Fifty years system dynamics of Japanese economy

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1. INTRODUCTION

I am going to tell a story about fifty years system dynamics of Japanese economy, forty years as a history and ten years as a futurology. There is a rich field in such adversities as the bubble inflated and released, double decade of slump, troublemaking bankruptcies of banks, and so on. It seems too much to warn against coming crises in the near future. Instead I almost take the place of fortune tellers to dandle people as a child, because the ultimate purpose of system dynamics modeling & simulation, I think, is to utter self-fulfilling prophecies in order to stir up them to be better off.

To begin with, I set the horizon of this paper. The following four table functions of time complete the whole. In the year t Japanese national economy aggregate the total products less intermediaries as valued $y(t)$ trillion yen in current prices, usually called the nominal GDP, while the total demand $z(t)$ trillion yen consists of consumption C, investment I, and other expenditures G that include government consumption, construction of residence, net change in inventories, and exports less imports of goods or services. All figures are drawn from the statistical data storage of the OECD[1].

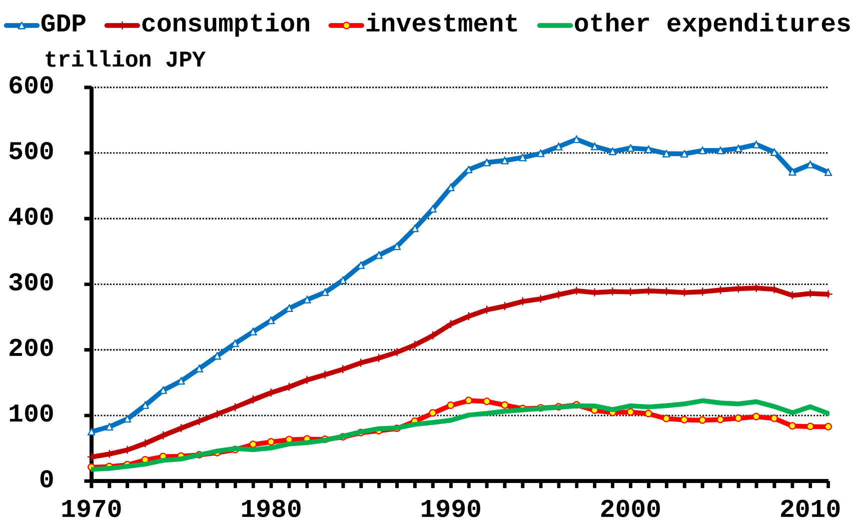

Fig.1-1 all statistical data used in this paper

They say that Japanese economy has been depressed since 1990 to date and call this period as the lost double decade. Someone says that there is nothing worried about because of the still growing GDP in real terms caused by the deflator effect of prices for the ordinary market basket, whereas other claims that the deflation observed in no other advanced countries in the world is itself the sole problem of Japanese economy of its own. Any claimer is based on each mental model to extract his assertion, but seldom tables the model itself unless he is at an academic discussion.

Only to observe the data as given in Fig.1-1, anyone should have required some model for interpretation of those series of figures into dynamic phenomena in the real world. Even when I do

[1] Downloaded from the http://stats.oecd.org/Index.aspx?datasetcode=SNA_TABLE1. All data are extracted on 27 Oct 2013 06:49 UTC (GMT) from OECD.Stat. and corrected by author to equate supply to demand by adding the discrepancies to the other expenditures and supplemented with the series of capital investment during 1970-1979 which were in the previously extracted data in 2003.

not know how various such mental models are there around the table, I may have one of them transformed into a set of equations that enables you to enjoy computer simulations to get prepared for some story telling about the past, present, and future performances of Japanese economy, with some comprehension about the cause of stagnation effects for these twenty years or more. Albeit that may not be better than a story nor a scientific discovery, the most important is for you to create alterative stories to tell yourselves. Writing and telling new stories for yourselves augment the probability of your coming across the counter-intuitive behaviors of the system. Presumably this is the only way to the revision of any mental model shared by people, in other words, to attain social learning in the process of decision making, which may result in accretion to national economic profitability also in Japan.

2. PROTOTYPING

Macroeconomic category of capital stock $x(t)$ as a composite of durable assets is accumulated by capital investment I as an aggregate result of all firms' decision making each of which maximizes each profit. Capital investment is composed of two independent decisions of each other, one is replacement of equipment $x(t)/T_D$ and the other is net investment $x'(t)$, where T_D is average duration period of total asset and $x'(t)$ designates derivative of x by time at time t. If retirement of durable assets R is equal to replacement of equipment i.e. $R.\mathrm{KL}=x.\mathrm{K}/T_D$, then the first one of level equations of the model written down as $x.\mathrm{K}=x.\mathrm{J}+\mathrm{DT}\times(I.\mathrm{JK}-R.\mathrm{JK})$ only means the definition of total differential in mathematical terms $dx = x'dt$, because $I.\mathrm{KL}=x.\mathrm{K}/T_D+x'.\mathrm{K}$. Although you may say that x is stock, the derivative of which is flow, I do not like to define x' as a rate but an auxiliary variable lest I should write the equation as $I.\mathrm{KL}=x.\mathrm{K}/T_D+x'.\mathrm{JK}$.

The second of level equations of the model is a composite of assets under construction $u(t)$, the inflow of which is newly planned investment P whereas the outflow $u(t)/T_K$ is flowing through the process of exponential delay with average construction period T_K out into capital stock as net investment $x'(t)$, that is, $u.\mathrm{K}=u.\mathrm{J}+\mathrm{DT}\times(P.\mathrm{JK}-u.\mathrm{J}/T_K)$, $x'.\mathrm{K}=u.\mathrm{K}/T_K$.

Planning process of capital investment is unlike those in the planned economies, open to all people with freedom of setting goals, and as a result subject to law of large numbers so that randomness of individual timing to complete his goal setting decision causes aggregate dynamic behavior of the whole as the first order exponential delay $P.\mathrm{KL}=(w.\mathrm{K}-x.\mathrm{K})/T_A$, where T_A is average length of adjustment period. $w(t)$ designates the level of capital required to attain the goal to meet demand $w.\mathrm{K}=v\times z.\mathrm{K}$, where v is capital to production ratio, in other words inverse of capital turnover rate, or average time period taken for production with turning all capital once over. It should be noted that v is measured by units of time, 'years' in this case. Despite that demand $z(t)$ is properly dimensioned as flow, allow me again to define it as one of auxiliary variables in order for its time subscript to be K in the right hand side of other equations of the model. Demand is composed of consumption, investment, and other expenditures, that is, $z.\mathrm{K}=C.\mathrm{K}+I.\mathrm{K}+G.\mathrm{K}$.

