC

International Federation of Automatic Control

IDENTIFICATION AND SYSTEM PARAMETER ESTIMATION

Volume 1

IFAC Conference Proceedings

ATHERTON: Multivariable Technological Systems
BANKS & PRITCHARD: Control of Distributed Parameter Systems
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FIFTH IFAC SYMPOSIUM ON IDENTIFICATION AND SYSTEM PARAMETER ESTIMATION

Organized by
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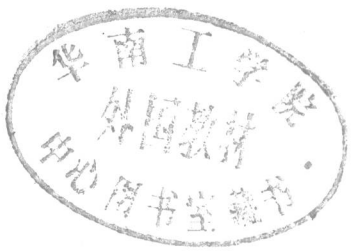

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OPENING ADDRESS ON BEHALF OF THE IFAC PRESIDENT. . . . .

Pieter Eykhoff

Eindhoven University of Technology, The Netherlands

Mr. Chairman, Ladies and Gentlemen,
Dear Colleagues,

This symposium is organized under the auspices of the International Federation of Automatic Control, IFAC.
It is my duty, and pleasure, to bring to you the greetings and the very best wishes of the President of this international organization.
Professor Sawaragi regrets very much that he can not be with us during this symposium. He asked me to speak to you on his behalf.
Using the few minutes available I like to pay some attention to IFAC, to our host country and to this symposium.

IFAC

The purpose of IFAC is:

> *"to promote the science and technology of automatic control in its broadest sense to all systems whether, for example, engineering, physical, biological, social or economic in both theory and application. IFAC is also concerned with the impact of automatic control on society"* (1).

It is a multinational federation, a federation of National Member Organizations of 40 countries. Among its activities are the organization of meetings for the exchange of knowledge, experience and.....problems. These meetings are: world-congresses, each 3 years. In the intermediate years there are many specialized conferences or symposia like this one and also rather informal workshops. Besides the oral exchange of information there is also the written one, e.g. through the preprints and proceedings of such meetings. These form important contributions to the professional literature.
Also the federation can point with some pride and satisfaction to the IFAC-journal AUTOMATICA, which ranks among the best control-engineering periodicals.
In this IFAC-work many people participate, e.g. through the 14 technical committees, ranging in subjects

> from mathematics of control to social effects;
> from biomedical- to space applications.

IFAC represents an open invitation to think, to plan and to work together on a multitude of tasks. The essence, the foundation under these tasks, can be expressed by one word *Service*; service to the control engineering community. The service may be directed to a variety of entities:

- The individual control engineer
- The National Member Organizations
- Regional groups of control engineers
- The control engineering community and professional societies
- Sister federations like IFIP, IMEKO, etc.
- Intergovernmental organizations
- The general public

Also the type of service that can be provided is quite extensive:

- To create possibilities for personal encounters of control specialists
- To simulate or provide further education
- To enable oral presentation of new knowledge
- To provide publications
- To contribute to evaluation of control engineering items, e.g. computer software
- To promote standardisation
- To initiate study and research
- To provide professional recognition

By considering the list of possible services and the list of potential users of those services it is clear that for the time being the development of IFAC is limited only by the number of people who care to contribute to this service.

Again: IFAC represents an open invitation to think, to plan and to work together on a multitude of tasks. It represents an invitation to you to participate in such activities and to make your professional views known:

- Through your National Member Organization,
- Through Technical Committees,
- Through the IFAC Secretariat,
- Through the Organizing Committee of this symposium.

IFAC invites open and honest opinions on its performance and on ways along which its performance can be improved.
During these few minutes only a limited amount of information can be given. Those desiring a more complete picture are advised to study the brochure "IFAC Information" (1) that can be requested from the IFAC Secretariat.

