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Introduction to the Works of Rodney C. Wingrove: Engineering Approaches to Macroeconomic Modeling

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Abstract A continuous-time control model was formulated and fitted to macroeconomic data by an expert control engineer who worked at NASA-AMES in the 1980s, Rodney C. Wingrove. Two articles were prepared and made available to the aerospace industry at that time, however the authors feel that wider distribution of his study posthumously is warranted at this time. This introduction to the two Wingrove articles that follow provides background information on the technologies Wingrove was working with, as well as subsequent developments in both macroeconomic and engineering modeling and analysis technology. Our purpose is to stimulate further research along the same lines which can potentially lead to structural and/or policy rule improvements that can prevent the extremely turbulent abberations that have been seen in recent years, and promote steady growth with low inflation and low unemployment in a sustainable way. Of particular concern is the exploding national debt problem.

Keywords Macroeconomic models · Stochastic dynamic control models · Parameter estimation · System identification · Business cycles · Money supply regulation · Simulation of policy alternatives

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Towards the end of 2010, I (Ron Davis) received an 1983 article "Classical Linear-Control Analysis Applied to Business-Cycle Dynamics and Stability" (NASA Technical Memorandum 84366) written by an aerospace engineer from NASA-AMES, Rodney C. Wingrove. It had been sent to me by a mutual friend because he felt that "it might be important." I agreed with his assessment and went with him to the library at NASA-AMES Research Center in Moffett Field, California to see if there were any other articles that Rodney wrote along the same lines. We found that there was a second one from 1984 entitled "Manual-Control Analysis Applied to the Money-Supply Task" (which appeared in 20th Ann. Conf. on Manual Control, Vol 2, pp. 181–109). Since Rodney had died in the early 1990s we felt that posthumous publication of these papers in the open literature might spark more work along the same lines using engineering and econometric technologies developed since that decade.

My friend told me that Dallas G. Denery had been Rodney's supervisor at NASA-AMES (now retired), and that Rodney's officemate had been Ralph Bach (who still works for NASA-AMES). They have provided a few paragraphs about Rodney's career there. Dr. Denery recommended looking at the books by Clark (1962, 1996) and by McRuer et al. (1973) to see the technologies that Wingrove was working with at the time he wrote the two macroeconomic articles. To find a journal suitable for publication, I contacted an economist I had worked for and collaborated with as a student at Harvard University in the 1960s, David A. Kendrick from the University of Texas at Austin. He wrote a few more paragraphs about the relationship of Wingrove's work to the economic literature and provided some references to work he and others have done along these lines. Finally, I contacted an expert control engineer who I had collaborated with in the 70s, Raman Mehra from Scientific Systems Company in Woburn, Massachusetts, and asked him to provide some information on engineering technologies that could be applied to extensions of the models Wingrove proposed to give some guidance for future research. He provided several more references as well. Their responses constitute the balance of this introduction to the macroeconomic works of Rodney C. Wingrove.

NASA History—(Dallas Denery and Ralph Bach)

Rodney C. Wingrove was a world renowned scientist having made numerous contributions to aerospace sciences. His earliest study led to the ability to precisely calculate the path that a spacecraft should follow to minimize the total heat on a spacecraft during reentry. The method was critical to the success of the Nation's early space programs. He was recognized for this study with the AIAA Lawrence Sperry Award, one of the most prestigious awards in aerospace. Rodney then turned his attention to flight data analysis. The problem was to extract as much information as possible regarding the characteristics of a spacecraft or aircraft, its control, or its environment from the limited data that may be available. In the 60s he developed a technique for analyzing Apollo data that allowed the community to understand the astronauts control responses on reentry. In the 70s he became involved with the National Transportation Safety Board to understand the cause of a number of unexplained private jet accidents by analyzing limited radar flight data. This was followed by the development of a computer program that was used by the National Transportation Safety Board to routinely analyze accidents for those aircraft that were not equipped with a flight data recorder. In the 80s Rodney expanded these techniques to extract information on the wind environment in cases where aircraft encountered extreme clear air turbulence or downburst activity. His work was used by the National Transportation Board in developing advisories for clear air turbulence and in the investigation of airliner accidents involving downburst activity.

As a side, Rodney had a deep interest in economics and on his own time applied the analysis techniques he used in aerospace sciences to understand the economy. To him, the effect of money supply on the gross national product and the effect of aircraft control surfaces on an aircraft response seemed similar. Although the work was done on his own time, NASA agreed to support the publication of this work in the spirit of technology transfer. Although never published in an economics venue, he proceeded to send out copies of his study to various economists. In an excerpt from a response by Mr. Thomas Humphrey, Vice President and Economist of the Federal Reserve Bank of Richmond, Mr. Humphrey stated: “I think your paper would be of great use in the classroom. One could use it to teach the essentials (1) of the quantity theory of money, (2) of countercyclical monetary policy and (3) of the use of differential equations in the analysis of monetary dynamics.”