Aggregate total of all products $y(t)$ is distributed as income among people, which they spend on their consumption written as $C.\mathrm{K}=c\times y.\mathrm{JK}$, where c is average propensity to consume and $y.\mathrm{JK}$ is annual flow rate $y(t-dt)$ fixed as constant during the time interval $[t-dt,\ t)$ for any given t. The precedence relation between production and consumption in successive determination is crucial to system dynamics formulation excepting simultaneous equations out of modeling. Later you will see an equilibrium condition such as $y.\mathrm{KL}=z.\mathrm{K}$, by which you mean that production decision be made slightly after the determination of demand by consumers, investors, and others. Alternatively you may formally use an exponential smoothing equation defining the recent production Y and rewrite the consumption function into $C.\mathrm{K}=c\times Y.\mathrm{K}$, where $Y.\mathrm{K}=Y.\mathrm{J}+\mathrm{DT}\times(y.\mathrm{JK}-Y.\mathrm{J})/\mathrm{DT}$ and $y.\mathrm{KL}=x.\mathrm{K}/v$. Thus we complete a prototype model of national economy. The equilibrium condition mentioned above is not required to be held at the first stage of prototyping. See Appendix 1, and you will find the flow diagram of the model.

Taking $dt\to 0$ you obtain the following system of equations.

1) capital $x'=u/T_K$

2) asset under construction $u'=(w-x)/T_A-u/T_K$

3) production $y=x/v$

4) demand $z=cy+x/T_D+x'+G$

5) required level of capital $w=vz$.

For given parameters; capital to production ratio v, propensity to consume c, duration of capital asset T_D, and exogenous variable $G(t)$ as a function of time with delay constants T_A and T_K, the prototype of our system model is closed. This prototype is well known as multiplier-accelerator model in ordinary textbooks of both macroeconomics and system dynamics[2]. It is easy to solve the model to get dynamic behaviors of x, y, z, u, and w as functions of t because the system can be reduced to such a single variable's second-order linear ordinary differential equation as

$$a_0 x'' + a_1 x' + a_2 x = G(t),$$

where $a_0 = T_A T_K/v$, $a_1 = T_A/v - 1$, $a_2 = (1-c)/v - 1/T_D$. Characteristic values can be found as a solution to an algebraic quadratic equation as $(-a_1 \pm \sqrt{a_1^2 - 4a_0a_2})/(2a_0)$. If exogenous variable is given as fixed constant $G(t) = G_0$, then $x(t) = G_0/a_2$ is a particular solution to the differential equation, which should be the equilibrium level of capital if the solution to a homogeneous differential equation $a_0 x'' + a_1 x' + a_2 x = 0$ converges to zero along with $t\to\infty$.

3. REPRODUCING STATISTICS

If any model simulates the real Japanese economy for these forty years, all values of variables in the model calculated by computer should successfully trace upon the series of actual figures of data in the real world. The first challenge of our modeling & simulation is to reproduce the whole table of

[2] In economics see Allen (1967) *Macro-economic theory*, and in system dynamics see Randers (1976) *Elements of the system dynamics method* for instance.

statistics designated in Fig.1-1 by specifying all parameters and initial conditions in the prototype of the model. Preliminary discussion suggests that taking $G(t)$ of the historical data as given you should successfully simulate the behavior of capital $x(t)$ during the same domain.

Try system dynamics simulation setting $c = 0.6$, $v = 2$, $T_D = 10$, $T_K = 1$, $T_A = 2$ as parameters of the prototype model, and you will get the following output immediately. You may take it for granted that the output of computer simulation does not always reproduce the actual statistics. It is also quite natural to think that there should be some reason in the reality why the calculated values of production $y(t)$ and demand $z(t)$ trace the actual GDP for the first twenty years not to go on beyond 1990. Because the results are seemingly quite simple and systematic, economists would say that in the era after the collapse of the bubble at the end of the 80s, Keynesian economic policy of effective demand turned out to be no longer effective. System dynamists would search for causal loop that brought about such unfavorable results to revise his model for simulation.

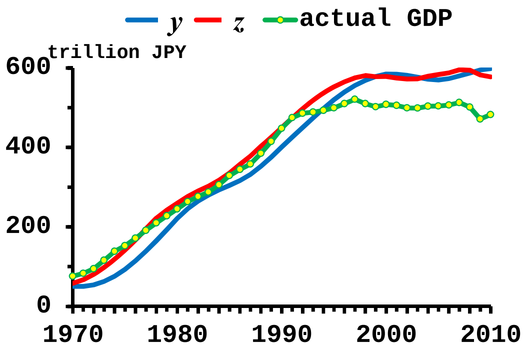

Fig.3-1 output of simulation

Let us back to the formulation of the goal setting in the decision process of capital investment. The prototype assumed that the level of capital required to attain the goal to meet demand w.K=v×z.K, where v is capital to production ratio and $z(t)$ is total demand. You may immediately realize that the assumption of v as a constant for forty years is suspicious. Secondly you may wonder if v×z suffices the capital required to attain the goal. Since there is no data of capital to production ratio in the database, I estimated the series of $\{v(t)\}$ according to the procedure indicated in Appendix 2. Secondly I revised the definition of required capital as w.K=v×(z.K+A.K), where A is additional demand that reflects the aggregate effect of all decision makers' speculation for the future.

$A(t)$ is estimated by backward induction from Fig.1-1 as follows. For given $\{I(t)\}$ and $\{x(t)\}$[3], calculate $\{u(t)\}$ such that $u(t) = T_K \times (I(t) - x(t)/T_D)$, and you will get $P(t)$ that is equal to

$$\{u(t+dt) - u(t)\}/dt + I(t) - x(t)/T_D.$$

Then calculate $\{w(t)\}$ such that $w(t) = P(t) \times T_A + x(t)$, and you will get

$$A(t) = w(t)/v(t) - z(t),$$

where $\{v(t)\}$ is already calculated in Appendix 2 and $\{z(t)\}$ is drawn from Fig.1-1.

