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LAWRENCE R. KLEIN AND THE ECONOMIC FORECASTING – A SURVEY

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Abstract

Lawrence Robert Klein played a fundamental role in the genesis and development of econometric applications and forecasting. The work dedicated to forecasting earned him the 1980 Nobel Prize in Economic Sciences "for the creation of econometric models and their application to the analysis of economic fluctuations and economic policies".

His pioneering initiatives and his research that spanned over almost 70 years make L. R. Klein one of the key figures in macroeconomics and econometrics.

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Introduction

Lawrence Robert Klein was born in Omaha, Nebraska, USA in 1920 and grew up during the Great Depression. This fact had a powerful impact on his "intellectual and professional career" as he noted in an autobiography designed for the Nobel committee (Klein, 1992/1980).

After spending two years at the Los Angeles City College, L. R. Klein completed his undergraduate training at the University of California, Berkley and graduated in 1942, showing a remarkeble talent towards both mathematics and economics. During the following summer, L.R. Klein worked with George Kuznets and conducted one of his

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first exercises in applied econometrics that consisted in estimating demand functions in agricultural applications.

L. R. Klein pursued graduate studies at the Massachusetts Institute of Technology and earned his doctorate in 1944 having Paul A. Samuleson as thesis advisor. Working as Samuelson's assistant proved to be an "unforgettable experience" (Mariano, 1987) "that is very hard to duplicate anywhere in the world" (Klein, 1992/1980).

After completing his Ph.D., Klein joined the Cowles Commission at the University of Chicago where he made efforts in consolidating Jan Tinbergen model for the case of the United States, working alongside other key economists such as Haavelmo T., Koopmans T., Anderson T., Hurwicz L., or Arrow K.

During the following two years Klein engaged in a series of academic travels to Europe and in 1948 joined the National Bureau of Economic Research in a post doctoral grant, studying the saving behavior and the effects on wealth. In 1954, he started a four year collaboration with Oxford University Institute of Statistics analyzing methods of statistical inference. In 1958, he accepted an invitation from the University of Pennsylvania and taught in the Penn economics faculty until he retired from teaching in 1991.

In 1980 L.R. Klein was awarded the Nobel Prize "for the creation of econometric models and the application to the analysis of economic fluctuations and economic policies" which highlighted his fundamental role in the progress of macromodel building.

This paper investigates a series of the works of L.R. Klein following his major contributions to the field of modern econometrics.

Econometric Modelling from the Perspective of L.R. Klein

The earliest works of L.R. Klein focus on a discussion on the statistical determination of the investment schedule (Klein, 1943; Klein, 1944). In the same period, the author focused on developing his doctoral thesis *The Keynesian revolution,* which was published as a book in 1947. Klein investigates, develops and explains the central arguments contained in the *The General Theory of Employment, Interest and Money* demonstrating the validity and the innovation brought to the economic perspective.

Klein dedicates an extensive chapter to the analysis of the main reviews on *The General Theory* dissecting the arguments brought by Lerner, Reddaway, Pigou, Knight, Cassel, Hicks, Viner, Hansen or Hawtrey. He also contributed to several controversies that raged at the time, such as the effects of money wages on employment, the savings – investment controversy or the liquidity – preference theory of interest.

Another important landmark of Klein's work from the Chicago years is the book *Economic Fluctuations in the United States,* which was published in 1950. In this book, Klein follows in the footsteps of Tinbergen and succeeds in building comprehensive macroeconomic models which are also estimated econometrically.

After a series of theoretical preliminaries, Klein suggests three types of models, built on annual data specific to the US for the 1921-1941 interval.

Model I, considered as the simplest application, assumes the existence of consumer goods and two factors of production: producer goods and human labor.

The equations of the model are the following:

$$C = \alpha_0 + \alpha_1 \left(W_1 + W_2 \right) + \alpha_2 \Pi + u_1 \tag{1}$$

$$I = \beta_0 + \beta_1 \Pi + \beta_2 \Pi_{-1} + \beta_3 K_{-1} + u_2 \tag{2}$$

$$W_1 = \gamma_0 + \gamma_1 \left(Y + T - W_2 \right) + \gamma_2 \left(Y + T - W_2 \right)_{-1} + \gamma_3 t + u_3 \tag{3}$$

$$Y + T = C + I + G \tag{4}$$

$$Y = W_1 + W_2 + \Pi \tag{5}$$

$$\Delta K = I \tag{6}$$

Where:

