International Institute for
Applied Systems Analysis
Schlossplatz 1
A-2361 Laxenburg, Austria

Tel: +43 2236 807 342
Fax: +43 2236 71313
E-mail: publications@iiasa.ac.at
Web: www.iiasa.ac.at

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The Reachability of Techno-Labor Homeostasis via Regulation of Investments in Labor and R&D: a Model-based Analysis

Arkadii Kryazhimskii (kryazhim@aha.ru)
Chihiro Watanabe (chihiro@me.titech.ac.jp)
Yuji Tou (ytou@me.titech.ac.jp)

Approved by

Arne Jernelöv (jernelov@iiasa.ac.at)
Acting Director, IIASA

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Abstract

This paper addressing, generally, the issue of optimizing the structure of investments in an economy sector focuses on the analysis of the distribution of investments between labor (education and wages) and technologies (production and R&D). The analysis is based on a model of techno-economic development involving production, technologies and welfare. The model design employs a modified Cobb-Douglas-type production function depending, in particular, on the "quality of labor". A model's trajectory is viewed as optimal if it exhibits techno-labor homeostasis, i.e., stable growth in technologies and welfare. A desirable regime is pre-homeostasis, a (relatively short) transition period followed by homeostasis. Non-desirable behaviors are qualified as collapse and pre-collapse. We describe the domains of model's parameters and initial states which correspond to different behaviors of the model and use this description to carry out a qualitative analysis of selected industry sectors of Japan in 1982 – 1998.

About the Authors

Arkadii Kryazhimskii
Principal Research Scholar
Steklov Institute of Mathematics
Russian Academy of Sciences
Moscow, Russia
and
Head of Dynamic Systems Project
International Institute for Applied Systems Analysis
A-2361 Laxenburg, Austria

Chihiro Watanabe
Department of Industrial Engineering & Management
Head of Laboratory
Tokyo Institute of Technology
Tokyo, Japan
and
Senior Advisor in Technology
International Institute for Applied Systems Analysis
A-2361 Laxenburg, Austria

Yuji Tou
Department of Industrial Engineering & Management
Researcher at Prof. C. Watanabe's Laboratory
Tokyo Institute of Technology
Tokyo, Japan

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Arkadii Kryazhimskii[*] *(kryazhim@aha.ru)*
Chihiro Watanabe (chihiro@me.titech.ac.jp)
Yuji Tou (ytou@me.titech.ac.jp)

Introduction

The optimization of investments in labor and technologies is becoming a key factor in techno-economic development nowadays. The rapid growth in complexity of technologies and production yields the necessity of raising the quality of labor. Raising the quality of labor implies growing investments in education. The educated employees have higher demands (in social, medical and material aspects), which implies growth in wages.

On the other hand, the growing complexity of technologies and production implies growing investments in new production and R&D.

Two areas of investements, labor (education and wages) and technologies (production and R&D), are in conflict: the increase in investments in labor deminishes investments in technologies and vise versa. An optimal techno-economic development arises under an optimal distribution of capital between labor and technologies.

An optimal techno-economic development is usually understood as *techno-labor homeostasis*, i.e., growth in technologies and growth in welfare. Quantitatively, the technology stock is measured as capital accumulated in technologies and welfare as capital accumulated in labor. In this context, an optimal techno-economic development, or techno-labor homeostasis, can be understood as growth in capital accumulated in technologies and growth in capital accumulated in labor. This understanding motivated the mathematical model presented here.

The model describes the evolution of an economy sector (or a country's economy) in three variables: capital accumulated in technologies, capital accumulated in labor and the annual production output. In what follows, we use a simplified terminology; we usually say "technologies" instead of "capital accumulated in technologies", "welfare" instead of "capital accumulated in labor" and "production" instead of "annual production output".

The model design refers to theory of economic growth (see Arrow, 1985; Arrow and Kurz, 1970). We introduce a Cobb-Douglas-type formula for the annual production output and derive the production dynamics via differentiating this formula with respect to time (here we essentially follow Tarasyev and Watanabe, 1999). The model assumes that the annual investments in technologies and in labor come from the capital stock gained through the sales of the annual production output. In this sense, the model describes a process of

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endogenous growth (see Grossman and Helpman, 1991). It is supposed that a fixed part of the annual capital stock is distributed between technologies and labor. The distribution of capital between technologies and labor is entirely characterized by the fraction of the annual capital stock which is allocated for technologies. In our setting, this parameter acts as a control.

In section 1 we introduce a model of a techno-labor system.

In section 2 we define model's behaviors. The most desirable behavior is growth in both welfare and technologies; we call this behavior *homeostasis*. The behavior called *pre-homeostasis* arises when the decline in either technologies or welfare changes to homeostasis within a finite period of time. The most undesirable behavior is decline in both welfare and technologies; we call this behavior *collapse*. Any behavior followed by collapse is called *pre-collapse*.

In section 3 we define the behavioral zones i.e., the sets of system's states, at which the system (with a given control) starts trajectories of different behavioral types.

In section 4 we provide an analytic description of the behavioral zones and chacacterize two mutually complementary cases of the model's dynamics, *stagnation* and *progress* (rigorous proves are given in Grichik and Mokhova, 2002).

In section 5 we discuss results of a numerical model-based analysis of production/wages trajectories for selected industries of Japan.

Section 6 concludes.

1 Model design

1.1 Production function

In the economic literature, production, Y, in an economy sector (or in a country's economy) is usually viewed as a function of the quantities of labor, L, capital, K, materials, M, energy, E, and technologies, T, accumulated in maunfacturing (see, e.g., Arrow and Kurz, 1970; Intriligator, 1971; Griliches, 1984; Watanabe, 1992):

$$Y = F(L, K, M, E, T).$$

The quality of labor is normally not listed explicitly among these factors. However, the quality of labor is positively related to the accumulated investments in labor, i.e., welfare; in this context it is an important component of techno-labor homeostasis. We introduce the *quality of labor*, Q, as an additional parameter determinig production, Y, and represent Y using a modified Cobb-Douglas formula

$$Y = c_0 K^{a_T} M^{a_T} E^{a_T} T^{a_T} Q^{a_Q}; \tag{1.1}$$

here $c_0 > 0$ and a_L, a_K, a_M, a_E lie between 0 and 1.

Usually, it is assumed that the optimal amounts of labor, capital, materials and energy are determined by the accumulated technology stock, T, as $L = c_L T^{b_L}$, $K = c_K T^{b_K}$, $M = c_M T^{b_M}$, $E = c_E T^{b_E}$; here b_L, b_K, b_M, b_E lie between 0 and 1 (see, e.g., [Tarasyev and Watanabe, 1999]). Substituting into (1.1), we get

$$Y = c_Y T^{\alpha} Q^{\beta} \tag{1.2}$$

where c_Y is a positive coefficient and α and β are located between 0 and 1 ($\beta = a_Q$). Let Z stand for capital accumulated in labor, or *welfare*. We assume that the quality of labor, Q, is proportional to welfare, $Q = c_Q Z$ (c_Q is a positive coefficient). Substituting in (1.2), we represent production as a function of technologies and welfare,

$$Y = c_Y c_Q T^{\alpha} Z^{\beta}. \tag{1.3}$$

1.2 Dynamical model

In what follows, we treat Y as the annual production output. We assume that the whole annual production output is sold on market for price $\sigma > 0$. Then σY represents the annual income due to the sales. Let $\delta\sigma Y$ where $0 < \delta < 1$ be the part of the annual income σY which is distributed between technologies and labor. Thus, $\delta\sigma Y = R + D$, where R is the current investment in technologies, and D the current investment in labor. Obviously,

$$R = u\delta\sigma Y, \quad D = (1-u)\delta\sigma Y \tag{1.4}$$

where $0 < u < 1$; u is the share of the current investment in technologies, and $1-u$ the share of the current investment in labor. We view u as a control parameter.

Now we let Z and T change over time. The annual change in capital accumulated in labor (welfare), $\dot{Z}$, is due to the current investment in labor, D, and the capital obscolessence; the latter we represent as $\rho_Z Z$ with a nonnegative obscolessence coefficient ρ_Z. Thus we get

$$\dot{Z} = D - \rho_Z Z. \tag{1.5}$$

Let us define a dynamics for T. The annual inflow of new technologies, $\dot{T}^+$, is proportional to the current investment in technologies, R. Moreover, the higher is the quality of labor, Q, the higher is the inflow of new technologies per unit of investment. Thus, we have $\dot{T}^+ = Rf(Q)$ where $f(Q)$ is a monotonically increasing function. For a fixed R, the dependence of $\dot{T}^+$ on Q, or, equivalently, welfare, Z, which is modeled as $Rf(Q) = Rf(Z)$, is by no means linear; the impact of a unit growth in Z on growth in $\dot{T}^+$ is strong if Z is low and not so strong if Z is high. This kind of impact can be modeled as $\dot{T}^+ = RZ^\gamma$ with $0 < \gamma < 1$. The total annual increment of the technology stock, $\dot{T}$, is the sum of the annual inflow of new technologies, $\dot{T}^+$, and the annual outflow of obscolete technologies, which is usually modeled as $\rho_T T$; here ρ_T is a nonnegative obscolessence coefficient. Thus, we arrive at

$$\dot{T} = RZ^\gamma - \rho_T T. \tag{1.6}$$

Substituting (1.4) and (1.3) into (1.5) and (1.6), we obtain the following system of differential equations:

$$\begin{aligned} \dot{Z} &= \mu(1-u)T^\alpha Z^\beta - \rho_Z Z, \\ \dot{T} &= \mu u T^\alpha Z^{\beta+\gamma} - \rho_T T; \end{aligned}$$

here

$$0 < \mu = \delta\sigma c_Y c_Q < 1,\ 0 < \alpha < 1,\ 0 < \beta < 1,\ 0 < \gamma < 1,\ 0 < u < 1,\ \rho_T \ge 0,\ \rho_Z \ge 0. \tag{1.7}$$

We treat system (1.2) as a model describing the dynamics of technologies, T, and welfare, Z, in the economy sector. We call (1.2) the *techno-labor system.* Note that the techno-labor system (1.2) describes also the dynamics of production, Y, which is a function of T and Z (see (1.3)). The state space of the techno-labor system (1.2) is the positive orthant in the 2-dimensional space, O^+ (O^+ is the set of all 2-dimensional vectors (Z,T) with positive coordinates Z and T). In what follows, the initial states of system (1.2),

$$(Z(0), T(0)) = (T_0, Z_0), \tag{1.8}$$

are restricted to the positive orthant O^+. Parameter u restricted to interval $(0,1)$ will be called a *control.* Recall that u is the fraction of the annual income, which is invested in technologies (the complementary fraction, $1-u$, is invested in labor). Control u is a variable parameter chosen by a decisionmaker; all the other parameters listed in (1.7) are fixed.