Thus the preparation for revised simulation is completed. Correct the equation of required capital

[3] $I(t)$ is drawn from Fig.1-1, but there is no data given for $x(t)$. I estimated the series of $x(t)$ previously in order to estimate $v(t)$. See Appendix 2.

and you will get the revised simulation output as in Fig.3-2. In this case ***c*** is slightly adjusted to 0.57. Observe that three graphs are approaching to each other. This convergence is brought about by introducing both variables ***v*(*t*)** and ***A*(*t*)** into the prototype, either of which solely applied never suffices the favorable effect.

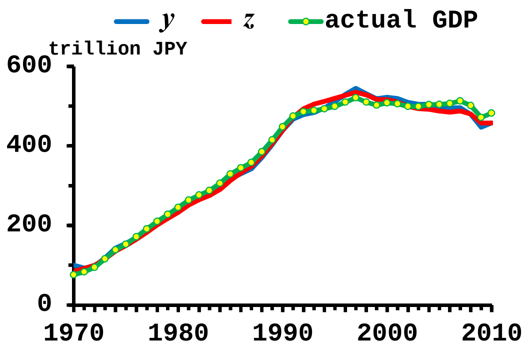

Fig.3-2 output of simulation revised

Besides, if you introduce series of ***c*(*t*)** calculated by ***C*(*t*)/*y*(*t*-*dt*)** from Fig.1-1, then you can get the perfect reproduction of statistics given at the beginning, calculated in the end. Final output of this analysis is the model itself that perfectly reproduces forty years historical data of Japanese economy from 1970 to 2010, which is represented in set of dynamo equations at Appendix 3.

4. FORCASTING

System dynamics modeling and simulation so far just shows us the way how to read the historical data if any of a national economy. If you are successful in reproducing statistics as carried out in the last section of the paper, then you are at the point of developing the future performance of the economy as a prediction with computer simulation of the system using the same model that telling the story of the past. In this case you have only to give the stream of figures to four exogenous variables; ***G***, ***A*** ***v***, ***c***, if you are undertaking to procure the prediction of all variables ***x***, ***y***, ***z***, ***u***, ***w*** consisting in the system. For instance set additional demand equal to zero and have other exogenous variables keep the same levels as those in 2011, and you will get the prediction of future GDP of Japan displayed in Fig.4-1. The rectangular area of the left graph is enlarged into the right one.

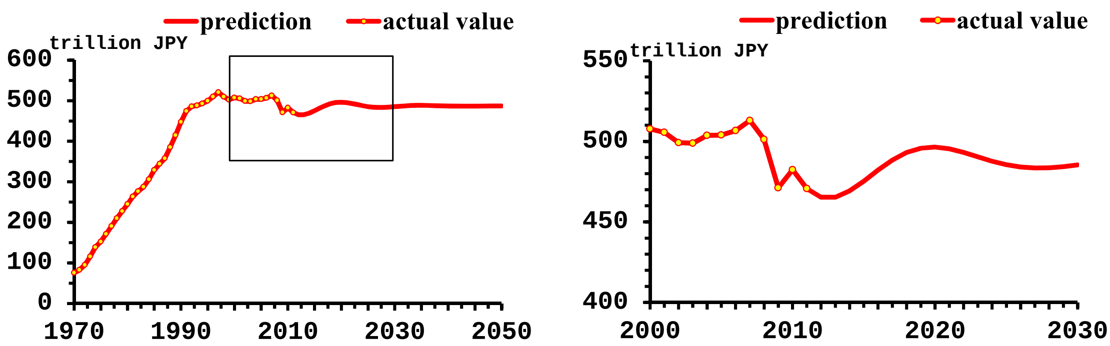

Fig.4-1 prediction of GDP for the future

Now in 2014 we are at the entrance of the prosperity period lasting to 2020 regardless of whether the

Olympic Games might be held at Tokyo or not.

5. POLISHING UP RESULT

On the occasion of the last simulation, I assumed without any reason at all that for $t > 2010$ $A(t) = 0$ and $v(t) = 1.9835$ are fixed forever. To claim that prosperity lasts until 2020, you have to comment on these strong assumptions. So do I even with intention to claim otherwise. Let us observe the behaviors of additional demand and capital to production ratio in the interval of the interpolation of variables from 1970 to 2010. See Fig.5-1 and 5-2, and you may find that it is not so ridiculous to assume the steady state on these variables during the period of extrapolation beyond 2011. However, any specific value is equally likely for additional demand and turnover rate depends on the situation of business cycle so that arbitrary suppositions on these two variables are unacceptable.