OUR HOST COUNTRY

Earlier in this speech I mentioned already the NMO, National Member Organizations of IFAC. If it were asked what NMO has been most influential on IFAC and has contributed most generously then I think the answer is clear. It certainly is the NMO of the Federal Republic of Germany. In the beginning.....September 1956, there was a "Regelungstechnik" Congress held in Heidelberg, not far from Darmstadt. That congress was made by our German colleagues.
During that congress the initiative was taken to establish an international cooperation and exchange which crystallized into IFAC(2). From 1957 till 1975 the IFAC Secretariat was in Düsseldorf, in the premises of the VDI/VDE. This implied a substantial financial support to IFAC. But also the German people involved in IFAC were of great calibre. Particularly we think of Dr. G. Ruppel as Honorary Secretary and Mrs. L. Schröder as Deputy Secretary.
I think IFAC was fortunate to have its cradle in Germany, because in this way it gained from a typically German characteristic: *"Gründlich_keit"*.Actually this word is difficult to translate. It is related to thoroughness, soundness, solidity, profoundness, dependability; but honestly, I do not know a proper translation into English. Anyhow, that does not matter. For understanding that word the only thing you have to do is just to look around you, here at this symposium. In the way this symposium has been organized, you will recognize this word "Gründlichkeit".

THIS SYMPOSIUM

It is the fifth one in a sequence of meetings: Prague, 1967; Prague, 1970; The Hague/Delft, 1973; Tbilisi, USSR, 1976.
These symposia have been very successful and there is little doubt in my mind that also this fifth one will continue along the same lines. The aim is "to present, discuss and summarize recent advances in theory and application of designing mathematical models of dynamic processes and signals by means of identification and parameter estimation. Furthermore procedures which are based on combination of identification and other methods will be presented".
How do we look at identification and system parameter estimation now, twelve years after the first symposium? Each of us has his own view, e.g.
- its relation to control applications in adaptive control;
- its relation to model building in order to understand physical reality;
- its relation to medical diagnosis;
- its relation to preventive maintenance e.g. of airplanes or turbines.

So among us there are many different views - this is a good situation to learn, *if* we are open to those other views, *if* we listen carefully and *if* we discuss without prejudice. Let me relate identification and parameter estimation to the frequently discussed gap between practice and theory, between classical control and modern control. For classical control applications a *rough* model was sufficient; this constituted the strength of discipline. For modern control application there is need for a *precise* model which can be found in space applications, but is difficult to attain down-to-earth. So part of the gap between classical and modern control certainly consists of the requirement with respect to the model needed. Now we may think of identification and parameter estimation as a way to bridge the gap, to find a useful model in spite of:
- a priori uncertainty;
- present uncertainty due to changing external conditions and changes in internal proces characteristics.

One of the discussion sessions is devoted to the theme: "Is identification obsolete?".
I think by these remarks I have already suggested my answer to this question.
May this symposium be stimulating and challenging to all of you....

The IFAC Executive Council realizes very well that activities like this symposium are completely dependent on organizations, on committees and on individuals.
On behalf of the President of IFAC I like to express his appreciation to the *IFAC National Member Organization*, the VDI/VDE-Gesellschaft Mess- und Regelungstechnik. IFAC is grateful to this organization for accepting the responsability to organize this symposium.
The sincere thanks of IFAC is also going to the *National Organizing Committee* for taking care of all the aspects that have to be handled in organizing a symposium.
With appreciation the *International Program Committee* is mentioned, but, above all, its chairman Prof_essor *Isermann* and the Secretaries *H. Kurz and R. Schumann* have to be recognized with special emphasis. Only those who have organized a symposium really know how much effort, intelligence, endurance and hard work is needed in order to make such a meeting a success. I think that both the initial conditions and the boundary conditions are well suited to make this symposium an optimal one!

I have to close this speech. On behalf of the President of IFAC I like to say to all of you..... I wish you an interesting, fruitful and very stimulating symposium. Thank you for your attention.

REFERENCES

(1) Brochure "IFAC Information: aims, structure, activities".

(2) Brochure "IFAC, twenty years old; twenty years young, an anniversary publication 1957-1977", also in Automatica, volume 14, pages 49-75.

Both brochures obtainable from the IFAC Secretariat, Schlossplatz 12, A-2361 Laxenburg, Austria.

OPENING ADDRESS ON BEHALF OF THE VDI/VDE-GESELLSCHAFT MESS- UND REGELUNGSTECHNIK

Tilo Pfeifer

President of VDI/VDE-GMR, Technische Hochschule Aachen, FR Germany

Ladies and Gentlemen,
Dear Colleagues,

It is a great and personal pleasure for me to have the opportunity to welcome you on behalf of the board of the VDI/VDE-Gesellschaft fuer Mess- und Regelungstechnik (GMR) to the 5th IFAC-Symposium on Identification and System Parameter Estimation here in Darmstadt. I like to convey the best wishes from the GMR-General Council and also from all my colleagues of this association for a successful course of your Congress.