Theory of ordinary differential equations (see, e.g., Hartman, 1964) yields that for every initial state (Z_0, T_0) and every control u there exists the unique solution $t \mapsto (Z(t), T(t))$ of equation (1.2) which is defined on the time interval $[0, \infty)$ and satisfies the initial condition (1.8) moreover, $(Z(t), T(t))$ lies in the positive orthant for every $t \geq 0$; we call $t \mapsto (Z(t), T(t))$ the *solution of the Cauchy problem* (1.2), (1.8).

2 Definitions of model behaviors

2.1 Homeostasis

In this paper, we hold the viewpoint that the economy sector exhibits techno-labor homeostasis if both welfare, Z, and technologies, T, grow over time. The most desirable form of techno-labor homeostasis is infinite growth in Z, and T: both Z and T grow and tend to infinity as time goes to infinity. One can call this form of homeostasis "progressive homeostasis". A less desirable form of homeostasis is "regressive homeostasis" which occurs when both Z and T reach finite limits at infinity (implying an infinitly slow growth in Z and T at large times).

In accordance with this understanding, we shall say that

(i) the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits *homeostasis* under control u if for the solution $t \mapsto (Z(t), T(t))$ of the Cauchy problem (1.2), (1.8) the functions $t \mapsto Z(t)$ and $t \mapsto T(t)$ are strictly increasing on $[0, \infty)$;

(ii) if, in addition, both $Z(t)$ and $T(t)$ tend to ∞ as t tends to ∞, we shall say that the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits *progressive homeostasis* under control u;

(iii) finally, if both $Z(t)$ and $T(t)$ tend to finite limits as t tends to ∞, we shall say that the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits *regressive homeostasis* under control u.

Remark 2.1 Theoretically, two other forms of homeostasis ($Z(t)$ grows to infinity whereas $T(t)$ grows to a finite limit, and, conversly, $T(t)$ grows to infinity whereas $Z(t)$ grows to a finite limit) are admissible. Later we shall see that these forms of homeostasis are not feasible for our model.

2.2 Pre-homeostasis

If the economy sector does not exhibit simultaneous growth in welfare and technologies, reaching techno-labor homeostasis in some future is an attractive perspective. If techno-labor homeostasis is reachable, the starting period of the evolution can be viewed as a transition to homeostasis. Formally, we define such behavior as "pre-homeostasis" and call it "progressive" or "regressive" depending on the type of the future homeostasis.

We shall say that

(i) the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits *pre-homeostasis* under control u if for the solution $t \mapsto (Z(t), T(t))$ of the Cauchy problem (1.2), (1.8) there exists a $t_0 \geq 0$ such that the functions $t \mapsto Z(t)$ and $t \mapsto T(t)$ are strictly increasing on $[t_0, \infty)$;

(ii) if, in addition, both $Z(t)$ and $T(t)$ tend to ∞ as t tends to ∞, we shall say that the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits *progressive pre-homeostasis* under control u;

(iii) finally, if both $Z(t)$ and $T(t)$ tend to finite limits as t tends to ∞, we shall say that the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits *regressive pre-homeostasis* under control u.

Remark 2.2 The notion of pre-homeostrasis is, evidently, broader than homeostasis. If the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits homeostasis under control u, then it necessarily exhibits pre-homeostasis under u. The same relation holds between progressive (regressive) homeostasis and progressive (regressive) pre-homeostasis.

Remark 2.3 Coming back to definition (i), note that, starting from time t_0, the techno-labor system (1.2) is in homeostasis.

2.3 Collapse

Now let us consider undesirable behaviors. The undesirable behavior "opposite" to homeostasis is the decline in both welfare and technologies. We call such behavior "collapse". We characterize "collapse" as "limited" if welfare and technologies reach positive limits and "total" if they eventually approach zero.

Formal definitions are as follows. We shall say that

(i) the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits *collapse* under control u if for the solution $t \mapsto (Z(t), T(t))$ of the Cauchy problem (1.2), (1.8) the functions $t \mapsto Z(t)$ and $t \mapsto T(t)$ are strictly decreasing on $[0, \infty)$;

(ii) if, in addition, both $Z(t)$ and $T(t)$ tend to positive limits as t tends to ∞, we shall say that the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits *limited collapse* under control u;

(iii) finally, if both $Z(t)$ and $T(t)$ tend to 0 as t tends to ∞, we shall say that the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits *total collapse* under control u.

Remark 2.4 Theoretically, two other cases of collapse ($Z(t)$ declines to a positive value and $T(t)$ declines to 0, and, conversly, $T(t)$ declines to a positive value and $Z(t)$ declines to 0). We shall see that such situations never take place in our model.

2.4 Pre-collapse

An economy sector which is not in collapse presently may enter collapse in some future. We characterize such behavior as "pre-collapse" and call it "limited" or "total" depending on the type of the future collapse.

We shall say that

(i) the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits *pre-collapse* under control u if for the solution $t \mapsto (Z(t), T(t))$ of the Cauchy problem (1.2), (1.8) there exists a $t_0 \geq 0$ such that the functions $t \mapsto Z(t)$ and $t \mapsto T(t)$ are strictly decreasing on $[t_0, \infty)$;

(ii) if, in addition, both $Z(t)$ and $T(t)$ tend to positive limits as t tends to ∞, we shall say that the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits *limited pre-collapse* under control u;

(iii) finally, if both $Z(t)$ and $T(t)$ tend to 0 as t tends to ∞, we shall say that the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits *total pre-collapse* under control u.

Remark 2.5 Starting from time t_0 (see (i)), the techno-labor system (1.2) is in collapse.

2.5 Growth-decline regimes

The growth-decline regimes occure when technologies grow and welfare declines or, conversely, welfare grows and technologies decline.

Formal definitions are as follows. We shall say that

(i) the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits *growth in welfare and decline in technologies* under control u if for the solution $t \mapsto (Z(t), T(t))$ of the Cauchy problem (1.2), (1.8) the function $t \mapsto Z(t)$ is strictly increasing and the function $t \mapsto T(t)$ strictly decreasing on $[0, \infty)$;

(ii) the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits *growth in technologies and decline in welfare* under control u if for the solution $t \mapsto (Z(t), T(t))$ of the Cauchy problem (1.2), (1.8) the function $t \mapsto Z(t)$ is strictly decreasing and the function $t \mapsto T(t)$ strictly increasing on $[0, \infty)$.

2.6 Summary

In Table 2.1 we sum up the above definitions using symbolic characterizations of the behaviors (for example, $\to\nearrow^{<\infty}$ symbolizes "any behavior followed by growth to a finite limit").

	behavior of welfare, Z	behavior of technologies, T,
homeostasis	$\nearrow$	$\nearrow$
progressive homeostasis	$\nearrow^{\infty}$	$\nearrow^{\infty}$
regressive homeostasis	$\nearrow^{<\infty}$	$\nearrow^{<\infty}$
pre-homeostasis	$\to\nearrow$	$\to\nearrow$
progressive pre-homeostasis	$\to\nearrow^{\infty}$	$\to\nearrow^{\infty}$
regressive pre-homeostasis	$\to\nearrow^{<\infty}$	$\to\nearrow^{<\infty}$
collapse	$\searrow$	$\searrow$
limited collapse	$\searrow_{>0}$	$\searrow_{>0}$
total collapse	$\searrow_{0}$	$\searrow_{0}$
pre-collapse	$^{\to}\searrow$	$^{\to}\searrow$
limited pre-collapse	$^{\to}\searrow_{>0}$	$^{\to}\searrow_{>0}$
total pre-collapse	$^{\to}\searrow_{0}$	$^{\to}\searrow_{0}$
growth in welfare and decline in technologies	$\nearrow$	$\searrow$
growth in technologies and decline in welfare	$\searrow$	$\nearrow$

Table 2.1.

3 Definition of behavioral zones

3.1 Zone of homeostasis

For a given control u, let $H^+(u)$ denote the set of all (Z_0, T_0) in the positive orthant O^+ such that the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits homeostasis under control u. We call $H^+(u)$ the *zone of homeostasis under control* u.

Remark 3.1 If the initial state, (Z_0, T_0), of the techno-labor system (1.2) lies in $H^+(u)$, and the system is controlled by u, then the system never abandons $H^+(u)$; more accurately, for the solution $t \mapsto (Z(t), T(t))$ of the Cauchy problem (1.2), (1.8) the state $(Z(t), T(t))$

lies in $H^+(u)$ for every $t \geq 0$. This observation follows straightforwardly from the definition of homeostasis.