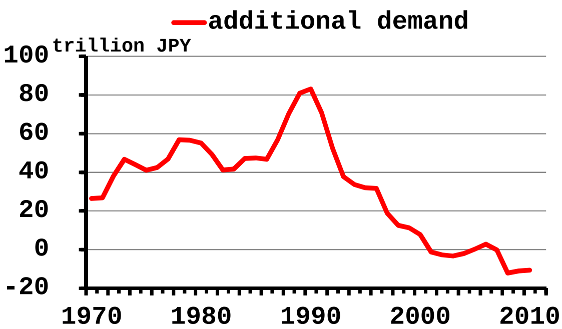

Fig.5-1 additional demand estimated

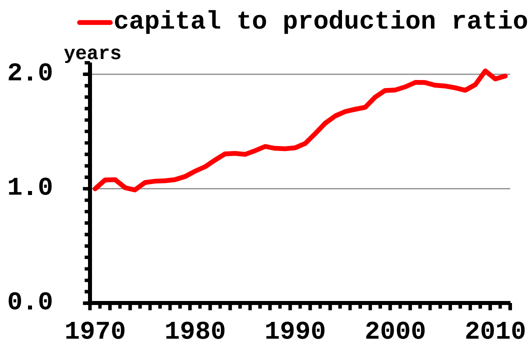

Fig.5-2 capital to production ratio estimated

Instead of taking these data as exogenous variables, it is my merit to consider causal loops on them via endogenous variables in the model. Capital to production ratio is defined as $v(t) = x(t)/y(t)$. Since the numerator is stock and denominator is flow, it is inconvenient to write dynamo equation as it is. The equation $v.\mathrm{K}=x.\mathrm{K}/y.\mathrm{JK}$ is not correct because you have already utilized the equation $y.\mathrm{KL}=x.\mathrm{K}/v.\mathrm{K}$. Consistency requires that $v.\mathrm{K}$ should be $x.\mathrm{K}/y.\mathrm{KL}$ contrary to the requisite for acceptance of the compiler. Correct answer to this problem is to use exponential smoothing to define as $v.\mathrm{K}=v.\mathrm{J}+\mathrm{DT}\times(x.\mathrm{J}/y.\mathrm{JK}-v.\mathrm{J})/T_V$, where T_V is smoothing constant. If you set $T_V=\mathrm{DT}$, then capital to production ratio used in the equation of required capital $w.\mathrm{K}=v.\mathrm{K}\times(z.\mathrm{K}+A.\mathrm{K})$ is the recent information of capital to production ratio in the current production process. Truly you need delay when you want to realize the current effective value of capital to production ratio. Now you are requested to give initial condition to exponential smoothing function and, at the same time, to refrain from using the equation $y.\mathrm{KL}=x.\mathrm{K}/v.\mathrm{K}$ not because of the requisite for any syntax exception. If you dare use it anyway, you are only to obtain the simulation output where $v(t)$ remains constant fixed at the initial value given by yourself. Then the equilibrium condition $y.\mathrm{KL}=z.\mathrm{K}$ add up to be introduced for the first time.

Now let us turn to additional demand. A little more analysis is required about capital investment decision made by the firm. There are at least two categories of inducement, one is optimization and the other is speculation. For given level of capital and volume of production each firm determines net capital investment in order to maximize his profit. Depending on production technology, net capital investment may be a decreasing or increasing function of capital and production. Aggregate amount of capital investment decisions may or may not reflect the individual optimization behaviors; it must result in macro dynamic behavior of total demand. Decision makers of the firms observe macro behavior of demand to forecast the future increase of opportunity and to augment his own investment. If there exist some macro investment function, it should be a function of capital $\boldsymbol{x}(t)$, production $\boldsymbol{y}(t)$, and increase in demand $\Delta z = z(t) - z(t-1)$. However rational it might be, the future value of demand should be expected on the basis of all data then available at time $\boldsymbol{t}$.

Suppose that macro investment function determines the level of appropriate net investment $N(t)$. Difference between appropriate net investment and actual net investment consists in additional demand. Since you have already calculated additional demand $\{A(t)\}$, it is straight forward to estimate the series of appropriate net investment $N(t) = A(t) + u.\mathrm{K}/T_K$. indicated in Fig.5-3.

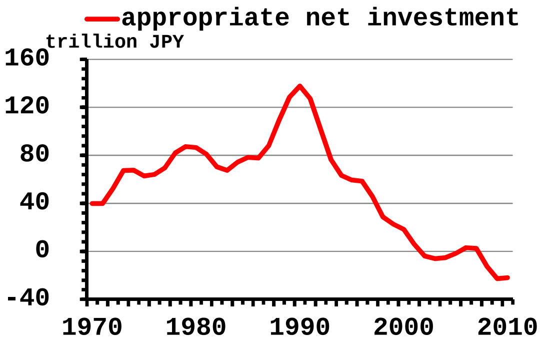

Fig.5-3 appropriate net investment

Try to estimate the parameters of regression model: $N.\mathrm{K} = b_0 + b_1 \times x.\mathrm{K} + b_2 \times y.\mathrm{JK} + b_3 \times \Delta z.\mathrm{K} + \varepsilon.\mathrm{K}$, by the ordinary least square method, and you will obtain the following results.

ANOVA					
	df	SS	MS	F	Significance F
Regression	3	68473.9	22824.62	234.79	3.98E-24
Residual	37	3596.9	97.21		
Total	40	72070.7			

Regression Statistics	
Multiple R	0.974727
R Square	0.950092
Adjusted R Square	0.946046
Standard Error	9.859678
Observations	41

Coefficients	Expected Value	Standard Error	t Stat
b_0	0.993089	5.401350	0.183859
b_1	-0.456664	0.030592	-14.927634
b_2	0.869127	0.059585	14.586355
b_3	1.061388	0.178848	5.934570

$\boldsymbol{F}$ statistics in the table of the analysis of variance says that the regression surface is significant. All estimates of the regression coefficients are significant, while the intercept b_0 may or may not be zero. It is quite safe to say that appropriate net investment N is a decreasing function of capital $\boldsymbol{x}$, whereas increasing function of production $\boldsymbol{y}$, and the accelerator i.e. coefficient for $[z(t) - z(t-1)]$ is around 1.

Hence it can be concluded that the introduction of additional demand into the model makes sense. There is no statistical data of appropriate net investment at all. It is required in scientific research that any concept that brings effective improvement to the model should be substantiated by hard data.

I believe in this case suffices the requirement.

The conclusion of the stochastic inference suggests an interpretation of statistics into history. If you trace the appropriate net investment of Japan with reference to its regression, you have an impressive survey of a nation's life full of ups and downs in history. See Fig.5-4. You may dislike the serial correlation in the series of residuals, but it eloquently tells us a long story as scene-by-scene.

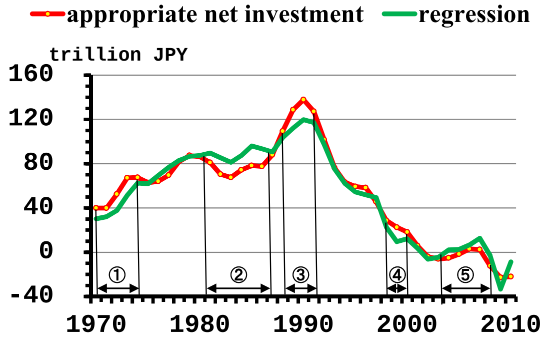

Fig.5-4 appropriate net investment and regression

Observe five sections of time period from 1970 to 2010 and recall the drama. Japanese exporting machine took advantage of energy saving technology in the first section of the period, which caused yen rise higher and higher to the recession in the second time section. Distinguished is the third scene by the bubble economy, which is followed by long lasting stagnation to date. The Bank of Japan announced to start the zero-interest-rate policy at the turn of the century, which had a little effect in the fourth scene. Finally in the fifth scene the mega-bank system of Japan metamorphosed into the realignment largely controlled by government. Visually discrepancies from the regression line appeared to display each scene.