We meet today at a time when almost every industry worldwide - in the highly developed countries as well as in the developing ones - is facing the perhaps most demanding and most difficult economic and social environment.

Some facts responsible for this critical situation are:

- the rapidly rising production and living costs resulting from limitedly available energy resources;
- the stagnation of world markets and
- the increasing dependence of our lives and schedules on the satisfactory performance of manufacturing processes, products and services.

Experiences over the past have shown that a key-element or a key-tool for achieving higher efficiency or a higher degree of performance and safety in the different processes of our industry is given by the consequent use of computer aided control and supervising techniques.

In order to automize technical processes, optimize or supervise them by using simple closed loop control techniques as well as very complex self-tuning or adaptive control systems, it is essential that the process itself and its different variations - or let me rather say its dynamic behaviour - is described by mathematical methods. To achieve progress in this very scientific field of research by designing mathematical models of various dynamic processes, so as to have a sound basis for a successful and broad application of computer-aided techniques in process control, lies within the very focus of your Symposium.

The previous 4 Symposia held since 1967 have clearly demonstrated the efficiency of the methods of Identification and System Parameter Estimation in solving the above mentioned problems. Besides, the increasing number of papers on application within the present Symposium underlines this fact and development trend.

Reviewing your program and the conference preprints I can feel certain that the success of your Symposium has been pre-programmed. Nevertheless, I wish you interesting discussions and a very fruitful exchange of experiences during your conference and your stay in Darmstadt.

OPENING ADDRESS ON BEHALF OF THE TECHNISCHE HOCHSCHULE DARMSTADT

Helmut Böhme

President of the TH Darmstadt, FR Germany

I would like to welcome you not only as participants of the

> 5th IFAC-Symposium on Identification and System Parameter Estimation

but also as guests of the Technische Hochschule Darmstadt.
I am very pleased that after Prag (Prague), Den Haag (The Hague) and Tiflis (Tbilisi) you have chosen Darmstadt for the site of this Symposium. Furthermore, I believe that your decision was based on the fact that our University has for some time shown a special interest in Regulation and Control problems both in research and in lecturing. Please allow me to mention in this context the names of two colleagues: Mr. Oppelt who layed the foundation here for the first Institut fuer Regelungstechnik 25 years ago and the deceased Mr. Küpfmüller who was particularly interested in this field of research. Rolf Isermann as scientific chairman of this Symposium has accepted the honourable but at the same time responsible position to demonstrate the latest development in research based on the long history in Engineering Sciences, on the somewhat shorter history of automatic control, on the experiences and aims of the IFAC to provide an opportunity to exchange scientific experiences and ideas and last but not least to find an easier way of introducing tutorial "newcomers" to this field.
For this undertaking I would like to express my very personal wish for success and satisfying results.
A rapid growth of knowledge as a result of an ever-increasing specialization in research is a landmark in the modern development of sciences. Evidence for this is shown by the 3oo papers that have been offered to this Symposium. - During the last decades, according to a rule of thumb, a doubling of knowledge has taken place every 1o years. At the same time it is assumed that within a period of 5 years in some areas of natural sciences half of our existing knowledge will be no longer valid and cannot be applied. The universities therefore necessarily have to deal with the problems of how to arrange studies so as to provide a meaningful guide for students. At the same time however, postgraduate courses are becoming more and more important.
This Symposium with 15o special lectures during the next few days seems to be suitable as such an offer, particularly because different levels of knowledge are being considered, and by means of 6 Tutorials on "System Identification" - based on the interest in the subject - the tools will be given to the non-specialists to cope with lectures presented by the specialists. Besides the scientific exchange between specialists I would like to point out the importance and significance of such symposias to further education.
I very much hope that the next few days spent at the Darmstadt Symposium will be of use to you and will remain a pleasant memory. I wish the Symposium every success.