C – consumption; I – investment; W_1 – private wage; W_2 – government wage payments; Y – output in constant dollars; P – profit in constant dollars; K_{-1} – stock of capital at the begining of the year

The second model found in Klein (1950) is designed to capture the influence of cash balances or lagged income on consumption and it is built around the following three equations:

$$\frac{C}{pN} = \alpha_0 + \alpha_1 \frac{Y}{pN} + \alpha_2 \left(\frac{Y}{pN} \right)_{-1} + \alpha_3 \left(\frac{M}{pN} \right)_{-1} + u \tag{7}$$

$$GNP = C + I' + G \tag{8}$$

$$GNP = Y + T \tag{9}$$

Where:

C – consumption in current dollars; Y – disposable income in current dollars; M – money supply in current dollars; I' – gross investement in current dollars; G – government expenditure; GNP – gross national product in current dollars; p – cost of living index; N – population; T – government receipts plus corporate savings plus business reserves minus transfer payments minus inventory profits; u – random disturbance.

Klein specifies that the endogenous variables are C, Y, GNP and the exogenous variables are: $\dfrac{I}{pN}, \dfrac{G}{pN}, \dfrac{T}{pN}, M$ and $\left(\dfrac{M}{pN} \right)_{-1}$ is a predetermined variable.

By combining equations (8) and (9) and replacing the result in equation (7) Klein obtains a reduced-form equation for which the method of least squares is unbiased and, thus, can be easily estimated.

$$\frac{Y}{pN} = \frac{\alpha_0}{1 - \alpha_1} + \frac{\alpha_2}{1 - \alpha_1} \left(\frac{Y}{pN} \right)_{-1} + \frac{\alpha_3}{1 - \alpha_1} \left(\frac{M}{pN} \right)_{-1} + \frac{1}{1 - \alpha_1} \left(\frac{I' + G - T}{pN} \right) + \frac{1}{1 - \alpha_1} u \tag{10}$$

The real gem in Klein (1950) is the third model, titled "large structural model", which is based on 16 equations, 16 endogenous variables and 13 exogenous variables. The main building blocks of model III as developed in Klein (1950) are listed below.

Demand for labor:

$$W_1 = \alpha_0 + \alpha_1 (pX - E) + \alpha_2 (pX - E)_{-1} + \alpha_3 t + u_1 \tag{11}$$

Demand for private producers' plant and equipment

$$I = \beta_0 + \beta_1 \left(\frac{pX - E}{q} \right) + \beta_2 \left(\frac{pX - E}{q} \right)_{-1} + \beta_3 K_{-1} + \beta_4 t + u_2 \tag{12}$$

Demand for inventories:

$$H = \gamma_0 + \gamma_1 (X - \Delta H) + \gamma_2 p + \gamma_3 p_{-1} + \gamma_4 H_{-1} + \gamma_5 t + u_3 \tag{13}$$

Demand for consumer goods:

$$C = \delta_0 + \delta_1 Y + \delta_2 t + u_4 \tag{14}$$

Demand for owner-occupied housing:

$$D_1 = \varepsilon_0 + \varepsilon_1 \left(\frac{r}{q_1} \right) + \varepsilon_2 (Y + Y_{-1} + Y_{-2}) + \varepsilon_3 \Delta F + u_5 \tag{15}$$

Demand for rental housing

$$D_2 = \zeta_0 + \zeta_1 r_{-1} + \zeta_2 (q_1)_{-1} + \zeta_3 (q_1)_{-2} + \zeta_4 i + \zeta_5 \Delta F_{-1} + u_6 \tag{16}$$

Demand-supply for dwelling space

$$\upsilon = \eta_0 + \eta_1 r + \eta_2 Y + \eta_3 t + \eta_4 N^S + u_7 \tag{17}$$

Rent ajustment equation:

$$\Delta r = \theta_0 + \theta_1 \upsilon_{-1} + \theta_2 Y + \theta_3 \frac{1}{r_{-1}} u_6 \tag{18}$$

Demand for active balances:

$$M_1^D = \iota_0 + \iota_1 p(Y + T) + \iota_2 t + \iota_3 p(Y + T)t + u_9 \tag{19}$$

Demand for idle cash balances:

$$M_2^D = \kappa_0 + \kappa_1 i + \kappa_2 i_{-1} + \kappa_3 (M_2^D)_{-1} + \kappa_4 t + u_{10} \tag{20}$$

Interest rate adjustment equation:

$$\Delta i = \lambda_0 + \lambda_1 E_R + \lambda_2 i_{-1} + \lambda_3 t + u_{11} \tag{21}$$

Output adjustment equation:

$$\Delta X = \mu_0 + \mu_1 (u_3)_{-1} + \mu_2 \Delta p + u_{12} \tag{22}$$

Definition of net national product:

$$Y + T = I + \Delta H + C + D_1 + D_2 + D_3 - D'' + G \tag{23}$$

Definition of private output exclusive of housing:

$$X = \frac{p(Y + T) - W_2 - R_1 - R_2}{p} \tag{24}$$

Definition of stock of capital:

$$\Delta K = I \tag{25}$$

Definition of rent payments:

$$R_1 = \rho_0 T \left(\frac{\upsilon N^S}{100} + \frac{\upsilon_{-1} N_{-1}^S}{100} \right) \frac{1}{2} \tag{26}$$

Sollow (1991) observes that one inovation brought by this model comes from the separate specifications for inventories of consumer goods and producer goods. Also, Sollow (1991) points out that Klein considers that residuals in the inventory equations drive changes in the output, and thus builds an output adjustment function.

Sollow (1991) makes another interesting observation regarding Klein (1950). The author comments on one of Klein's applications in which the wage rate is expressed as a linear function of unemployment, lagged unemployment, lagged wage and a time trend, pointing out that this might be the first econometric Phillips curve.

Before Klein (1950), models II and III had been used in a study on the formation of economic policies (Klein, 1947b).

In Klein (1947 c), the author compares three theories on the evolution of employment: the classical, the Keynesian and the Marxian in order to "indentify the necessary and sufficient assumptions that underlie each theory".

Klein's perspective is similar to that found in *The Keynesian revolution,* reasserting that the main distinctive feature of the Keynesian theory is the low interest-elasticity of the investment function.

De Vroey and Malgrange (2010) point out the fact that, according to Klein, the difference between a classical and a Keynesian analysis comes from the manner in which the overdetermination problem is solved. The authors note that, the classical solution can be defined as the Pigou effect (Pigou, 1934), which consists in a replacement of the saving-investment equation with the following one:

$$S(i, Y, M / p) = I(i, Y) \tag{27}$$

Considering that the current literature had a gap in the study of the rate of change of real fixed capital, Klein (1951) offeres a substantial study on the investment behaviour. In order to investigate the investment process from an empirical point of view, the author focuses on two types of investment sectors: railroad investment and the electric light and power invesment, and tries to identify the factors that influence investments in these sectors.

The main conclusions of the study point to the fact that investments are cleary influenced by the gross operating profits of the preceding year and that gross investment is influenced by the interest rate.

In his "On the Interpretation of Professors Leontief's System" (1953), L.R. Kleins targets a "more realsitic interpreatation" (Klein, 1953). The author develops a

theoretical model that charcterizes the logic of the input-output analysis and which eliminates the assumption that each economic sector can only generate a single output.

Klein succeeds in offering a technological interpretation of the input-output coefficients as structural parameters and concludes that these coefficients depend on the parameters of the factor demand and supply functions.

After the modelling experience gathered developing the monograph *Economic Fluctuations in the United States*, L.R. Klein focused on another monograph in collaboration with Goldberger (Klein and Goldberger, 1955) that meant the launch of the homonymous model.

The model is based on 15 structural equations accompanied by 10 other identities and relationships and was estimated by limited information maximum likelihood.

Klein considered the Keynesian system "an extremely useful pedagogic model", but at the same time "not adequate to explain observed behavior" (Klein, 1955) and highlighted the need for a dynamic model able to characterize processes over time.

Thus, the main challenge in Klein and Goldberger (1955) was to metamorphose the Keynesian theoretical background into an empirical and dynamic model.

Klein (1955) focuses on a methodology that transforms the Keynesian model into an empirical construction. The main challenge is again the search for a dynamic solution for the static Keynesian system.

The author starts from the classic Keynesian background and in order to emphasize the dynamic character uses a new form of the equation that relates the demand and supply of labor:

$$\frac{dw}{dt} = f\left(N^S - N^D\right) \tag{28}$$

Klein (1958) reviews the lag scheme launched in Koyck (1954) for the study of investment behavior. The author estimates several statistical parameters and discusses the suitability of the model for econometric applications.

Klein (1960) consists of a discussion on the efficiency of the estimation process in building econometric models and tackles several problems related to the use of the conventional least-squares methods.