Simulation output in Fig.5-5 summarizes Japanese economy in the contemporary history. Just one sentence is enough to sum up the result; "Japan has attained her goal". They lived happily ever after.

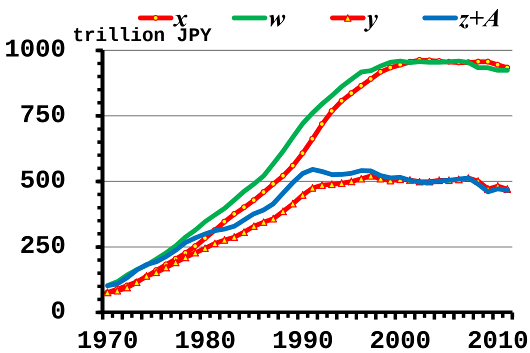

Fig.5-5 Japanese economy 1970-2010

It is one hundred and forty five years since Japan began to catch up the western developed countries. The people have laboriously accumulated capital $\boldsymbol{x}$ heading towards their own goal targeted as $\boldsymbol{w}$ in order to fill their effective demand $\boldsymbol{z}$ plus aspiration $\boldsymbol{A}$. The last forty years they have done it.

6. ENJOYING SIMULATION

Suppose you bring appropriate net investment function into the prototype model. Let us convert the equations of the model into new one.

1) Introducing the equilibrium condition: Convert “y.KL=x.K/v.K” into “y.KL=z.K”.

2) Redefining v: Convert “v.K=**TABXL()**”[4] into “v.K=v.J+**DT**×(x.J/y.JK-v.J)/T_V”.

3) Redefining A: Convert “A.K=**TABXL()**” into “A.K=N.K-u.K/T_K”.

4) Defining appropriate net investment: Add an equation “N.K=b_0+b_1×x.K+b_2×y.JK+b_3×Δz.K”.

5) Defining increase in demand: Add an equation “Δz.K=z.K-s.K”.

6) Defining demand in previous year: Add an equation “s.K=s.J+**DT**×(z.J-s.J)”.

If the system converges into the equilibrium point, then the stationary solutions are $x(t)=x_0$, $v(t)=v_0$, and $z(t)=z_0$, which are calculated as follows:

7) Stationary solution for x is calculated as “x_0.K=(b_2×G.K+b_0×(1-c))/(-b_2/T_D-b_1×(1-c))”.

8) Stationary solution for v is calculated as “v_0.K=x_0.K×(1-c)/(x_0.K/T_D+G.K)”.

9) Stationary solution for z is calculated as “z_0.K=x_0.K/v_0.K”.

10) Set the parameters at T_V=0.5, b_0=1, b_1=-0.5, b_2=0.5, b_3=1.

11) Set the initial conditions at x=x_0, u=0, v=v_0, z=z_0, s=z.

12) Change “**DT**=1” to “**DT**=0.25”

13) Set “G.K=G_0+**STEP**(G_1,10)”, “G_0=100”, “G_1=20” and run,

and you will get the output as displayed in Fig.6-1.

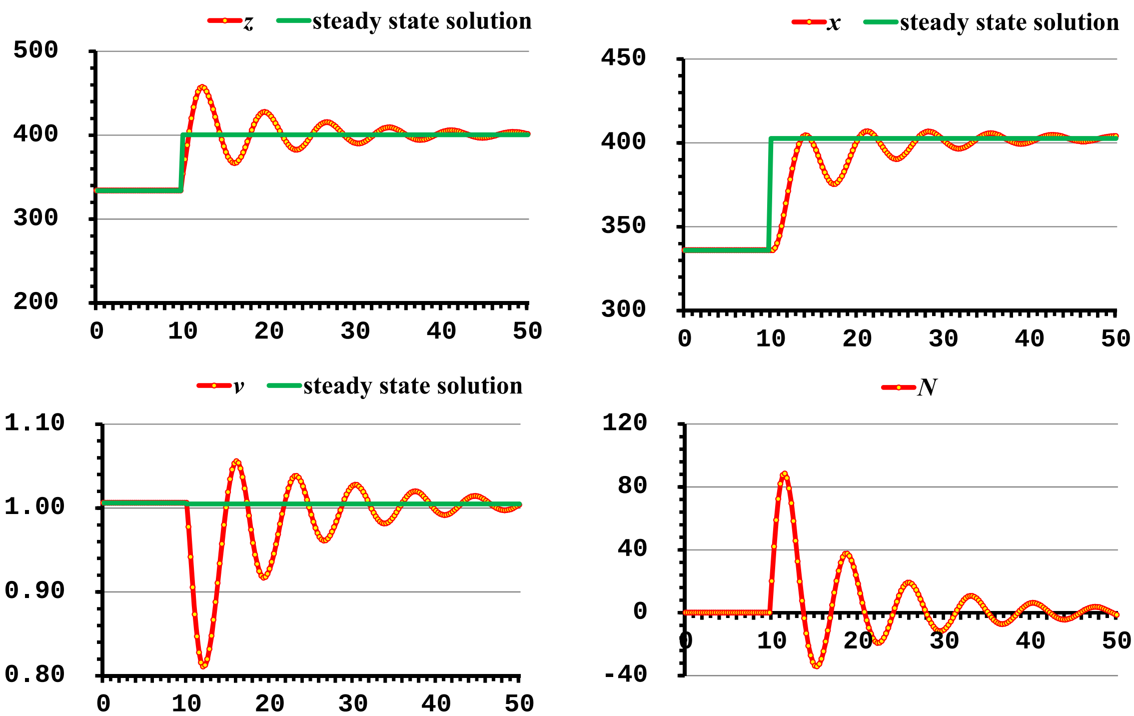

Fig.6-1 simulation output of the model with appropriate net investment function

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4 See Appendix 2.

Observe the stationary level for N should be zero; i.e. necessary condition for convergence of the system. As you observed in the previous section, you can get to the conclusion that calculated prediction curves in the simulation output can always reproduce the statistics during the interpolated period and that beyond the last point of time they go on to trace their own paths during any given interval of extrapolated period regardless of how they reached the last state by the time when they start afresh. The behavior of reaching the new goal they set themselves for the future can be calculated according to the parameters and exogenous variables as you see above. Whether the condition for convergence should be satisfied or not is dependent on estimated values of parameters.