OPENING SPEECH

N. S. Rajbman

Professor, Institute of Control Sciences, Profsojuznaja, 65, Moscow GSP-312, USSR

Mr. Chairman, Ladies and Gentlemen, dear Colleagues:

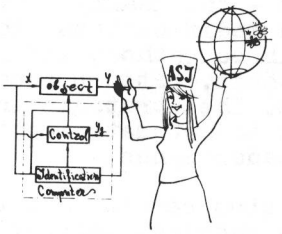
Here we are about to start the 5th Symposium on Identification. Time flies. It seems that only recently we attended the first two Symposia held in Prague. But in fact 12 years have passed.

I see here many of those who were in Prague. It is very pleasent to meet once again our friends and colleagues who are in love with identification and are loyal to it. It also is very gratifying to see new alert faces, those of bearded men and charming ladies*. I am sure that all present here

are in love with identification regardless of age, country, the specific application or the specific problem of identification they work at. I do not doubt that this passion for identification possesses everybody present from the beginning; this is a domain for which one can feel nothing but love - it attracts, appeals and absorbs, and secondly, anybody not sharing this passion would rather participate in other IFAC Symposia instead of this one, wouldn't he?

The scope of identification is boundless. It is needed in every sphere of human activity: management, forecasting, approximation and filtering. It is required in any field of science and technology using a computer. It is an indispensable tool of an engineer and a doctor, a biologist and physicist, a chemist and an agronomist, a theoretician and a practician, an experimentator and a plant engineer at all levels of hierarchical management. You just have to look

through the proceedings of IFAC Symposia and Congresses to see that I am right. No doubt everybody present here is well aware of this, but I am tempted to remind you of it once again, since this knowledge is very gratifying to all of us. The scope of identification, its origin and goals are excellently presented in opening addresses by Prof. V.Strejc and Prof. P.Eykhoff published in the proceedings of the previous Symposia. That's why I would like to use this opportunity to let imagination have its way. I hope that this forecast will have a nonzero probability. Before discussing the future I'd like to say a few words about the present



* I am indebted to Ms. Ye.A.Razorya for her kind help with the slides.

since this is where the future has its origin. Thus I have to start with ASI's. This is the abbreviation for Adaptive Systems with an Identifier in closed loop.

ASI - the present

First of all I should say that the ASI is the result of efforts made by many authors. I cannot mention all of them here. But I must recall at least the founders such as: Prof. K. Aström (Sweden), Prof. A.V. Balakrishnan (USA), Prof. P. Eykhoff (The Netherlands), Prof. A.A. Fel'dbaum (USSR), Prof. R. Isermann (FRG), Prof. V.S. Pugachev (USSR), Prof. Y. Sawaragi (Japan), Prof. V. Strejc (Czechoslavakia), Prof. J. Richalet (France), Prof. Ya.Z. Tsypkin (USSR), Prof. L.A. Zadeh (USA).

Apart from a controller the ASI has an identifier in closed loop. The ASI has two modes of operation. The first one is the learning. In the learning mode the identification is carried out using the input-output data. The identification ends when the model is an adequate representation of the system and fulfills the control objective. When this is done the system passes on to the second mode - that of control. During the second mode the identification is continued. It is required to check current changes in the system. At present identification functions have been considerably expanded. We had even to split identification into two components - strategic and tactical or operational. Preliminary identification is carried our in the strategic identifier. This is done off-line. Here the input-output data are used to select the structure of the model, its order and dimension, to find out if the system is identifiable at all. To define the level of identity, stationarity and nonlinearity, and to define the control payoff. This rather incomplete list shows that the strategic identifier tackles important and complicated tasks which often can not be solved by the practical methods available. A basic model which can be used for tactical identification is built in the strategic identifier. Use is made chiefly of the so-called "classical" algorithms - the least-squares method and its modifications, the maximum likelihood method, information theory methods, pattern recognition and others. The strategic identifier enables us to automate identification in the broader sense.

Identification results are transmitted to the tactical identifier. Its basic function is to respond quickly to variations in the system characteristics. These variations can be caused by wear, ageing or burn-out. The system changes with time and these changes should be taken care of by the model. This task is carried out "on-line" by the tactical identifier. Such an approach assumes that one model for the system is insufficient. As a rule iterative one- or two-step algorithms are used here. Various modifications of these algorithms are well-known. Introduction of the identifier into the feedback loop permits a new view of the control system. It has already been stressed that we succeeded in automating the identification process, the process of building and updating a model in such systems. The ASI needs no efforts to gain admirers.