These two articles covered some of Rodney’s endeavors in the field of economics. As individuals who worked with Rodney and appreciated his intellect and unique approach to understanding the essence of a problem, we commend the Journal of Computational Economics for revisiting this important work.

Relation to the Economics Literature—(David Kendrick)

Recently, a former student and collaborator of mine—Ron Davis, approached me with an unusual request. The request was to see if it might be possible to publish posthumously an article on the application of control theory methods to macroeconomic stabilization that had been written by a NASA engineer, Rodney Wingrove, in the mid 1980s. Wingrove apparently died not many years after completion of the article.

In the 1970s and 1980s there was much work by both engineers and economists in this area. There were annual conferences of the Society of Economic Dynamics and Control. Also there was publication of many articles on the subject first in the Annals of Economic and Social Measurement and then in the Journal of Economic Dynamics and Control (JEDC). A list of some of these articles and books from that time, as cited in the Kendrick review article (Kendrick 2005, is as follows: Aoki 1967; Athans and Chow 1972; Chow 1975; Craine 1979; Fair 1978; Holt 1962; Karakitsos and Rustem 1984; Kendrick 1981; Livesey 1971; Norman 1976; Phillips 1954; Pindyck 1973; Prescott 1972; Shupp 1972; Simon 1956; Swamy and Tinsley 1980; Taylor 1974; Theil 1957 and Turnovsky 1975) given below. Apparently in this period Wingrove was working along the same lines on his own at NASA, but so far as I know, he never presented his study at one of the economic conferences nor submitted it to the JEDC.

This was unfortunate because one can see in retrospect that he would have added much to the ongoing discussion.

Most of the work at that time was on discrete time models; however, in his paper "Classical Linear Control Analysis Applied to Business-Cycle Dynamics and Stability" Wingrove made use of continuous time models with additive noise terms. The focus is on monetary policy and part of the analysis uses Laplace transforms so some of the discussion is in the frequency domain rather than the time domain.

Thus it appeared to me that more than twenty-five years after the article was written it might offer a good starting point for some engineers and economists who want to use continuous time models to analyze economic stabilization issues. Thus I wrote to Hans Amman, the editor of Computational Economics, and suggested that he consider the possible submission of this article posthumously.

Relation to the Engineering Literature—(Raman Mehra)

Since Rodney Wingrove did his work, there have been major advancements in the fields of System Identification and Optimal Control. Similarly, there are major new developments in Macroeconomic modeling and availability of data for model estimation and testing. Optimization theory and algorithms have also advanced tremendously and the previous computational barriers are no longer there. These offer very promising opportunities for future research on the applications of Control Theory to economic systems.

1. *System Identification* (SI) Rodney used classical methods for system identification, mainly based on least-squares regression or frequency domain techniques for transfer function identification. We now have much more general multi-input multi-output state space model SI methods called Subspace Identification Methods, which grew out of early study by Akaike on Canonical Correlation methods for SI (Akaike 1974; Mehra and Lainiotis 1976). An application to Econometrics is given in Ref (Mehra 1982). There are now several books on Subspace Identification and a Matlab Toolbox (Katayama 2005; Van Overschee and De Moor 1999). The advantage of using these algorithms is that one can feed multi-dimensional time-series data and they produce state space and transfer function models between all inputs and outputs. They also work for high dimensional systems and determine system order. If data is limited, the parameter estimates can be further refined using Maximum Likelihood Estimation (MLE) (Mehra 1994; Schön et al. 2011). There are other research developments suitable for nonlinear system dynamics which is an important area for economic modeling. Over the last 30 years, very significant progress has been made in estimation, control and identification of nonlinear systems (Sastry 2010; Arulampalam et al. 2002).
2. *Optimal Control* A very promising approach for Control of Economic Systems where there are lots of constraints and nonlinearities is Model Predictive Control (MPC) (Rawlings and Mayne 2009). MPC is now widely used in Chemical Process Control and is finding increasing use in aerospace and other application areas. MPC is basically on-line iterative optimization for implementing Approximate Dynamic Programming and has been applied to hundreds of applications

with great success. There are a number of books on MPC and a Matlab Toolbox. MPC has its origin in the early work by Richalet et al. (1978), which was followed by theoretical analysis by Rouhani and Mehra (1982).

3. *Application to Economic Data* The real challenge here is defining the problems to be studied, availability of suitable data and economic models, and the policy issues to be analyzed. Economists can provide valuable insights into these aspects for future interdisciplinary research on the applications of Optimal Control to economic systems.

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