Therefore the reasonable estimation is crucial to forecasting and policymaking. The requisite in this context is elaborate modeling and simulation with insightful consideration of the systems. You must get more accustomed to SD modeling and simulation, which should give you a better insight into the future. With this hackneyed expression the story is almost happily ending, but it is not that simple. Counter-intuitively, you might have noticed that the simulation output you see above is very sensitive to errors in estimation of regression parameters b_1, b_2, and b_3. For instance see below.

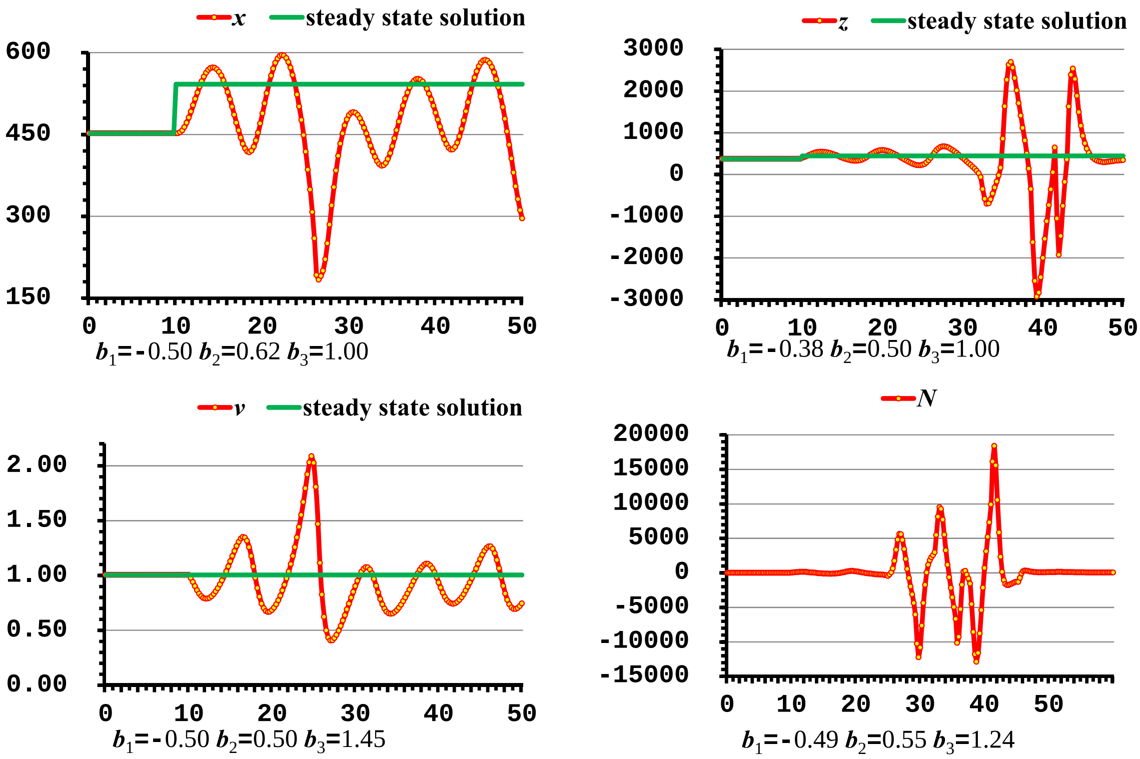


Fig.6-2 sensitive behaviors to parameter estimation errors for b_1, b_2, b_3

When you thought that what if capital to production ratio be an endogenous variable, nonlinearity was introduced into the prototype that had been a system of linear equations. Chaotic behaviors observed in Fig.6-2 are brought about by nonlinearity in formulation. Either the real economy or the model formulated includes chaos in its structure. If either does it, regression analysis for stochastic estimation of parameters makes no sense, because however precisely may you calculate those parameters' expected values, you could not specify the confidence interval of any variables you forecasted. The point in the parameter space (b_0, b_1, b_2, b_3) indicated by the regression analysis in the previous section is located out of the region where you may expect that the locus of the point in the behavioral space $[x(t), z(t), v(t), N(t)]$ approaches to $(x_0, z_0, v_0, 0)$ along with $t \to \infty$. The important fact thus found or otherwise does not make any sense, when the model or the reality implies chaotic behaviors of the system whichever the case it might be.

I must say that regression surface by no means substitutes for the functional relationship but provides a black box intermediating appropriate net investment and other variables. Mistake lies in the process of equation writing that deems its regression to capital, production, and demand as a function of them. Correct revision of the prototype should be carried out by probing the box that is nothing other than the decision process of capital investment in itself. That shall be discussed some other day.

7. CONCLUSION

The purpose of this paper is to tell a story of fifty years system dynamics of Japanese economy, which I have done. There are so many stories other than mine told by historians, economists, journalists, politicians, and so on. Variety is important especially in policy argumentation of, by, for the people. Every story teller has his own mental model, of which on the basis he constructs the argument. He seldom discloses his mental model not only to the public, but also to himself because he has no information of his own model. If all participants in policymaking process talk of their mental models to each other, there should be much improvement on policymaking itself, because such conversation augments likelihood for them to encounter the occasion of stimulating themselves to make their model revised. Revision of mental model is the only way to the social learning. With it the whole is better off. I intended to demonstrate a manner of storytelling with disclosing the mental model by myself. The latter I don't know is successful or not. I do hope that modeling method and software technology are still more innovated to bring about improvement on mental model disclosure and to encourage people to take an active interest in revision of mental model shared by themselves. Storytelling with disclosing the mental model takes a crucial role in that way. I believe.