At present we already have in some countries encouraging examples of the ASI application.

First of all due to the introduction of an identifier directly into the control system high efficiency of the ASI has become possible. The merit of the ASI as of any control system lies in its algorithms and programs. These are mainly the algorithms and programs which we discussed at our previous Symposia and they are published in the proceedings. I believe that the ASI is a result of our meetings and our discussions, - I would even say that our Symposia gave birth to the ASI and the ASI is our child or rather a child for some of us and already a grandchild for others.

ASI - the future

It is obvious that the ASI's are systems of the future. They are going to be of great use to humanity. But we have many problems to overcome yet. It is necessary to improve ASI's and increase their efficiency. Besides, we have to widen the ASI application range. It can be seen that ASI has some of the properties which we ourselves possess. It collects information and constructs a model. It uses that model to tackle a specific task. The ASI changes its decision if the situation changes or the model has changed. Doesn't a human being behave likewise? This has become possible due to the introduction of the identifier into the feedback loop. The identifier provides the system with "intelligence". Even today the ASI implies high efficiency and quality in metallurgy, the paper and pulp industry, optimal management of a power station and a comfortable flight. And tomorrow ASI functions will no doubt increase. The identifier will model the functioning of a large system

a human being

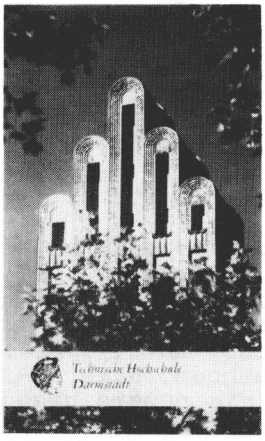
an environment

and many other systems.

IFAC provided us with these opportunities at its Symposia and Congresses where most of us met and became friends. We can say that IFAC inspired new ideas, novel approaches and original methods. High standards of the scientific papers urged us to work harder. I would also like to express my appreciation of the friendly criticism and mutual assistance so helpful in our work. I was aware of them all along the discussions. I am confident that these traditions will be maintained in IFAC and at our meetings on identification. I am always happy to attend them. I wanted to give a concise definition of what an IFAC Symposium on Identification was like - but I failed. I had to go with a descriptive definition. I would rather say that the IFAC Symposia on Identification give birth to new approaches, algorithms and identification methods which are effectively applied to many fields of science and technology.

It is very pleasant that the 5th Symposium is held here in Darmstadt. I admire the charm of the city and its landscape. One has a feeling of being in a kingdom of gardens, parks and woods. Darmstadt and its environs are famous for their history. It is full of legends about the Roman conquerors, Nibelungen, hunters and

others. The city also is beautiful. Its fine architecture and planning, combining modern and ancient architectural features, is outstanding. Thus the ASI has been instrumental in bringing us together in such a nice place.



Ich möchte die Gelegenheit benutzen, um die Stadt Darmstadt und die Professoren und Studenten der Technischen Hochschule auf das herzlichste zu begrüssen und Ihnen wünschen, daß Sie mit Zuversicht in das zweite Jahrhundert der Technischen Hochshule Darmstadt treten, und möchte Ihnen auch wünschen, daß Sie das Banner der Hochschulbildung, des Fortschritts und der Menschlichkeit hoch tragen.

Our dear hosts have done everything possible and even impossible, I think, to organize everything properly - the supply of information has been excellent. The organizing Committee headed by Professor R. Isermann has been working hard in a friendly and creative atmosphere. I would like to use this opportunity to thank them for it. I am honoured to pass over to the IPC Chairman a nonchallenge cup, a Russian Samovar. We hope that it will remind you of the important part you played in organizing the 5th Symposium on Identification.

In conclusion, I would like to wish you all a very successful Symposium.

ERRATA

Paper by J. M. Maciejowski (page 743)

1. In this paper there is some confusion of 0 and 1. The equations which appear are correct if $\mu = \hat{x}(1|0)$, except that $\Phi(k,0;\hat{\theta}_o)$ should be replaced by $\Phi(k,1;\hat{\theta}_o)$ wherever it appears. To estimate the initial condition at time 0 instead of 1, one can either use $\mu=A(0;\hat{\theta}_o)\pi$, where $\pi=\hat{x}(0|0)$, or one can repeat the development of the paper, in which case the corresponding equations are:

$$\frac{d\ell(Z|\hat{\theta}_1)}{d\,\pi} = \beta'-\pi'U \qquad (12a)$$

$$\beta' = \sum_{k=1}^{N} \{\nu'(k;\hat{\theta}_o)-\pi_o'\Psi'(k-1,0;\hat{\theta}_o) A'(k-1;\hat{\theta}_o)C'(k;\hat{\theta}_o)\}S^{-1}(k;\hat{\theta}_o) C(k;\hat{\theta}_o)A(k-1;\hat{\theta}_o)\Psi(k-1,0;\hat{\theta}_o) \qquad (13a)$$

$$U = -\sum_{k=1}^{N} \Psi'(k-1,0;\hat{\theta}_o)A'(k-1;\hat{\theta}_o)C'(k;\hat{\theta}_o) S^{-1}(k;\hat{\theta}_o)C(k;\hat{\theta}_o)A(k-1;\hat{\theta}_o) \Psi(k-1,0;\hat{\theta}_o) \qquad (14a)$$

$$\Psi(k,k-1;\hat{\theta}) = \left\{I-K(k;\hat{\theta})C(k;\hat{\theta})\right\}A(k-1;\hat{\theta}) \qquad (6a)$$

$$\Psi(k,0;\hat{\theta}) = \Psi(k,k-1;\hat{\theta})\ (k-1,0;\hat{\theta}) \qquad (18a)$$

2. In the section on computational aspects (page 745) it is stated that the inversion of S imposes a computational burden. This is not so, because S^{-1} will usually be already available from the Kalman filter, which is required in any case.

Paper by C. C. Lau and J. R. Leigh (page 923)

Page 925, col. 1. Line 13 should read:

C_o is the vector to be identified

Equation 6 should read:

$$\therefore D(n+1)-D(n)=2\Delta C(n)^T_p\partial C_m(n+1) \cdot \cdot \cdot \cdot$$

Equation 9 should read:

Thus $D(n+1)-D(n)=\mu^2 e(n)^T p^{-1} e(n) \cdot \cdot \cdot \cdot$

Equation 10 should read:

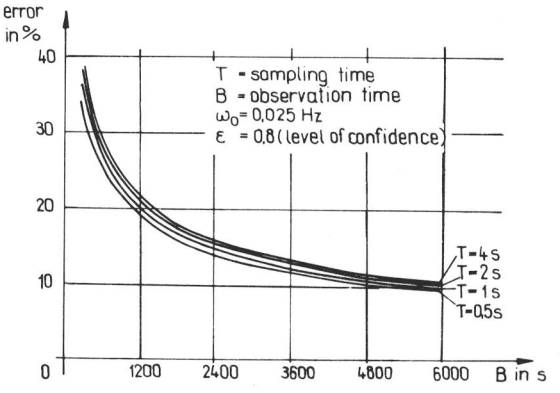
$$\mu = \frac{\lambda\varepsilon(n)}{e^T(n)p^{-1}e(n)}$$

Page 926, col. 2. Line below the heading "Application of the Identification Method to Equation (30)" should read:

The matrix C_o is here given by $C_o^T=[\Phi:\Phi]$

Paper by J. Fischer and H. H. Wilfert (page 1235)

Page 1238, Fig. 1.



Paper by P. B. L. Castrucci and J. D. G. Garcia (page 1241)

Page 1242, col. 1. Equation 5 should read:

$$C_t=[-0.262^{-1}+0.22z^{-3}+0.10z^{-6}]\,Pt + Nt$$

Page 1243, col. 1. Equation 14 should read:

$$u_t^x = \frac{-G(z)z^k}{B(z)F(z)}\,Y_t$$

Page 1243, col. 1. Equation 18 should read:

$$C_t^* = \frac{-0.6z^7Yt}{B(z)}$$

Page 1247, Fig. 7. TC should read C_t; TP should read P_t; Y should read Y_t

Page 1247, Fig. 9. CI should read C_t; PI should read P_t

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