In the chapter *A Postwar Quarterly Model: Description and Applications, in Models of Income Determination,* published as a part of the National Bureau of Economic Research volume *Models of Income Determination* (1964), Klein develops another extensive model, different than his annual predecessors, such as the Klein-Goldberger modelling scheme (Klein, 1964).

Klein identifies five major distinctive factors: a less aggregative nature, the presence of anticipatory data, explicit relations between inventories, sales, backlogs, and order flow, the use of the capacity concept and the clear expression of accounting identities in current prices.

The author splits the consumer expenditures into three cathegories (durables, nondurables and services) and provides quantification for the aggregate income as a precursor of consumption. For the investment equations, Klein divides capital

formations into producers' plant and equipment residential construction and inventory investment (Klein, 1964).

The model also incorporates three equations that relate to the non-wage income components covering: corporate saving, non-coporate to corporate income and depreciation.

Other key building blocks of the model are: an equation for production functions, specifications for wage, labour force, orders and backlogs, foreign trade, money and interest, prices and a number of identities.

In his Nobel Lecture of 1980 titled *Some Economic Scenarios for the 1980s*, Klein discusses a series of economic trends forecasted through the use of two econometric models: one for the United States and an aggregate model for the rest of the world based on the Project Link model.

For the case of the USA, the model forecast shows a constant growth pattern around the value of 3%. This tendency is accompanied by a higher inflation, higher interest costs and an elevated rate of unemployment. For the rest of the world, Klein detects a tendency of moderate growth and lower inflation for the industrial market economies. The author notes that in the case of developing countries the results are mixed and depend highly on country classification.

Klein and Coutiño (1996) considered the crisis that shook Mexico at the end of 1994. By estimating import and export equations on the basis of data with monthly frequency belonging to the 1982-1983 period, the authors offer extrapolations that suggest a milder contraction and a fast recovery in the following year.

Klein (2003) examines the flow-of-funds accounts given its role in the determination of interest rates across maturities and debt qualities. The author offers an analysis that can cast some light on the dynamics of relevant mortgage rates, dynamics useful in the understanding of capital formation in the real estate sector.

In the article *Measurement of a shift in the world's center of economic gravity,* published in 2009, Klein starts from the general idea that the 21st century brought a shift in economic strength from Northern America and Western Europe to Asia and the Pacific area. The author estimates the economic predominance position of Asia and other possible shifts that could lead to new centers of economic concentration. By studying aspects like economic activity, national economic accounts, demographic variables, education, health, life expectancy and the energy output, Klein concludes that new growth centers had emerged in the Asia-Pacific area during the last decade.

Klein's interest in the Asian economies was not launched by this paper, but date back to previous studies such as Marwah and Klein (1995), Klein (1998), Klein and Ichimura (2000), Klein and Palanivel (2001), Klein and Özmucur (2003) or Klein (2004).

For example, the work in Klein and Palanivel (2001) consists in a thorough analysis of India's development strategies and discusses its economic performance and its perspectives.

In the final section of the paper the authors develop a forecast scenario for the following five years using a model consisting of nine blocks of equations. The first five blocks characterize a sector of the economy (agriculture, manufacturing,

infrastructure, services and public administration) while the others deal with consumption, monetary sector, trade and balance of payments and, finally, macro aggregates and identities.

The model predicts that in certain conditions suggested by the authors, India's economy can achieve a higher growth pace with a decent inflation rate.

Another interesting observation is that India's trade to GDP ratio increased in the analysed period, but not to the same extent as in other developing countries, such as China.

In a 2010 paper, Klein and Özmucur investigate the potential role of consumer and business surveys in economic forecasting. The authors use a benchmark AR (12) model and a series of ten other models based on indices constructed from answers deriving from survey questions.

Klein and Özmucur (2010) conclude that surveys are able to improve forecasting performance by "adding explanatory power of a model based on only past values of manufacturing growth".

Klein, Kushnirsky, and Maksymenk (2012) perform a macroeconomic study on Ukraine's economic growth. They build two structural modelling approaches, a high frequency model based on monthly observations and low frequency model that assumes annual observations. Their forecast on ten endogenous macroeconomic variables for Ukraine (GDP, capital stock, labor force, employment, household final consumption expenditure, private investment, exports of goods and services, imports of goods and services, wages and the official exchange rate) reveals a mild growth for all of them, except for employment and export in the 2011-2015 period.

Conclusions

The achievements of L. R. Klein represent an innovative, pioneering and singular contribution to econometrics and macroeconomics. His work on large-scale economic model construction changed both the academic perspectives and political decision making on a global scale.

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