Reference

This paper is written mainly with reference to the following three papers;

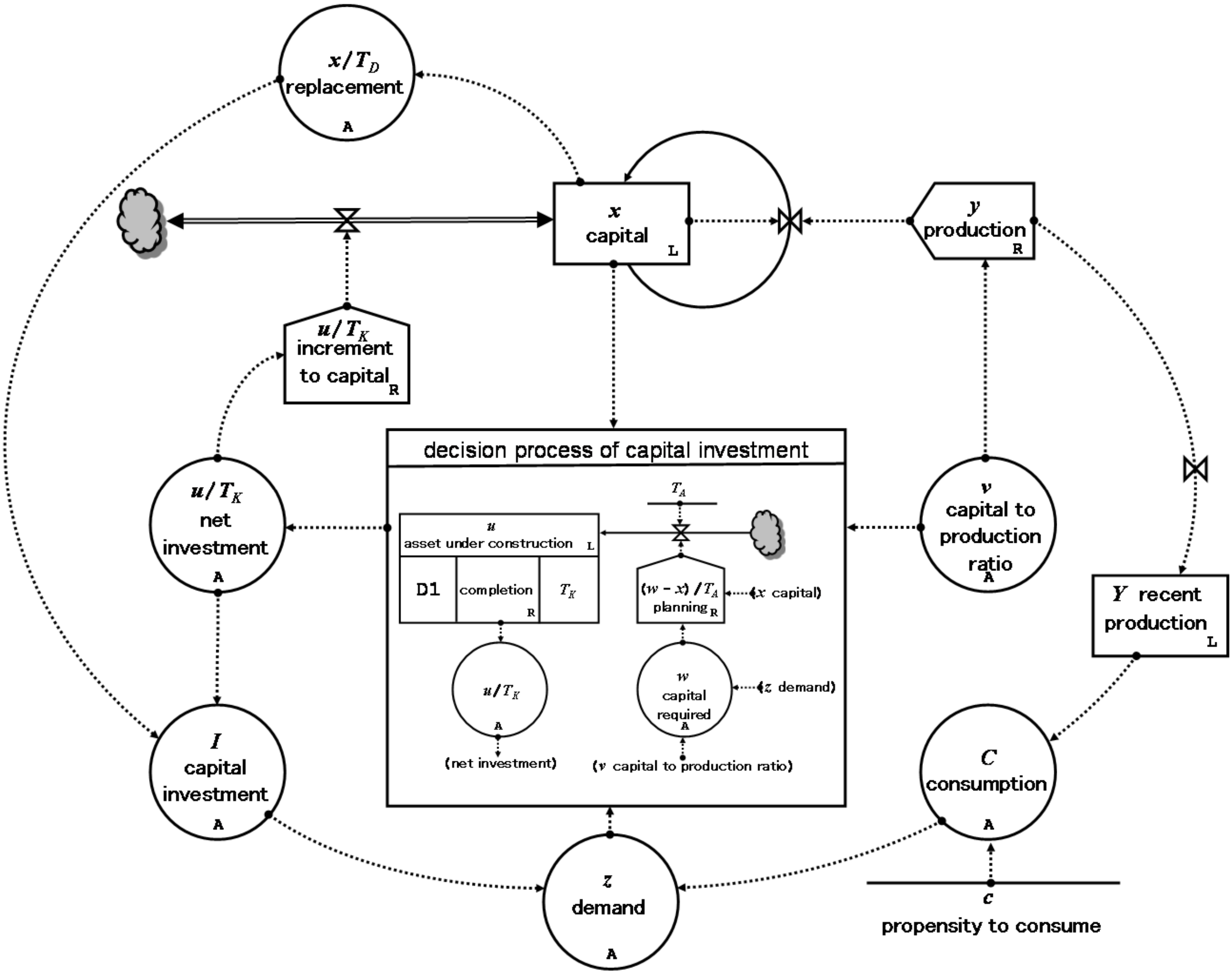
[1] Hidenori Kobayashi (2010) "Structural change in Japanese economy with respect to capital investment decisions", *Japanese Journal of System Dynamics*, Vol.9.

[2] ___________________ (2009) "Extensions of macroeconomic modeling & simulation", *Japanese Journal of System Dynamics*, Vol.8.

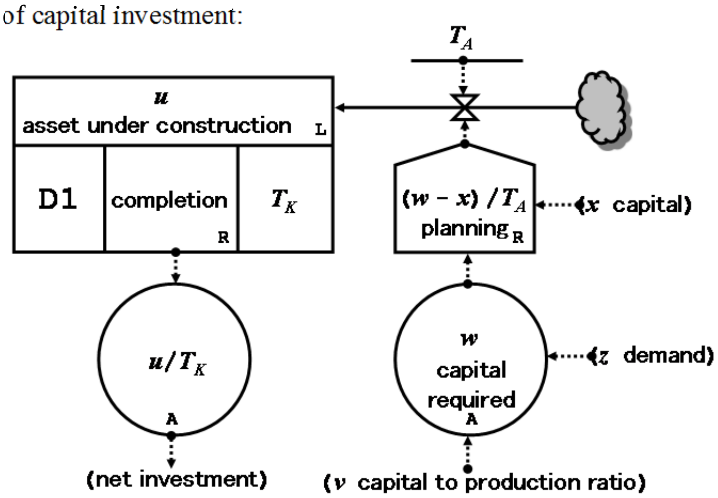
[3] __________________ (2005) "Perspective of Japanese economy in the twenty-first century" *Japanese Journal of System Dynamics*, Vol.4.

Appendix 1

Flow diagram of the prototype:



Decision process of capital investment:



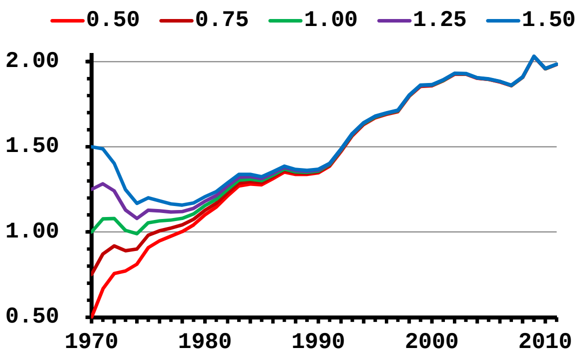
Appendix 2

Estimation of capital to production ratio $\boldsymbol{v}$:

For given any $\{y(t)\}, \{I(t)\}$;

1. Set temporarily the initial value of $\boldsymbol{v}$: $\boldsymbol{v}(0) = \boldsymbol{v}_0$
2. Calculate the initial value of capital $\boldsymbol{x}$: $\boldsymbol{x}(0) = \boldsymbol{v}(0) \times y(0)$
3. For $k = 1$ to 40 calculate successively $x(k) = x(k-1) + DT \times \{I(k-1) - x(k-1)/T_D\}$
4. For $k = 1$ to 40 calculate successively $v(k) = x(k) / y(k)$
5. Go to 1.
6. For alternate v_0 trace the series of $v(t)$ on the same coordinate system.
7. Select one line out of all graphs drawn in 6.