3.2 Zone of pre-homeostasis

For a given control u, we denote by $H(u)$ the set of all (Z_0, T_0) in O^+ such that the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits pre-homeostasis under control u. We call $H(u)$ the *zone of pre-homeostasis under control* u.

Remark 3.2 It is clear that for every control u the zone of pre-homeostasis under control u contains the zone of homeostasis under this control, $H^+(u) \subset H(u)$ (in this context see Remark 2.2).

Remark 3.3 If the initial state, (Z_0, T_0), of the techno-labor system (1.2) lies in $H(u)$, and the system is controlled by u, then the system never abandons $H(u)$; more accurately, for the solution $t \mapsto (Z(t), T(t))$ of the Cauchy problem (1.2), (1.8) the state $(Z(t), T(t))$ lies in $H(u)$ for every $t \geq 0$. This observation follows straightforwardly from the definition of homeostasis.

3.3 Zones of collapse and pre-collapse

For a given control u, we denote by $C^{--}(u)$ the set of all (Z_0, T_0) in O^+ such that the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits collapse under control u and by $C(u)$ the set of all (Z_0, T_0) in O^+ such that the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits pre-collapse under control u. We call $C^{--}(u)$ the *zone of collapse under control* u and $C(u)$ the *zone of pre-collapse under control* u.

Remark 3.4 Obviously, $C^{--}(u)$ is contained in $C(u)$, $C^{--}(u) \subset C(u)$, and the latter does not intersect with $H(u)$, the zone of pre-homeostasis under u, $C(u) \cap H(u) = \emptyset$.

4 Description of behavioral zones. Stagnation and progress

4.1 Structure of the vector field

Let us fix a control u. Analyzing the vector field of the techno-labor system (1.2), we easily find the set of all points (Z, T), at which this vector field has the zero projection onto the Z axis, and the set of all (Z, T), at which it has the zero projection onto the T axis; we denote these sets $G_Z(u)$ and $G_T(u)$, respectively. The set $G_Z(u)$ is shaped as a curve whose equation is

$$T = \left(\frac{\rho Z}{\mu}\right)^{1/\alpha} \frac{1}{(1-u)^{1/\alpha}} z^{(1-\beta)/\alpha} \tag{4.1}$$

and set $G_T(u)$ as the curve whose equation is

$$T = \left(\frac{\rho Z}{\mu}\right)^{1/(1-\alpha)} u^{1/(1-\alpha)} z^{(\beta+\gamma)/(1-\alpha)}. \tag{4.2}$$

Generically, the curves $G_Z(u)$ and $G_T(u)$ intersect at the unique point $(Z^*(u), T^*(u))$ defined as the solution of the algebraic system (4.1), (4.2). Point $(Z^*(u), T^*(u))$ is the unique rest point of the techno-labor system (1.2) under control u.

Let us plot the curves $G_Z(u)$ and $G_T(u)$ on the (Z, T) plain with the horizontal axis Z and vertical axis T. Two different locations of the curves $G_Z(u)$ and $G_T(u)$ on the

(Z, T) plain give rise to two different structures of the vector field of system (1.2). These locations are characterized as follows.

Case 1: at the rest point $(Z^*(u), T^*(u))$, the slope of $G_Z(u)$ on the (Z, T) plain is greater than the slope of $G_T(u)$; this happens if

$$\alpha + \alpha\gamma + \beta < 1. \tag{4.3}$$

Case 2 is opposite: at the rest point $(Z^*(u), T^*(u))$, the slope of $G_Z(u)$ on the (Z, T) plain is smaller than the slope of $G_T(u)$; this happens if

$$\alpha + \alpha\gamma + \beta > 1. \tag{4.4}$$

Remark 4.1 Note that case 1 or case 2 takes place for all controls u simultaneously.

Fig. 4.1 and Fig. 4.2 show the vector field of system (1.2) in cases 1 and 2, respectively.

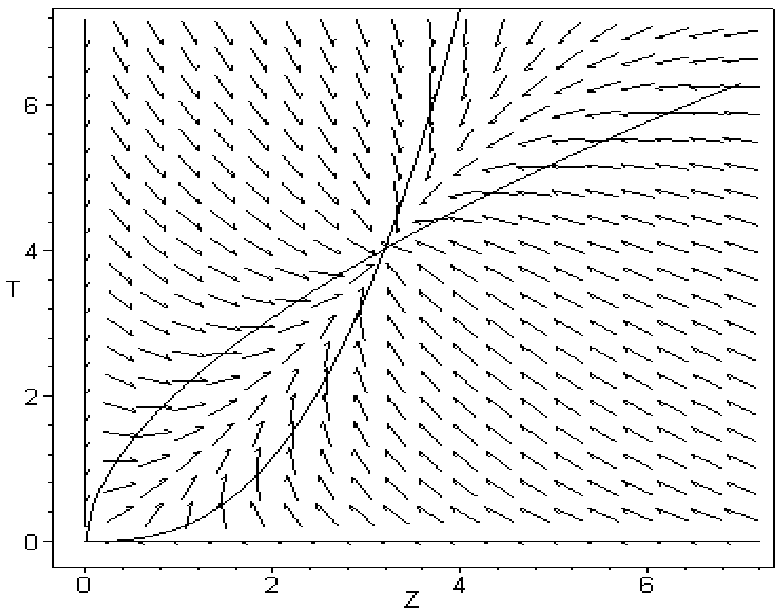

Fig. 4.1.
The vector field of the techno-labor system (1.2) in case 1.
The curve $G_Z(u)$ lies lower than $G_T(u)$ in a neighborhood of the origin and higher than $G_T(u)$ in a neighborhood of infinity.

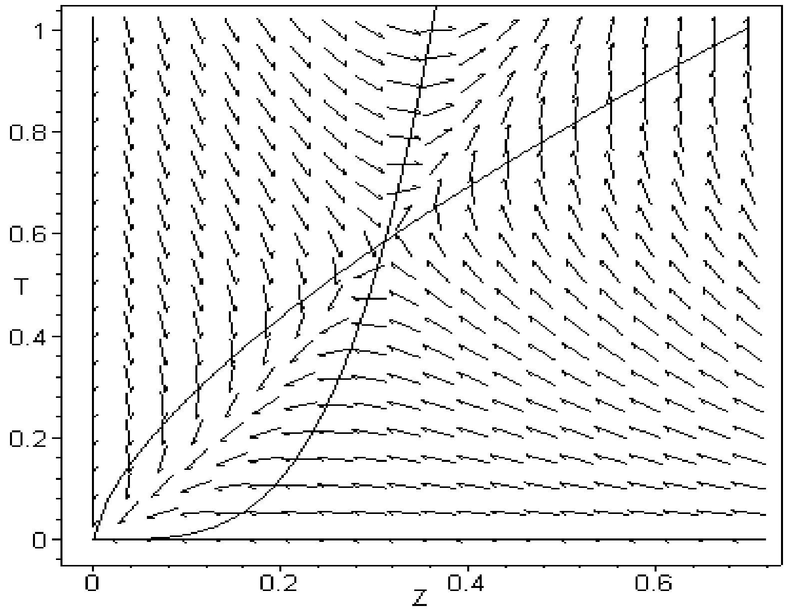

Fig. 4.2.
The vector field of the techno-labor system (1.2) in case 2.
The curve $G_Z(u)$ lies higher than $G_T(u)$ in a neighborhood of the origin
and lower than $G_T(u)$ in a neighborhood of infinity.

Fig. 3.1 and Fig. 3.2 show that in each of cases 1 and 2 system (1.2) exhibits 4 different behaviors within 4 "angle" areas in the (Z, T) plain, which are determined by the curves $G_Z(u)$ and $G_T(u)$; we call these angle areas the *north-east, south-east, north-west and south-west angles* (for control u) according to their locations and denote $G_{ZT}^{++}(u)$, $G_{ZT}^{--}(u)$, $G_{ZT}^{+-}(u)$, $G_{ZT}^{-+}(u)$, respectively. We assume that the north-west and south-east angles, $G_{ZT}^{++}(u)$, $G_{ZT}^{--}(u)$, are closed, i.e., contain their boundaries, and the north-west and south-west angles, $G_{ZT}^{+-}(u)$, $G_{ZT}^{-+}(u)$, are open, i.e., do not contain their boundaries.

Remark 4.2 In cases 1 and 2 the upper and lower boundaries the north-east, south-east, north-west and south-west angles are parts of different curves. For example, in case 1 (4.3) the upper boundary of the north-east anlge $G_{ZT}^{++}(u)$ is the part of the curve $G_Z(u)$ which is located above the rest point $(Z^*(u), T^*(u))$ (including this point), whereas in case 2 this part of the curve $G_Z(u)$ is the lower boundary of $G_{ZT}^{++}(u)$.

4.2 Behavioral zones. Case 1: stagnation

Proposition 4.1 given below provides the accurate characterization of the behaviors of the techno-labor system (1.2) in case 1.

Prior to the formulation of Proposition 4.1, let us comment it informally. A graphical illustration is given in Fig. 4.3.

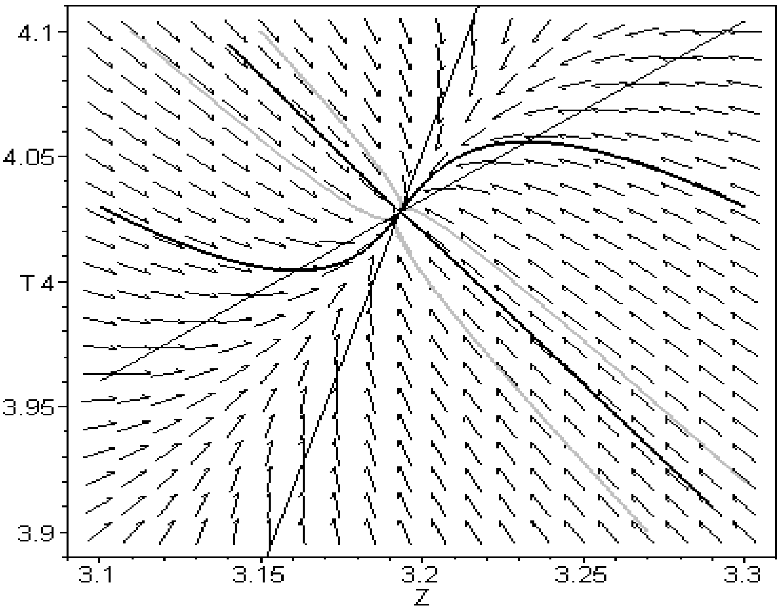

Fig. 4.3.
Trajectories of the techno-labor system (1.2) in case 1 (stagnation).
The separation curves in the north-east and south-west
angles are shown in grey.

Statement (i) of Proposition 4.1 claims that in case 1 the techno-labor system controlled by a fixed u converges to the rest point $(Z^*(u), T^*(u))$ no matter where it starts. In other words, for a given control all the system's trajectories are equivalent in the long run. Therefore, the difference between homeostasis and collapse vanishes at late stages of evolution; moreover, homeostasis is necessarily regressive and collapse necessarily limited (statements (ii) and (iii)). These observations allow us to characterize case 1 as *stagnation.*

Statements (ii) and (iii) claim that the zone of homeostasis under control u, $H^{++}(u)$, is the south-west angle, $G_{ZT}^{--}(u)$, and the zone of collapse under control u, $C^{--}(u)$, is the north-east angle, $G_{ZT}^{++}(u)$.

In statements (iv) – (xi) two facts are claimed. Firstly, the techno-labor system exhibits pre-homeostasis if its initial state, (Z_0, T_0), is located below a separation curve $\Lambda_{-}^{-+}(u)$ crossing the north-west angle $G_{ZT}^{-+}(u)$, or below a separation curve $\Lambda_{-}^{+-}(u)$ crossing the south-east angle $G_{ZT}^{+-}(u)$; symmetrically, the techno-labor system exibits pre-collapse if (Z_0, T_0) is located above a separation curve $\Lambda_{+}^{-+}(u)$ crossing the north-west angle $G_{ZT}^{-+}(u)$ above $\Lambda_{-}^{-+}(u)$, or above a separation curve $\Lambda_{+}^{+-}(u)$ crossing the south-east angle $G_{ZT}^{+-}(u)$ above $\Lambda_{-}^{-+}(u)$. Secondly, if (Z_0, T_0) is located between the lower curve $\Lambda_{-}^{-+}(u)$ and upper curve $\Lambda_{+}^{-+}(u)$ in the north-west angle, $G_{ZT}^{-+}(u)$, the techno-labor system exhibits growth in welfare and decline in technologies; symmetrically, if (Z_0, T_0) is located between the lower curve $\Lambda_{-}^{+-}(u)$ and upper curve $\Lambda_{+}^{+-}(u)$ in the south-east angle, $G_{ZT}^{+-}(u)$, the techno-labor system exhibits growth in technologies and decline in welfare.

Proposition 4.1 (Kryazhimskii, et. al., 2002, Proposition 4.1). Let case 1, stagnation, take place, i.e., (4.3) hold. Let $u \in (0, 1)$ be an arbitrary control. Then

(i) the rest point $(Z^*(u), T^*(u))$ is the unique attractor for the techno-labor system (1.2) under control u; more accurately, for any initial state (Z_0, T_0), the solution

$t \mapsto (Z(t), T(t))$ of the Cauchy problem (1.2), (1.8) satisfies $\lim_{t\to\infty} Z(t) = Z^*(u)$ and $\lim_{t\to\infty} T(t) = T^*(u)$;

(ii) the zone of homeostasis under control u, $H^{++}(u)$, is the south-west angle $G^{--}_{ZT}(u)$; moreover, the zone of regressive homeostasis under control u coincides with $H^{++}(u)$;

(iii) the zone of collapse under control u, $C^{--}(u)$, is the north-east angle $G^{++}_{ZT}(u)$; moreover, the zone of limited collapse under control u coincides with $C^{--}(u)$;

(iv) there exists the unique solution $t \mapsto (Z^{+-}_{-}(t), T^{+-}_{-}(t))$ of system (1.2), which is defined on $(-\infty, \infty)$, takes values, in the north-west angle, $G^{+-}_{ZT}(u)$, and is minimal in the following sense: for every (Z_0, T_0) located to the south-west of the trajectory, $\Lambda^{+-}_{-}(u)$, of the solution $t \mapsto (Z^{+-}_{-}(t), T^{+-}_{-}(t))$, the solution $t \mapsto (Z(t), T(t))$ of system (1.2), with the initial state (Z_0, T_0) crosses the boundary of the north-west angle, $G^{+-}_{ZT}(u)$;

(v) there exists the unique solution $t \mapsto (Z^{+-}_{+}(t), T^{+-}_{+}(t))$ of system (1.2), which is defined on $(-\infty, \infty)$, takes values in the north-west angle, $G^{+-}_{ZT}(u)$, and is maximal in the following sense: for every (Z_0, T_0) located to the north-east of the trajectory, $\Lambda^{+-}_{+}(u)$, of the solution $t \mapsto (Z^{+-}_{+}(t), T^{+-}_{+}(t))$, the solution $t \mapsto (Z(t), T(t))$ of system (1.2), with the initial state (Z_0, T_0) crosses the boundary of the north-west angle, $G^{+-}_{ZT}(u)$;

(vi) there exists the unique solution $t \mapsto (Z^{-+}_{-}(t), T^{-+}_{-}(t))$ of system (1.2), which is defined on $(-\infty, \infty)$, takes values in the south-east angle, $G^{-+}_{ZT}(u)$, and is minimal in the following sense: for every (Z_0, T_0) located to the south-west of the trajectory, $\Lambda^{-+}_{-}(u)$, of the solution $t \mapsto (Z^{-+}_{-}(t), T^{-+}_{-}(t))$, the solution $t \mapsto (Z(t), T(t))$ of system (1.2), with the initial state (Z_0, T_0) crosses the boundary of the south-east angle, $G^{-+}_{ZT}(u)$;

(vii) there exists the unique solution $t \mapsto (Z^{-+}_{+}(t), T^{-+}_{+}(t))$ of system (1.2), which is defined on $(-\infty, \infty)$, takes values in the south-east angle, $G^{-+}_{ZT}(u)$, and is maximal in the following sense: for every (Z_0, T_0) located to the north-east of the trajectory, $\Lambda^{-+}_{+}(u)$, of the solution $t \mapsto (Z^{-+}_{+}(t), T^{-+}_{+}(t))$, the solution $t \mapsto (Z(t), T(t))$ of system (1.2), with the initial state (Z_0, T_0) crosses the boundary of the south-east angle, $G^{-+}_{ZT}(u)$;

(viii) $H(u)$, the zone of pre-homeostasis under control u, is the union of the domain $\hat{H}^{+-}(u)$ located in the north-west angle, $G^{+-}_{ZT}(u)$, to the south-west of trajectory $\Lambda^{+-}_{-}(u)$, and the domain $\hat{H}^{-+}(u)$ located in the south-east angle $G^{-+}_{ZT}(u)$ to the south-west of trajectory $\Lambda^{-+}_{-}(u)$; moreover, the zone of regressive pre-homeostasis under control u coincides with $H(u)$;

(ix) $C(u)$, the zone of pre-collapse under control u, is the union of the domain $\hat{C}^{+-}(u)$ located in the north-west angle, $G^{+-}_{ZT}(u)$, to the north-east of trajectory $\Lambda^{+-}_{+}(u)$, and the domain $\hat{C}^{-+}(u)$ located in the south-east angle $G^{-+}_{ZT}(u)$ to the north-east of trajectory $\Lambda^{-+}_{+}(u)$; moreover, the zone of limited pre-collapse under control u coincides with $C(u)$;

(x) for every (Z_0, T_0) located in the north-west angle, $G^{+-}_{ZT}(u)$, between the trajectories $\Lambda^{+-}_{-}(u)$ and $\Lambda^{+-}_{+}(u)$ the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits growth in welfare and decline in technologies under control u;

(xi) for every (Z_0, T_0) located in the south-east angle, $G^{-+}_{ZT}(u)$, between the trajectories $\Lambda^{-+}_{-}(u)$ and $\Lambda^{-+}_{+}(u)$ the techno-labor system (1.2) with the initial state (Z_0, T_0) exhibits growth in technologies and decline in welfare under control u.

An accurate proof of Proposition 4.1 is given in Grichik and Mokhova, 2002.

4.3 Behavioral zones. Case 2: progress

Proposition 4.2 given below characterizes the behaviors of the techno-labor system (1.2) in case 2.

Let us comment it informally. A graphical illustration is given in Fig. 4.4.

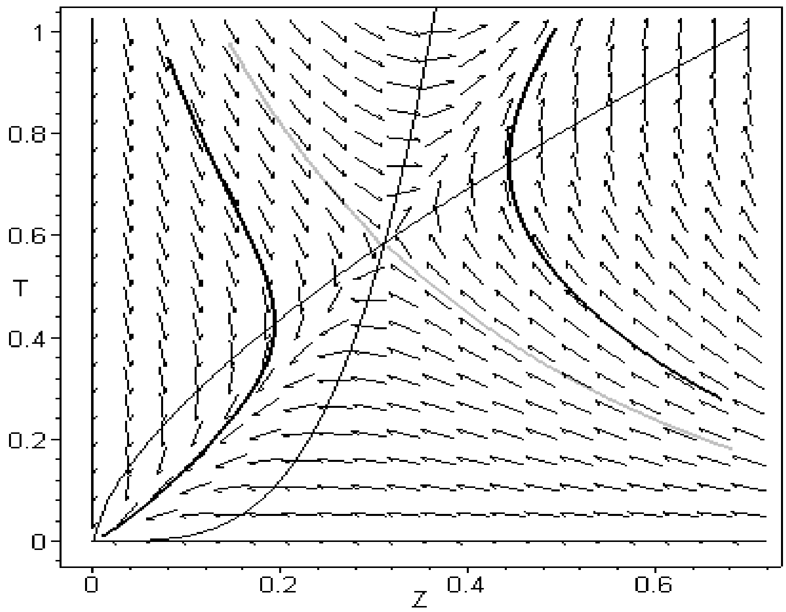

Fig. 4.4.
Trajectories of the techno-labor system (1.2) in case 2 (progress).
The sepration curves in the north-east and south-west
angles are shown in grey.

Statement (i) of Proposition 4.2 claims that, generically, in case 2 the techno-labor system controlled by any fixed u does not converge to the rest point $(Z^*(u), T^*(u))$.

Statements (ii) and (iii) imply that homeostasis and collapse are radically different in the long run: homeostasis is necessarily prgressive (both welfare, Z, and technolofies, T, grow to infinity) and collapse necessarily total (welfare, Z, and technologies, T, eventually vanish).

This key observation is complemented by statements (iv) – (vii) implying that, generically, the system enters either (progressive) homeostasis or, alternatively, (total) collapse. In other words, in case 2 the techno-labor system with a fixed control u has, generically, a perspective of infinite progress or, alternatively, total collapse depending on the location of the initial state. This situation agrees with the informal understanding of progress as a risky process coupled with a chance of a catastrophe. We characterize case 2 as *progress*.

Statements (iv) – (vii) describe also the structure of the zones of pre-homeeostasis and pre-collapse under a given control, which is symmetric to the structure of these zones in case 1 (Proposition 4.1, (iv) – (vii)). Namely, in case 2 the techno-labor system exhibits pre-homeostasis if its initial state (Z_0, T_0), is located above a separation curve $\Lambda^{-+}(u)$ crossing the north-west angle $G_{ZT}^{-+}(u)$, or above a separation curve $\Lambda^{+-}(u)$ crossing the south-east angle $G_{ZT}^{+-}(u)$, and the techno-labor system exibits pre-collapse if (Z_0, T_0) is located below $\Lambda^{-+}(u)$ or below $\Lambda^{+-}(u)$. The behaviors of the techno-labor system in the exceptional situations where (Z_0, T_0) is located on the curve $\Lambda^{-+}(u)$ or on the curve $\Lambda^{+-}(u)$ are similar to those in case 1.

The generic behavior of the techno-labor system under control u in case of progress (case 2) is as follows. If the initial state (Z_0, T_0), lies in the north-east angle, $G_{ZT}^{++}(u)$, the system exhibits progressive homeeostasis; it remains in $G_{ZT}^{++}(u)$, while both welfare,

Z, and technologies, T, grow to infinity. If (Z_0, T_0) lies in the south-east angle, $G^{--}_{ZT}(u)$, the system exhibits total collapse; it remains in $G^{--}_{ZT}(u)$, while both welfare, Z, and technologies, T, decline to 0. If (Z_0, T_0) lies in the north-west angle $G^{+-}_{ZT}(u)$ above the separation curve $\Lambda^{+-}(u)$, the system exhibits progressive pre-homeostasis; in the beginning of the ebvolution welfare, Z, grows and technologies, T, decline; sooner or later, the system enters the zone of homeostasis, $H^{++}(u) = G^{++}_{ZT}(u)$, and remains there forever while both welfare, Z, and technologies, T, grow to infinity. If (Z_0, T_0), lies in the south-east angle $G^{-+}_{ZT}(u)$ above the separation curve $\Lambda^{-+}(u)$, the system's bahavior is identical; the only difference is that in the beginning of the ebvolution welfare, Z, declines and technologies, T, grow. If (Z_0, T_0) lies in the north-west angle $G^{+-}_{ZT}(u)$ below the separation curve $\Lambda^{+-}(u)$, the system exhibits total pre-collapse; in the beginning of the ebvolution welfare, Z, grows and technologies, T, decline; sooner or later, the system enters the zone of collapse, $C^{--}(u) = G^{--}_{ZT}(u)$; it remains there forever while both welfare, Z, and technologies, T, decline to 0. If (Z_0, T_0) lies in the south-east angle $G^{-+}_{ZT}(u)$ below the separation curve $\Lambda^{-+}(u)$, the system's bahavior is identical; the only difference is that in the beginning of the ebvolution welfare, Z, declines and technologies, T, grow.

Proposition 4.2 (Kryazhimskii, et. al., 2002, Proposition 4.2). Let case 2 (progress) take place, i.e., (4.4) hold. Let u be an arbitrary control. Then

(i) the rest point $(Z^*(u), T^*(u))$ of the techno-labor system (1.2) under control u is unstable;

(ii) the zone of homeostasis under control u, $H^{++}(u)$, is the north-east angle $G^{++}_{ZT}(u)$; moreover, the zone of progressive homeostasis under control u coincides with $H^{++}(u)$;

(iii) the zone of collapse under control u, $C^{--}(u)$, is the south-west angle $G^{--}_{ZT}(u)$; moreover, the zone of total collapse under control u coincides with $C^{--}(u)$;

(iv) there exists the unique solution $t \mapsto (Z^{-+}(t), T^{-+})$ of system (1.2), which is defined on $(-\infty, \infty)$ and takes values in the north-west angle, $G^{+-}_{ZT}(u)$; moreover, the trajectory $\Lambda^{+-}(u)$ of this solution splits $G^{+-}_{ZT}(u)$, in two open areas, $\hat{H}^{+-}(u)$ and $\hat{C}^{+-}(u)$, adjoining the north-east angle $G^{++}_{ZT}(u)$ and south-west angle $G^{--}_{ZT}(u)$ respectively;

(v) symmetrically, there exists the unique solution $t \mapsto (Z^{-+}(t), T^{-+})$ of system (1.2), which is defined on $(-\infty, \infty)$ and takes values in the south-east angle, $G^{-+}_{ZT}(u)$; moreover, the trajectory $\Lambda^{-+}(u)$ of this solution splits $G^{-+}_{ZT}(u)$, in two open areas, $\hat{H}^{-+}(u)$ and $\hat{C}^{-+}(u)$, adjoining the north-east angle $G^{++}_{ZT}(u)$ and south-west angle $G^{--}_{ZT}(u)$ respectively;

(vi) $H(u)$, the zone of pre-homeostasis under control u, is the union of $\hat{H}^{+-}(u)$ and $\hat{H}^{-+}(u)$; moreover, the zone of progressive pre-homeostasis under control u coincides with $H(u)$;

(vii) $C(u)$, the zone of pre-collapse under control u, is the union of $\hat{C}^{+-}(u)$ and $\hat{C}^{-+}(u)$; moreover, the zone of total pre-collapse under control u coincides with $C(u)$.

An accurate proof of Proposition 4.2 is given in Grichik and Mokhova, 2002.

5 Model-based analysis of selected Japan's industries

5.1 Methodology

In this section we compare model trajectories with data series for selected Japan's industry sectors[1] and use the analytic results for interpretations[2].

We employ the following three-stage methodolody.

[1]The data collection of the Tokyo Institute of Technology has been used.

[2]The authors are thankful to Mikhail Grichik and Mariya Mokhova for carrying out numerical tests presented in this section.

Stage 1. The model of the techno-labor system, (1.2), is identified. Namely, given a record of the trajectory of a real techno-labor system, the parameters of the model, for which the model's trajectory lies close to the real trajectory, are found.

Stage 2. The character of the techno-labor dynamics – stagnation or progress – is identified. Stagnation is registered if the model's parameters satisfy inequality (4.3), progress is registered if inequality (4.4) holds.

Stage 3. The behavior of the system is characterized, i.e., the behavioral zone containing the system's trajectory is identified. If the system's trajectory lies in the zone of homeostasis, $H^{++}(u)$ (resp., in the zone of pre-homeostasis, $H(u)$), the system's behavior is characterized as regressive homeostasis (resp., regressive pre-homeostasis) in case of stagnation and as progressive homeostasis (resp., progressive pre-homeostasis) in case of progress. If the trajectory lies in the zone of collapse, $C^{--}(u)$ (resp., in the zone of pre-collapse, $C(u)$), the system's behavior is characterized as limited collapse (resp., limited pre-collapse) in case of stagnation and as total collapse (resp., total pre-collapse) in case of progress.

The analyzed data show the dynamics of production, Y, and wage, W, in Japan's industry sectors. In terms of our model, we relate wage, W, to the investment in labor, D (see section 1). We assume that the investment in labor, D, covers W, and also compensates $\rho_Z Z$, the natural decrease in welfare due to the obscolessence of capital accumulated in labor: $D = W + \rho_Z Z$. Thus, we set $W = D - \rho_Z Z$, or $W = \dot{Z}$ (see (1.5)). In order to identify the model (at stage 1) using the time series in Y and W, we change the original variables (Z, T) to (Y, W):

$$Y = c_Y c_Q T^\alpha Z^\beta, \quad W = \dot{Z} = \mu(1-u)T^\alpha Z^\beta - \rho_Z Z,$$

(here we refer to (1.3) and (1.2)). The system equation (1.2) in the (Y, W) variables can be found in Grichik and Mokhova, 2002.

Remark 5.1 Since a negative wage, W, is incompatible with the performance of a techno-labor system, the trajectories with $\dot{Z} = W < 0$ are not feasible without any exogenous inputs. Therefore, collapse implying decline in welfare ($\dot{Z} < 0$) by definition, is not feasible in a techno-labor system provided the latter is not supported exogenously. Practically, that means that a pre-collapse system has to restructurize (ensuring $\dot{Z} = W > 0$) prior entering collapse. This conjecture is to a certain extent confirmed by our analysis of the data on the Japan's food industry in 1986 – 1992 (subsection 5.3).

5.2 Manufacturing, 1982 – 1998

Fig. 5.1 shows the actual dynamics of production, Y (billion yens), and wage, W (billion yens), in Japan's manufacturing in period 1982 – 1998 and the trajectories of the identified model (1.2).

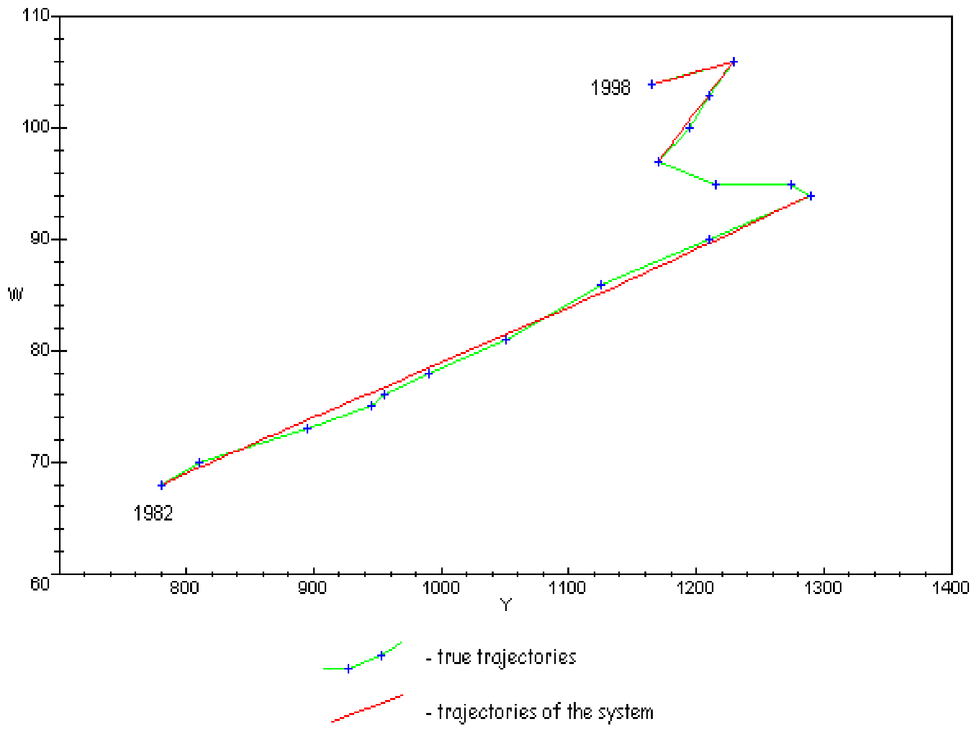

Fig. 5.1.
Production, Y (billion yens), and wage, W (billion yens),
in Japan's manufacturing in 1982 – 1998 and the trajectories of
the model identified at stage 1.

In the actual evolution, four periods with the different dynamics are seen. In period 1982 – 1991 both production and wage grow. In period 1991 – 1994 production declines while wage continues to grow. In period 1994 – 1997 both production and wage grow again. In period 1997 – 1998 both production and wage decline. Essential differences in the dynamics in these periods imply that the techno-labor system restructurized in 1991/1992, in 1994/1995 and in 1997/1998. We identified the model for periods 1982 – 1991 and 1994 – 1997 where both production and wage grow. (The actual behavior in 1991 – 1994 when production declines and wage grows is incompatible with the model; we also do not provide any results for period 1997 – 1998 which is too short for the identification of the model.)

Table 5.1 shows the parameters of the identified model (the outcome of stage 1), characterizes the dynamics in terms of stagnation/progress (the outcome of stage 2), and identifies the behaviors of the techno-labor system in periods 1982 – 1991 and 1994 – 1997 (the outcome of stage 3).

	1982 – 1991	1994 – 1997
μ	0.85	0.8
α	0.32	0.32
β	0.8	0.8
γ	0.5	0.1
ρ_T	0.045	0.22
ρ_Z	0.09	0.037
u	0.79	0.5
case	progress	progress
behavior	progressive pre-homeostasis	progressive homeostasis

Table 5.1.

Fig. 5.2 shows the trajectories of the identified model for periods 1982 – 1991 and 1994 – 1997 in the logarithmic coordinates $z = \log Z$, $\tau = \log T$. In 1982 the trajectory starts in the zone of progressive pre-homerostasis, $H(u)$ (in the north-east angle, $G^{+-}_{ZT}(u)$) and in 1991 ends up in the zone of progressive homeostasis, $H^{++}(u)$. The trajectory of 1994 – 1997 lies in the zone of progressive homeostasis, $H^{++}(u)$.

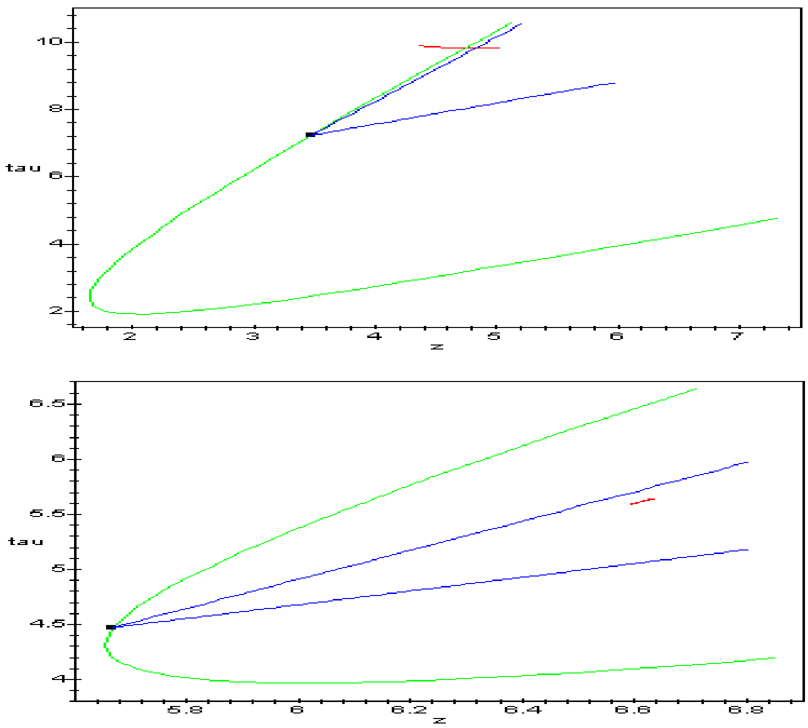

Fig. 5.2.
The model trajectories for 1982 – 1991 (progressive pre-homeostasis: the short curve in the upper figure) and for 1994 – 1997 (progressive homeostasis: the short curve in the lower figure) in the logarithmic coordinates $z = \log Z$, $\tau = \log T$. The north-west angle is the zone of progressive homeostasis for the identified control u (see Table 5.1). The interior of the grey loop is the union of the zones of progressive homeostasis over all controls.

5.3 Food industry, 1982 – 1992

Fig. 5.3 shows the actual dynamics of production, Y (billion yens), and wage, W (billion yens), in Japan's food industry in 1982 – 1992 and the trajectories of the identified model (1.2).

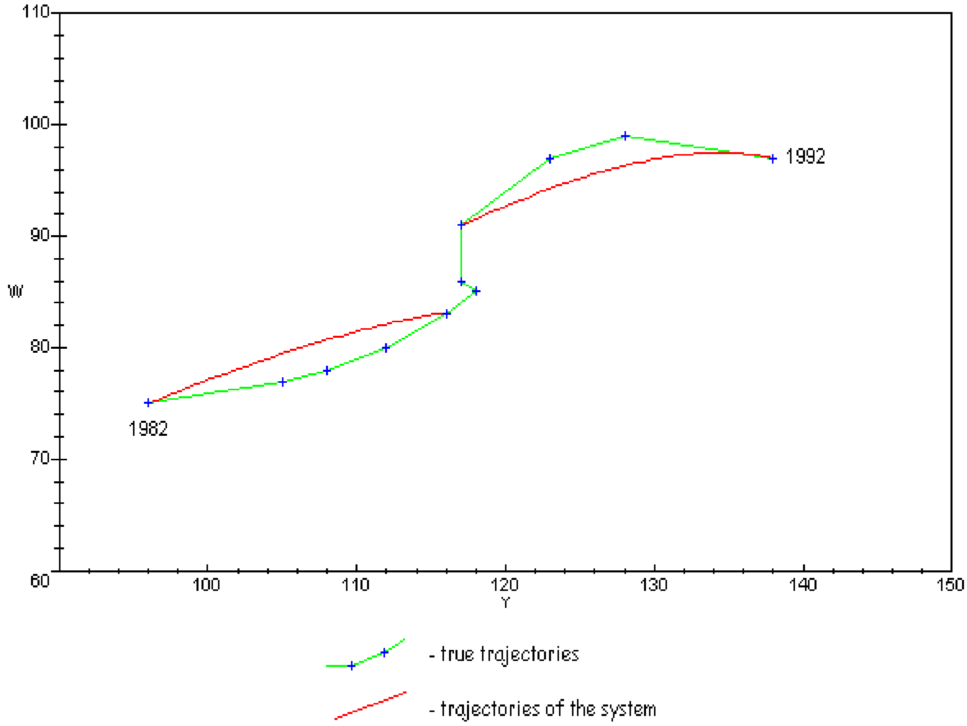

Fig. 5.3.
Production, Y (billion yens), and wage, W (billion yens),
in Japan's food industry in 1982 – 1992 and the trajectories of
the model identified at stage 1.

In the actual evolution, three periods with the different dynamics are seen. In period 1982 – 1986 production and wage grow. Period 1986 – 1989 shows up an approximately constant level in production and a jump in wage. In period 1994 – 1992 production grows steadily and wage undergoes a smooth switch from growth to decline. The techno-labor system restructurized in 1987/1987 and in 1989/1990. We identified the model for the periods of smooth development, 1982 – 1986 and 1989 – 1992.

Table 5.2 shows the parameters of the identified model (the outcome of stage 1), characterizes the dynamics in terms of stagnation/progress (the outcome of stage 2), and identifies the behaviors of the techno-labor system in periods 1982 – 1986 and 1989 – 1992 (the outcome of stage 3).

	1982 – 1986	1989 – 1992
μ	0.99	1
α	0.4	0.4
β	0.4	0.1
γ	0.2	0.3
ρ_T	0.05	0.01
ρ_Z	0.03	0.036
u	0.1	0.2
case	stagnation	stagnation
behavior	limited pre-collapse	limited pre-collapse

Table 5.2.

Fig. 5.4 shows the trajectories of the identified model for periods 1982 – 1986 and 1989 – 1992 (the short black curves) and the extrapolations of these trajectories to future periods in coordinates (Y, W) (the grey curves). The trajectories are extrapolated to the future via simulations of the identified models. The trajectories of 1982 – 1986 and 1989 – 1992 remain in the zone of limited pre-collapse, $C(u)$, without entering the zone of limited collapse, $C^{--}(u)$. Each of the trajectories terminates in a neighborhood of the point of the maximum wages which is followed by three periods in the simulated evolution: a period of slow growth in production and decline in wages, a period of decline in both production and wages, and a period of decline in production and growth in wages. In the second period, the extrapolated trajectory enters the domain of negative wages anr remains there forever. In Remark 5.1 we noted that negative wages are incompatible with the performance of a techno-labor; in this context, we conjectured that a pre-collapse system has to restructurize prior entering collapse. This conjecture is to a certain extent confirmed by the simulations. Indeed, each of the smooth pre-collapse evolutions of 1982 – 1986 and 1989 – 1992 terminates far distant from the domain of negative wages (which is contained in the zone of collapse), and each of these smooth evolutions is followed by a period of an irregular behavior implying restructurization.

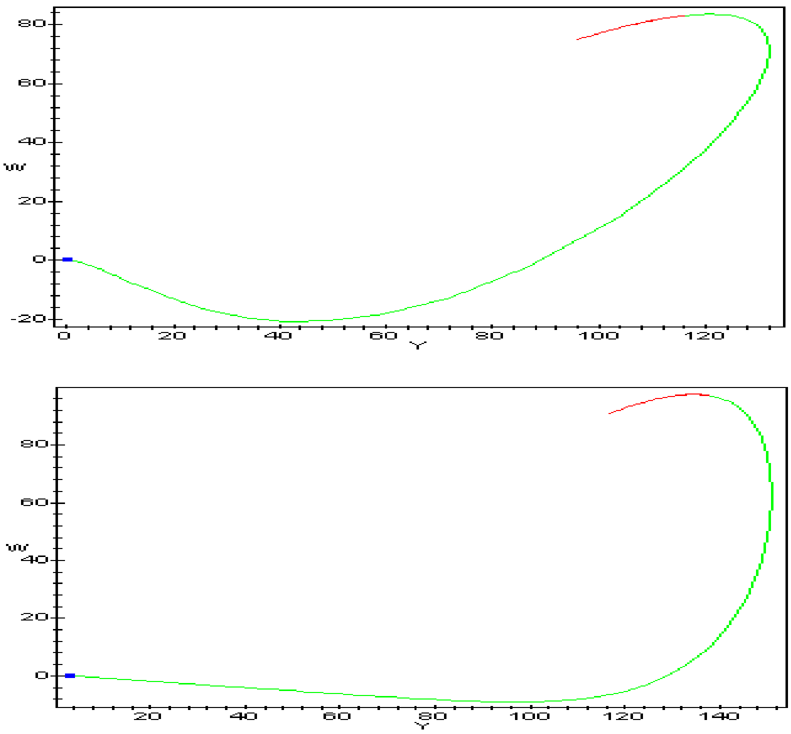

Fig. 5.4.
The model trajectories for 1982 – 1986 (limited pre-collapse: the short black curve in the left bottom part of the upper figure) and for 1989 – 1992 (limited pre-collapse: the short black curve in the left bottom part of the lower figure) and their extrapolations in coordinates (Y, W).

5.4 Electric industry, 1982 – 1998

Fig. 5.5 shows the actual dynamics of production, Y (billion yens), and wage, W (billion yens), in Japan's electric industry in period 1982 – 1998 and the trajectories of the identified model (1.2).

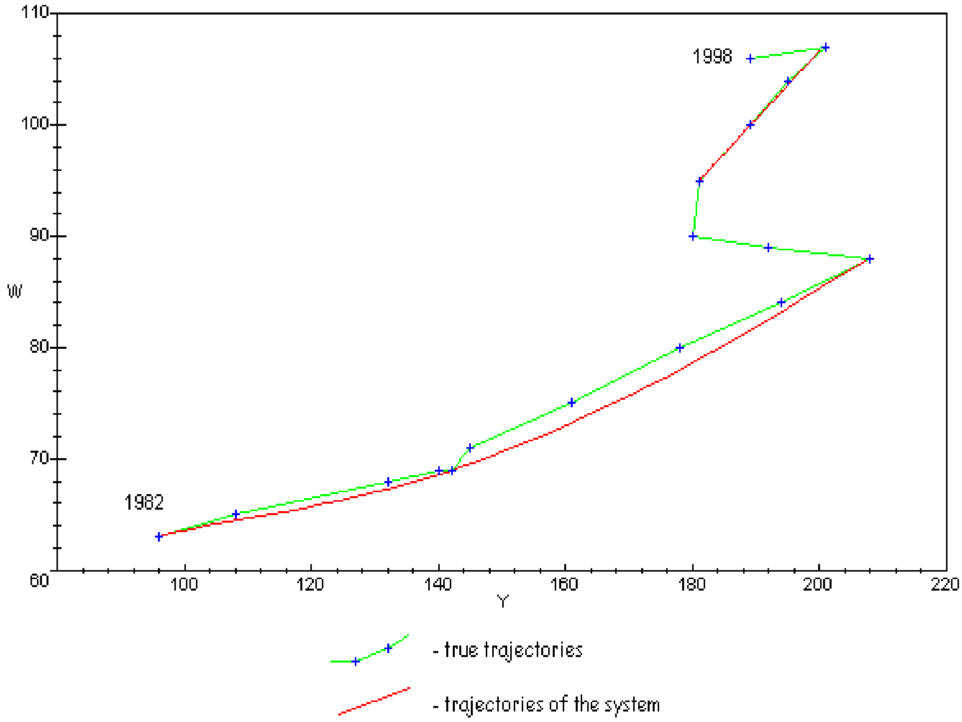

Fig. 5.5.
Production, Y (billion yens), and wage, W (billion yens),
in Japan's electric industry in 1982 – 1998 and the trajectories
of the model identified at stage 1.

The evolution is close to the evolution in Japan's manufacturing (see subsection 4.2). There are four periods in the evolution. In period 1982 – 1991 both production and wage grow. In 1991 – 1994 the system survives a transition characterized by decline in production and a jump in wage. In period 1994 – 1997 both production and wage grow again. In 1997 – 1998 production and wage decline. The techno-labor system restructurized in 1991/1992, in 1994/1995 and in 1997/1998. We identified the model for periods 1982 – 1991 and 1994 – 1997 where production and wage grow smoothly.

Table 5.3 shows the parameters of the identified model (the outcome of stage 1), characterizes the dynamics in terms of stagnation/progress (the outcome of stage 2), and identifies the behaviors of the techno-labor system in periods 1982 – 1991 and 1994 – 1997 (the outcome of stage 3).

	1982 – 1991	1994 – 1997
μ	0.98	1
α	0.8	0.32
β	0.28	0.52
γ	0.5	0.6
ρ_T	0.015	0.022
ρ_Z	0.117	0.018
u	0.08	0.1
case	progress	progress
behavior	progressive homeostasis	progressive homeostasis

Table 5.3.

Fig. 5.6 shows the trajectories of the identified model for periods 1982 – 1991 and 1994 – 1997 in the logarithmic coordinates $z = \log Z$, $\tau = \log T$. Each of the trajectories lie in the zone of progressive homeostasis, $H^{++}(u)$.

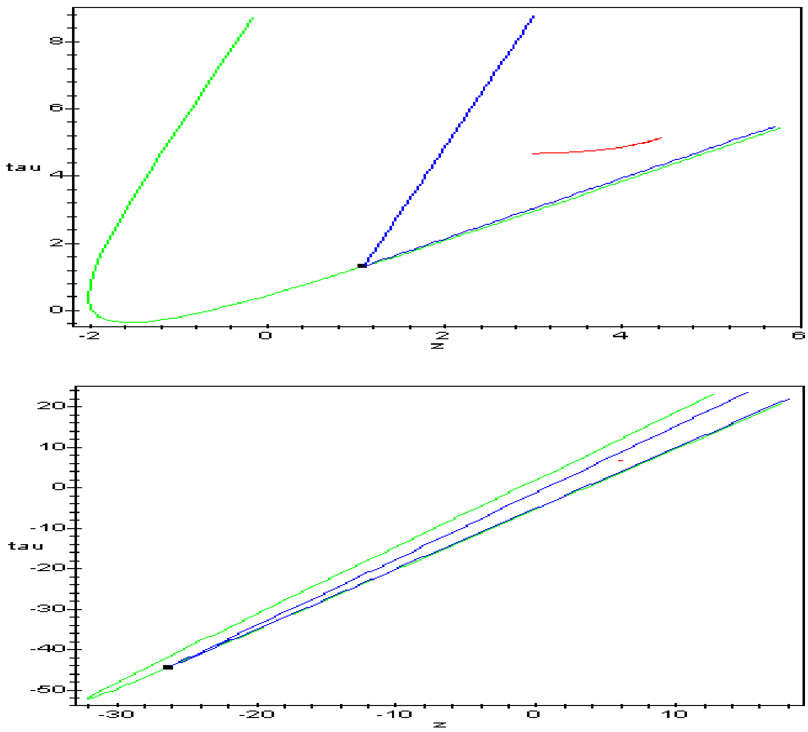

Fig. 5.6.
The model trajectories for 1982 – 1991 (progressive homeostasis: the short curve in the upper figure) and for 1994 – 1997 (progressive homeostasis: the short curve in the lower figure) in the logarithmic coordinates $z = \log Z$, $\tau = \log T$. The north-west angle is the zone of progressive homeostasis for the identified control u (see Table 5.3). The interior of the grey loop is the union of the zones of progressive homeostasis over all controls.

5.5 Nonfarm less housing, 1982 – 1998

Fig. 5.7 shows the actual dynamics of production, Y (billion yens), and wage, W (billion yens), in Japan's nonfarm less housing in period 1982 – 1998 and the trajectories of the identified model (1.2).

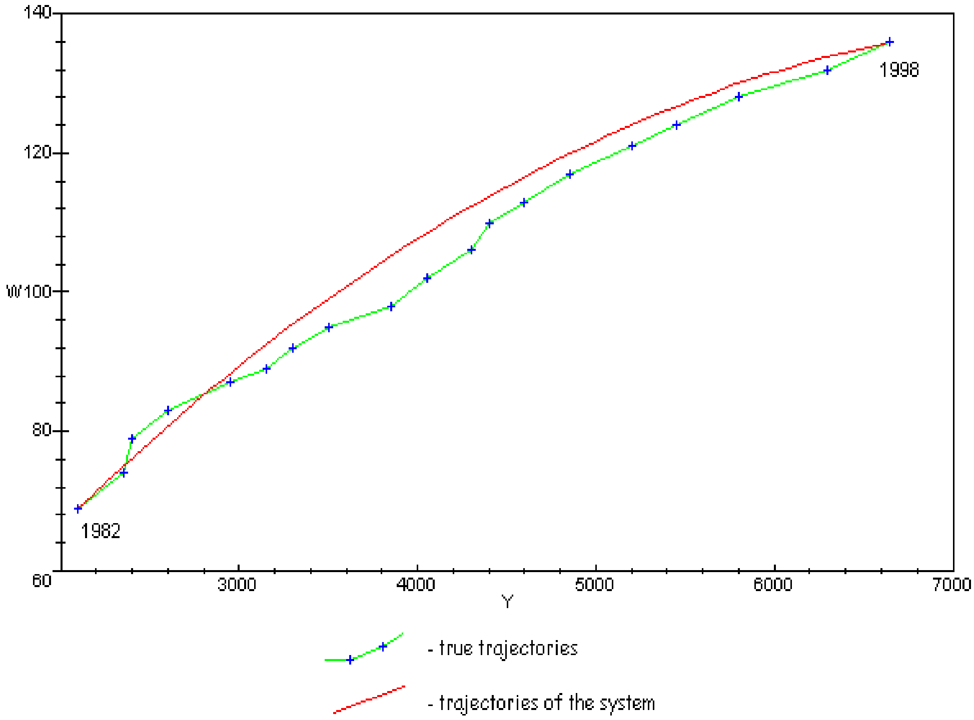

Fig. 5.7.
Production, Y (billion yens), and wage, W (billion yens), in Japan's nonfarm less housing in 1982 – 1998 and the trajectories of the model identified at stage 1.

Unlike the data analyzed previously, the data series for Japan's nonfarm less housing does not indicate any transitions and restructutizations. Table 5.4 shows the parameters of the identified model (the outcome of stage 1), characterizes the dynamics in terms of stagnation/progress (the outcome of stage 2), and identifies the behaviors of the techno-labor system in period 1982 – 1998 (the outcome of stage 3).

	1982 – 1998
μ	0.85
α	0.32
β	0.8
γ	0.5
ρ_T	0.045
ρ_Z	0.03
u	0.93
case	progress
behavior	total pre-collapse

Table 5.4.

Fig. 5.8 shows the trajectory of the identified model for period 1982 – 1998 (the short black curve) and the extrapolation of the trajectory to a future period (the grey curve) in the logarithmic coordinates $z = \log Z$, $\tau = \log T$. The trajectory is extrapolated via the simulation of the model. The trajectory remains in the zone of total pre-collapse, $C(u)$, with growing wages and nearly constant technologies. It does not reach the zone of total collapse, $C^{--}(u)$, since $W = \dot{Z} > 0$. However, the final point of the trajectory is close to the critical point of the extrapolated trajectory, at which both walfare and technologies begin to decline; at this point the extrapolated trajectory enters the zone of total collapse, $C^{--}(u)$. In Fig. 5.8, the "south-west" boundary of the union of the zones of homeostasis, $H^{++}(u)$, over all controls u is also shown. The trajectory never crosses this boundary, which shows that the system is never able to enter homeostasis.

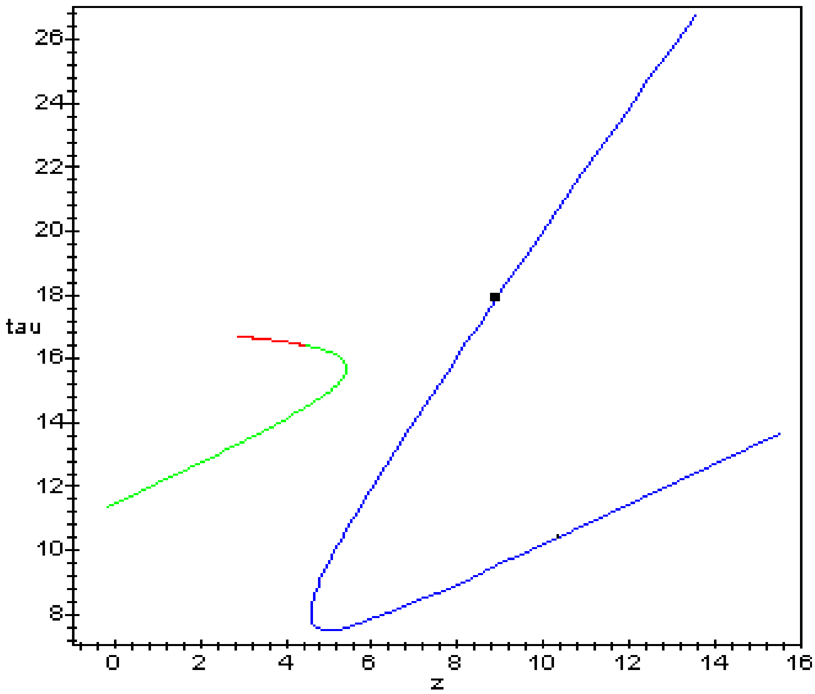

Fig. 5.8.
The model trajectory for 1982 – 1998 (total pre-collapse: the short black curve in the left part of the figure) and its extrapolation in the logarithmic coordinates $z = \log Z$, $\tau = \log T$. The interior of the black loop is the union of the zones of regressive homeostasis over all controls.

6 Conclusions

The paper suggests a model of techno-labor development of an economy sector. The model is closed in the sense that the annual investments in labor and technologies are due to the sales of the annual production output. The scope of model's behaviors comprises homeostasis (the most desirable behavioral type) and collapse (opposite to homeostasis), as well as transition behaviors leading to homeostasis or collapse. Moreover, the model's parameters pre-determine one of the admissible cases in the model's dynamics: progress or stagnation. We use production/wages data series to identify the model for several industry sectors of Japan in 1982 – 1998. Depending on the location of the identified parametrers and states, we characterize the associated cases and behaviors. The next table summarizes the resulting observations:

Japan's industry sector	Case	Behavior
Manufacturing, 1982 – 1991	progress	progressive pre-homeostasis
Manufacturing, 1994 – 1997	progress	progressive homeostasis
Food industry, 1982 – 1986	stagnation	limited pre-collapse
Food industry, 1989 – 1992	stagnation	limited pre-collapse
Electric industry, 1982 – 1991	progress	progressive homeostasis
Electric industry, 1994 – 1997	progress	progressive homeostasis
Nonfarm less housing, 1982 – 1998	progress	total pre-collapse

It could be anticipated that this classification given in terms of our formal model may differ from expert estimates based on a complex economic analysis and much more detailed sets of data. On the other hand, situations where our model-based qualitative observations agree with experts' estimates, may indicate that the suggested model-based approach can, potentially, be developed into a useful tool to support assessment of techno-labor dynamics in economy sectors.

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