For example see Fig.A2. Seeing the graphs you probably understand that no matter which line you might select, $\{v(t)\}$ is significantly the same from 1990 onward.



Appendix 3

List of DYNAMO equations of the prototype:

L x.K=x.J+DT×u.J/T_K

R y.KL=x.K/v.K

A z.K=c.K×y.JK+x.K/T_D+u.K/T_K+G.K

L u.K=u.J+DT×(((w.J-x.J)/T_A-u.J/T_K)

A v.K=TABXL(SHEET2!H4)

A w.K=v.K×(z.K+A.K)

A A.K=TABXL(SHEET2!Q4)

A c.K=TABXL(SHEET2!R4)

A G.K=TABXL(SHEET2!E4)

C T_D=10

C T_K=1

C T_A=2

N x=75.5795

N u=13.5540

N TIME=1970

PLOT y,z

SPEC DT=1/LENGTH=40/PRTPER=1/PLTPER=1

* **TABXL( )** is a table function that refers any column of the Excel worksheet. This function is available when you use the file named “DYNAMOPⅢ” attached, which can also be downloaded from “ http://policysciences.jp“.

Open the attached file with enabling macros and run on the work sheet Dyna1.

Appendix 4

List of DYNAMO equations of the prototype revised:

L $x.K = x.J + DT \times u.J / T_K$

R $y.KL = z.K$

A $z.K = c.K \times y.JK + x.K / T_D + u.K / T_K + G.K$

L $u.K = u.J + DT \times ((w.J - x.J) / T_A - u.J / T_K)$

L $v.K = v.J + DT \times (x.J / y.JK - v.J) / T_V$

A $w.K = v.K \times (z.K + A.K)$

A $A.K = N.K - u.K / T_K$

A $N.K = b_0 + b_1 \times x.K + b_2 \times y.JK + b_3 \times \Delta z.K$

A $\Delta z.K = z.K - s.K$

L $s.K = s.J + DT \times (z.J - s.J)$

C $c = 0.6$

A $G.K = G_0 + STEP(G_1, 10)$

C $G_0 = 100$

C $G_1 = 20$

A $x_0.K = (b_2 \times G.K + b_0 \times (1 - c)) / (-b_2 / T_D - b_1 \times (1 - c))$

A $v_0.K = x_0.K \times (1 - c) / (x_0.K / T_D + G.K)$

A $z_0.K = x_0.K / v_0.K$

C $T_D = 10$

C $T_K = 1$

C $T_A = 2$

C $T_V = 0.5$

C $b_0 = 1$

C $b_1 = -0.5$

C $b_2 = 0.5$

C $b_3 = 1$

N $x = x_0$

N $u = 0$

N $v = v_0$

N $z = z_0$

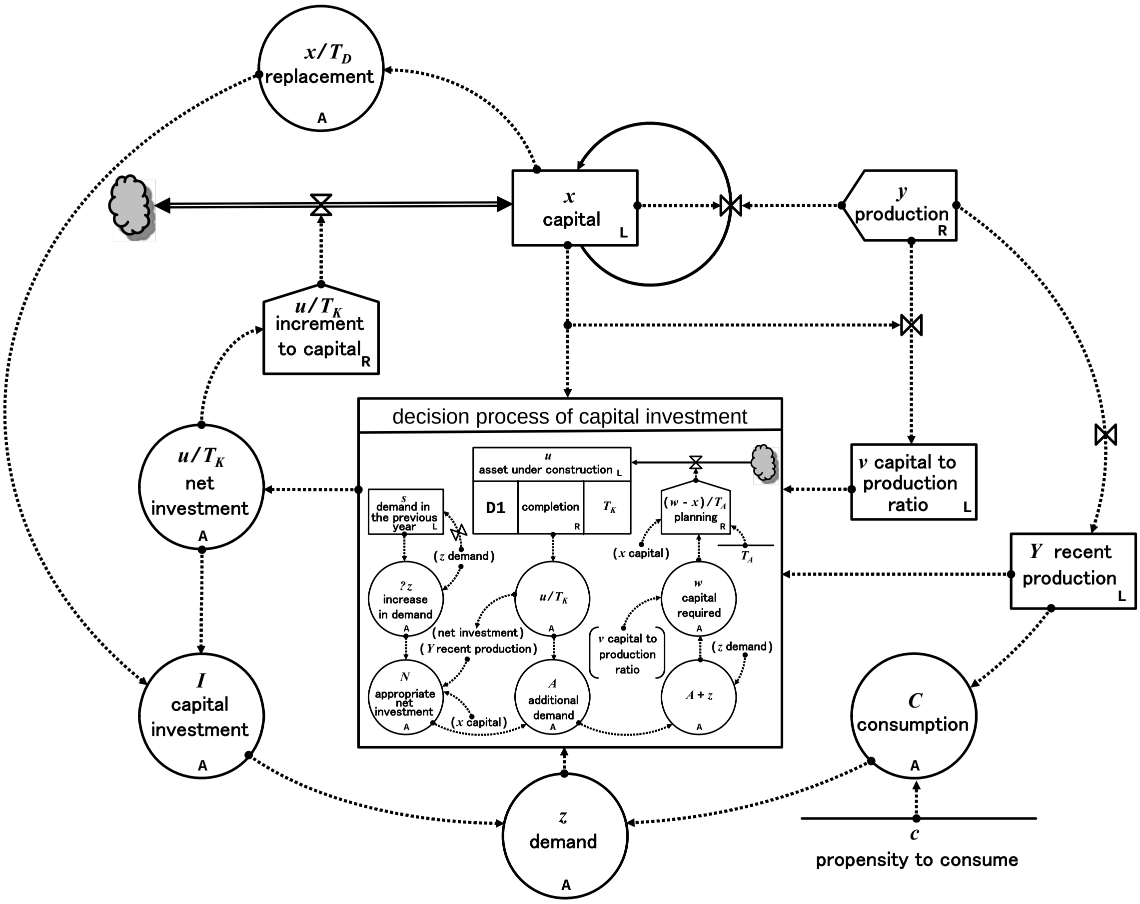
N $s = z$

PLOT $x, v, z, N, x_0, v_0, z_0$

SPEC DT=0.25/LENGTH=60/PRTPER=1/PLTPER=0.25

Appendix 5

Flow diagram of the prototype revised:



Decision process of capital investment: