THE ACCELERATION AND SLOWDOWN OF TECHNICAL PROGRESS IN THE US SINCE THE CIVIL WAR:

THE TRANSITION BETWEEN TWO PARADIGMS

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RÉSUMÉ

L'ACCÉLÉRATION ET LE RALENTISSEMENT DU PROGRÈS TECHNIQUE AUX ÉTATS-UNIS DEPUIS LA GUERRE DE SÉCESSION : *LA TRANSITION ENTRE DEUX PARADIGMES*

Cette étude analyse les caractères fondamentaux des changements de la technique et de la répartition aux États-Unis depuis la Guerre de Sécession comme l'expression de l'émergence progressive d'un nouveau paradigme, correspondant à une Révolution Managériale, et sa substitution à l'ancien paradigme hérité de la Révolution Industrielle. Un modèle du changement technique, d'inspiration évolutionniste, est introduit en vue de rendre compte du profil des transformations de la technique et de la répartition à l'intérieur de chaque paradigme (l'innovation est un processus stochastique, et les nouvelles techniques sont sélectionnées selon leur rentabilité). En faisant la moyenne des deux secteurs de l'économie correspondant aux deux paradigmes, il est possible de reproduire les tendances historiques des variables. Par exemple, le modèle explique pourquoi la productivité du capital et le taux de profit manifestent successivement des tendances à la baisse, à la hausse et à la baisse, au cours des trois périodes : 1869-1910, 1910-1950 et 1950-1992. La diffusion du nouveau paradigme rend compte, à la fois, de l'apparition puis de l'érosion des traits favorables de la période intermédiaire.

ABSTRACT

THE ACCELERATION AND SLOWDOWN OF TECHNICAL PROGRESS IN THE UNITED STATES SINCE THE CIVIL WAR : *THE TRANSITION BETWEEN TWO PARADIGMS*

This paper analyzes the basic features of technical and distributional changes in the US since the Civil War as the expression of the gradual emergence of a new paradigm, corresponding to a Managerial Revolution, and its replacement of the earlier organization inherited from the Industrial Revolution. A stochastic model of technical change of evolutionary inspiration is presented that accounts for the profiles of technology and distribution, within each paradigm. (Innovation is random, and new techniques are selected depending on their profitability.) By averaging the two sectors of the productive system corresponding to each paradigm, it is possible to reproduce the historical trends for each variable. For example, the model explains why the productivity of capital and the profit rate displayed successively downward, upward, and downward trends over the three subperiods, 1869-1910, 1910-1950, and 1950-1992. Both the emergence and erosion of the favorable features of the intermediate period, 1910-1950, are explained by the diffusion of the new paradigm.

MOTS CLEFS : Changement technique, taux de profit, tendances historiques, modèle évolutionniste, paradigme.
KEYWORDS : Technical change, profit rate, historical tendencies, evolutionary model, paradigm.
J.E.L. Nomenclature : 040.

INTRODUCTION

The investigation of the historical profile of technology and distribution in the US economy, since the Civil War, reveals a periodization into three stages, corresponding, by and large, to the late 19th century, the first half of the 20th century, and the post-1950s. There is an interesting similarity between the first and third periods, with slower growth rates of labor productivity and real wages, and a *declining* productivity of capital and profit rate. Conversely, and despite the paradoxical interruption of the Great Depression, the intermediate period — the first half of the century — combines several exceptionally favorable features: a stronger growth rate of labor productivity and real wages, and a *rising* productivity of capital and profit rate.

This paper is a new attempt at the interpretation of these profiles to which we already devoted a number of studies (G. Duménil, M. Glick, D. Lévy, "The Rise of the Profit Rate during World War II", *The Review of Economics and Statistics*, LXXV (1993) p. 315-319, G. Duménil, D. Lévy, *The Economics of the Profit Rate: Competition, Crises, and Historical Tendencies in Capitalism*, Aldershot: Edward Elgar, 1993, "Stylized Facts about Technical Progress since the Civil War: A Vintage Model", *Structural Change and Economic Dynamics*, V (1994) p. 1-23, and "A Stochastic Model of Technical Change, Application to the US Economy (1869-1989)", *Metroeconomica*, XLVI (1995) p. 213-245). There are several aspects relevant to this analysis:

1. The first and third periods can be characterized as two distinct *paradigms* (encompassing under this label, technology, management, related institutions, and their dynamics or, collectively, *technical progress*). The first paradigm is typical of mature capitalism, and was inherited from the English *Industrial Revolution*. The second paradigm is that of *Managerial Capitalism*. The revolution observed between the two paradigms relates to the *more efficient use of resources*, capital and labor.
2. The intermediate period is interpreted as the progressive transition from the earlier to the more recent paradigm. As the new organization is gradually extended to all segments of the productive system, progress is manifested in the larger growth rates of labor productivity and the exceptional *rise* of the productivity of capital, paralleled by the simultaneous increase in the growth rate of real wages and a rising profit rate.
3. During the third period, when the diffusion of the new paradigm was almost completed, the resurgence of earlier trends echoes the fact that technical progress is largely subject to the same rules under the two paradigms. A profile similar to that observed during the first period is reasserted, which we call a pattern *à la Marx*, since its combines the basic features described in Volume III of *Capital*, in particular a strongly rising capital-labor ratio (the composition of capital) and a declining profit rate (K. Marx, *Capital, Volume III*, New York: First Vintage Book Edition, 1894, Part Three).
4. Each paradigm is described by a stochastic dynamical model of evolutionary inspiration, in which firms search for and select new techniques. In this respect, our approach is akin to that of Richard Nelson and Sidney Winter ("Factor Prices Changes and Factor Substitution in an Evolutionary Model", *Bell Journal of Economics*, VI (1975) p. 466-486 and *An Evolutionary Theory of Economic Change*, Cambridge: Harvard University Press, 1982). The purpose of this analysis is not only to argue for a more

realistic approach to innovation and technical change than that provided by the production function — or to show how it is possible, within a nonconventional framework, *to relate factor prices and factor substitution* — but also to propose a simple and analytically manageable model.

There is no denying the fact that the analysis of these historical trends and fluctuations is difficult, and that the available data are not sufficient to establish the above account fully empirically. analysis in this paper must be understood as a possible "interpretation". The methodology is similar to that used in previous research. Beginning with stylized facts, we outline a provisional "story", which matches other aspects of our research ; the simplest possible model accounting for this interpretation is then built in order to verify the overall consistency of the story and, often, to reveal some of its hidden implications; then, under the pressure of our own and other's criticisms, time is ripe for sophistication or rejection !

The paper is composed of four main sections. Section 1 recalls stylized facts and makes explicit the interpretation in terms of transition between two paradigms outlined above. This section also compares our analysis to similar approaches. Section 2 presents the evolutionary model of technical change and its generalization to the case of two paradigms. Section 3 applies this model to the analysis of historical trends in the US. Section 4 introduces a number of possible developments, and discusses the robustness of the results.

1 - THE US ECONOMY SINCE THE CIVIL WAR: THE TRANSITION BETWEEN TWO PARADIGMS

Section 1.1 documents the historical trends of the main variables accounting for technology and distribution since the Civil War, and describes in some detail the basic features of the three stages. Section 1.2 explains how we understand these movements as the transition between two distinct paradigms. Section 1.3 is devoted to a survey of the literature.

1.1 A PERIODIZATION IN THREE STAGES

The description of technical and distributional trends below is based on the conventional representation of production, in which two factors, labor and capital, are combined. Labor income corresponds to total labor compensation (including a correction for self-employed). "Profits" measure the entire excess of the Net National Product (NNP) over labor income. More precisely, the variables are defined as follows: (1) Labor productivity, Y/L, is the ratio of the NNP in constant dollars to the total number of hours worked, (2) The productivity of capital, Y/K, is the ratio of the NNP to the gross stock of fixed capital, both in constant dollars, (3) The capital-labor ratio, K/L, is defined as the gross stock of fixed capital in constant dollars divided by the number of hours worked, (4) Labor cost, w, is the hourly nominal wage (total compensation) divided by the deflator of the NNP, (5) The wage share, ω is the ratio of labor income to the NNP, and (6) The profit

Table 1 - Average Annual Growth Rates (% per Year) and Average Value of the Wage Share (%)

	1869-1910	1910-1950	1950-1992	*1869-1992*
$\rho(Y/L)$	1.22	2.33	1.48	*1.95*
$\rho(Y/K)$	−1.22	1.39	−0.88	*0.04*
$\rho(K/L)$	2.07	0.40	2.24	*1.48*
$\rho(w)$	1.46	2.33	1.48	*1.95*
$\rho(r)$	−1.66	1.40	−0.88	*0.05*
ω	65.7	68.5	65.2	*66.4*

rate, r, is obtained by dividing profits, *i.e.*, *the NNP minus total labor income*, by the *net stock of fixed capital*, both in current dollars.[1]

The profiles of labor productivity, the productivity of capital, the profit rate, and labor cost are presented in figures 1 to 4 (——) (together with the reconstruction of the series). Table 1 displays the average growth rates of the variables for three subperiods of approximately forty years and the entire period 1869-1992 (and the average value of the wage share). An examination of these figures and the table reveals a very similar pattern in three stages for the growth rates of each variable :

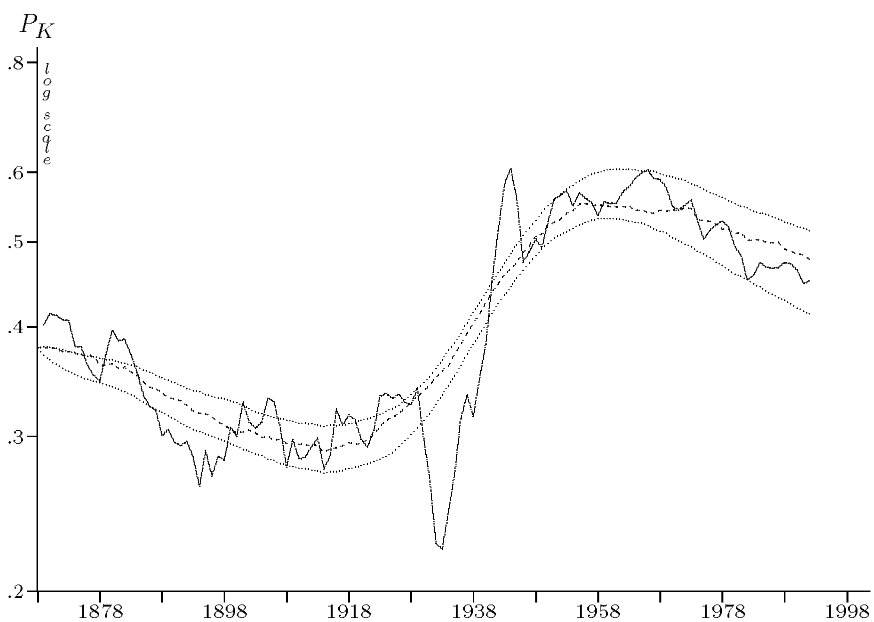
1. The movements of labor productivity, in figure 1 (——), and labor cost, in figure 4 (——), are very similar. From 1869 to the turn of the century or early 20th century, these growth rates are smaller than the average for the entire period. Then the trend is steeper. Finally, a slowdown is observed, and the growth rates return to values close to those observed in the 19th century.
2. The historical fluctuations of the productivity of capital, in figure 2 (——), and the profit rate, in figure 3 (——), are similar : declining during the first and third periods, and rising in between.
3. The capital-labor ratio rises steeply during the first and third periods, and stagnates during the second period.
4. The wage share is approximately constant, as could be gleaned from the similarity between the profiles of labor cost and labor productivity (since $\omega = w/(Y/L)$).

These observations clearly reveal the similarity between the first and third periods, as well as the exceptional features of the intermediate period. During this period, 1910-1950, the growth rates of labor productivity and wages were stronger than the average ; the capital-labor ratio only grew slowly, and the trends of the profit rate and of the productivity of capital were *upward*. The coincidence of the larger growth rates of wages and of the rise in the profit rate emphasizes the very favorable character of this intermediate period. Conversely, we denote as periods *à la Marx* the first and third periods, where the profit rate *declines*, while the rate of growth of labor cost, as well as that of labor productivity are below the average !

1. Sources and the construction of the variables are presented in G. Duménil, D. Lévy, The U.S. Economy since the Civil War : Sources and Construction of the Series, Cepremap, Modem, Paris. The series presented in this study can be obtained on a diskette (USLT4), 1994.

Figure 1 Labor Productivity: Series (——) and Model (-----) as in Section 3.3.2

Figure 2 The Productivity of Capital: Series (——), Model (-----) as in Section 3.3.2, and Confidence Interval (·········) as in Section 3.3.3



In spite of the similar pattern in three stages observed for all variables, small differences are also evident. For example, the growth rate of the productivity of capital culminates in 1940, whereas the growth rate of labor productivity reaches its peak in 1951, that is eleven years later, simultaneously to the growth rate of labor cost (also in 1951).[2]

1.2 TWO PARADIGMS

We interpret these patterns as a manifestation of the existence of two distinct paradigms, characteristic of the first and third periods, and the gradual transition from the first to the second paradigm, during the intermediate period. Thus, our analysis combines two aspects of technical change : the transition between two paradigms, *i.e.*, the "revolutionary" component of technical change (section 1.2.1), and the dynamics of technical change within each paradigm, which accounts for the less dramatic component of technical change (section 1.2.2).

1.2.1 The Transition between Two Paradigms

By *paradigm*, we mean a specific technology and its dynamics, *i.e.*, technical *change*. It is important to stress that technology must be understood in the very broad sense of the term, since it cannot be separated from a complex of social relations and institutions, such as the institutional framework of laws and regulations, the educational system, state involvement in research programs, etc., but also, at a more general level of analysis, relations of production and class patterns, inasmuch as they are related to technology and technical change.[3]

The first paradigm is inherited from the Industrial Revolution in England, as described in particular by Marx in *Capital*. It is dominated by the factory system within industry (surrounded by more traditional organization within other sectors, such as agriculture or services). The main feature of technical change is *mechanization*. The progress of labor productivity follows from the use of more and more sophisticated equipment, and the application of energy to production. The technical composition of capital, or the capital-labor ratio, grows rapidly, whereas labor productivity and real wages only grow slowly, and the productivity of capital and the profit rate decline. The typical social relation is that which antagonizes the capitalist owner to the productive worker.

The second paradigm corresponds to a "revolution" of a distinct type, a *revolution in management*: Firm management was transferred from traditional capitalist owners to a new class of managers, surrounded by numerous employees, *managerial and clerical personnel* (G. Duménil, D. Lévy, "The Emergence and Functions of Managerial and Clerical Personnel in Marx's Capital", *in* N. Garston (ed.), *Bureaucracy : Three Paradigms*,

2. In the dating of the maximum growth rates, we abstract from short-term fluctuations. More specifically, a trend line is determined using the Whittaker filter (see R.J. Hodrick, E.C. Prescott, Postwar US Business Cycles : an Empirical Investigation, Working Paper, Carnegie Mellon University, 1980), and the year of maximum growth is that of the trend line. A parameter $\lambda = 1000$ is used in the filter, but these results are not very sensitive to this choice. (For $\lambda = 10000$, the maximum growth rate is obtained in 1938 instead of 1940 for the productivity of capital.)

3. An interesting analysis of "*Institutions Supporting Technical Change in the United States*" can be found in R.R. Nelson, "Institutions Supporting Technical Change in the United States", *in* G. Dosi, C. Freeman, R. Nelson, G. Silverberg, L. Soete (eds.), *Technical Change and Economic Theory*, London : Pinter, 1988, p. 312-329.

Figure 3 The Profit Rate: Series (——) and Model (-----) as in Section 3.3.2

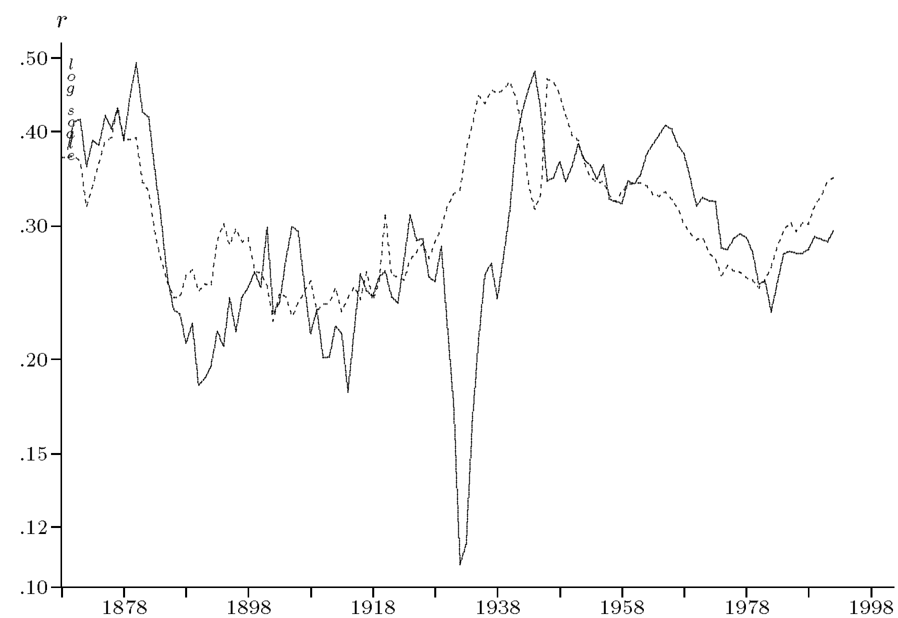


Figure 4 Labor Cost: Series (——) and Model (-----) as in Section 3.4

Boston: Kluwer Academic, 1994, p. 61-81). Simultaneously, capitalists retreated to the financial sector of the economy.

An important literature, with often ambiguous motivations, has been devoted to this managerial revolution. Alfred Chandler (*The Visible Hand. The Managerial Revolution in American Business*, Cambridge: Harvard University Press, 1977 and *Scale and Scope. The Dynamics of Industrial Capitalism*, Cambridge: Harvard University Press, 1990), for example, describes the rise of the large industrial corporation with its hierarchical management by salaried managers. He shows how this transition was performed in relation to new technical achievements and new industries, such as transportation and communications. During our intermediate period, this new organization infiltrated progressively all sectors of the economy, including trade and services.

These transformations were accompanied by those of competition and the mechanisms governing capital mobility among industries (and, therefore, relative investment). In the late 19th century, US capitalism was actually at a crossroad, when the rise of "big business" represented a real threat on competition. Actually, two typical forms of consolidation were progressing simultaneously: *loose* consolidation (trusts, cartels, pools) in which firms survive with basically unchanged organisational features, and *tight* consolidation (actual mergers) (H.B. Thorelli, *The Federal Antitrust Policy. Organization of an American Tradition*, Baltimore: Johns Hopkins Press, 1955). The development of a new legal framework under the Sherman act, and the superior efficiency of the new organization gave the advantage to tight consolidation, *i.e.*, the new managerial large corporation.

The major characteristic of this new management can be summarized in one word, *efficiency*. Technology and all aspects of firm management were transformed, diminishing costs, and saving on fixed capital, inventories, liquidities, etc. The typical form of this new organization in the workshop is the assembly line, which, in a sense, can be described as a new shift toward *mechanization*. However, this equipment has been originally devised in order to ensure its continuous and intensive use. It simultaneously guarantees larger labor and capital productivities, instead of the traditional rise of labor productivity at the cost of a diminished productivity of capital (and does not result in a strongly increased capital-output ratio).

Note that the transfer of firm management to managerial and clerical personnel does not imply that management is no longer targeted at the maximizing of profits. Quite the contrary, we believe that diminished profit rates in the late 19th century strongly stimulated this transformation, and that these new groups devoted their efforts to obtaining maximum profits. These efforts were successful and led to the rise of the profit rate during the first half of the 20th century. This restoration came as a bonanza after a period of significant decline of the profit rate.

Note that during the period of transition, technology and management are actually *heterogeneous*. Two segments coexist within the economy. There is no instantaneous switch to the new paradigm, simply because it is more profitable. This feature relates to the institutional facet of the metamorphosis, in which education, laws, etc. are involved. Even more fundamentally, relations of production are at issue: Corporate ownership must be substituted for individual ownership, property must be redistributed, a new class of managerial and clerical personnel moves to the fore, etc.

Last, it must be stressed that the favorable features of our intermediate period mirror the *diffusion* of the new paradigm (from the origin, more efficient than the former paradigm), not *a priori* more favorable patterns of evolution (dynamics of technical change). It would be incorrect to relate the third stage to the *exhaustion* of the new paradigm; it actually reflects the *completion of the transition*.

1.2.2 Technical Change within Each Paradigm

A paradigm corresponds simultaneously to a given state of technology at each point in time, and its law of evolution, *i.e.*, the rules governing technical change.

In order to analyze technical change within each paradigm, we use the model of evolutionary inspiration that we introduced in earlier studies (G. Duménil, D. Lévy, "Complexity and Stylization: An Evolutionary Model of Technical Change in the US Economy", *in* R. Delorme, K. Dopfer (eds.), *The Political Economy of Diversity: Evolutionary Perspectives on Economic Order and Disorder*, Aldershot: Edward Elgar, 1994, p. 229-251 and "A Stochastic Model of Technical Change, Application to the US Economy (1869-1989)", *Metroeconomica*, XLVI (1995) p. 213-245):

1. Innovation is a *random* and *local* process, expressing the outcome of R&D activities.
2. Firms select new techniques on the basis of a profitability criterion.

Because of this reference to the profit rate, prices and, in particular, labor cost have an impact on technical change. A rising labor cost results in a rising capital-labor ratio. This dependency is important in the explanation of the profiles observed during our first and third periods, where labor productivity *rises* and the productivity of capital *declines*.

For simplicity, we assume that each paradigm follows its own law of evolution, *i.e.*, that the features of technical change within each paradigm are autonomous (in particular, the existence of the new, more efficient, paradigm does not accelerate the rhythm of technical change in the older paradigm).

The model used in this paper is simpler than that presented in G. Duménil, D. Lévy, "Complexity and Stylization", *op. cit.* note 3, since the productive system is considered globally, and little attention is paid to heterogeneity and disequilibrium (see section 4).

1.3 HISTORICAL TRENDS AND PARADIGMS IN THE LITERATURE

The historical trends described in section 1.1 have not gone totally unnoticed. A number of early works identified the acceleration of labor productivity at the beginning of the 20th century (in particular, J.W. Kendrick, *Productivity Trends in the United States*, Princeton: Princeton University Press, 1961); much research has been devoted to the analysis of the (labor) productivity slowdown during recent decades (E.F. Denison, *Accounting for Slower Economic Growth: The United States in the 1970s*, Washington: The Brookings Institution, 1979); Robert Gordon ("The Incidence of the Corporation Income Tax in US Manufacturing", *American Economic Review*, LVII (1967) p. 731-758) analyzed the rise of the profit rate through World War II, and its relationship to the rise of capital productivity. The notion of a periodization in three stages is not widespread, however. This is clearly revealed by the acknowledgement by Gordon, in a recent paper, that he borrowed this idea from our work (see R.J. Gordon, American Economic Growth: One Big Wave?, Working Paper, Northwestern University and NBER, 1993, footnote 1). Gordon uses the expression *one big wave* to designate the above profile.

There is actually a Darwinian aspect in our analysis. The new paradigm can be described as a kind of new species which emerges at some point in time. It is different from the previous species, the former paradigm, and later evolves autonomously in its environment. There is no "coevolution". Originally, the new species is outnumbered by the old one, but it gradually pervades the entire system.

This vision of competing paradigms (and the way we model technical change within a paradigm) relates to the evolutionary inspiration of our approach. It seems, therefore, useful to provide here a few elements of comparison with other works adopting a similar perspective. (In this comparison, we will mainly refer to the recent synthesis in G. Dosi, C. Freeman, R. Nelson, G. Silverberg, L. Soete, *Technical Change and Economic Theory*, London : Pinter, 1988.)

The use of the notion of *paradigm*, or related notions, is rather broad in this literature, but with various definitions. For example, Giovanni Dosi ("The nature of the Innovative Process", *in* G. Dosi, C. Freeman, R. Nelson, G. Silverberg, L. Soete (eds.), *Technical Change and Economic Theory*, London : Pinter, 1988, p. 221-238) gives a rather narrow meaning to the notion of *technological paradigm*, which corresponds to a given equipment (the internal combustion engine) or industry (microelectronics). What we call a *paradigm* is closer to what Freeman and Perez (C. Freeman, C. Perez, "Structural Crises of Adjustment : Business Cycles and Investment Behavior", *in* G. Dosi, C. Freeman, R. Nelson, G. Silverberg, L. Soete (eds.), *Technical Change and Economic Theory*, London : Pinter, 1988, p. 38-66) call *technico-economic paradigm*. In their analysis, each Kondratieff corresponds to such a paradigm. Another common point relates to the distinction that we make between *technical change within a given paradigm* and *the shift to a new paradigm*. This distinction echoes their hierarchy between incremental innovation, radical innovation, change of "technology system", and change of "technico-economic paradigm" (p. 45-47).

It is probably not fruitful, however, to interpret the historical fluctuation that we observed in terms of "long waves" or "Kondratieff cycles," as in C. Freeman, C. Perez, *ibid.*, since, over the period of more than a century covered by our study, the observed pattern was never repeated.[4,5] Our approach is closer to that of Maddison (*Dynamic Forces in Capitalist Development. A Long-Run Comparative View*, Oxford : Oxford University Press, 1991), who also studies technology from a macroeconomic point of view, and identifies periods similar to ours.

The notion of *régulation*, as used within the *Régulation School* is even broader in content than our definition of paradigm. Under the label of *régulation*, régulationists include a large system of institutions related to macro policies, accumulation, competition, wage determination, as well as technical change. The emphasis is actually not necessarily on the rules governing technical change, but rather on the forms of competition and the "wage relation". R. Boyer, "Technical Change and the Theory of 'Régulation"', *in* G. Dosi, C. Freeman, R. Nelson, G. Silverberg, L. Soete (eds.), *Technical Change and Economic Theory*, London : Pinter, 1988, p. 67-94 uses the terminology *Competitive Régulation* vs *Monopolistic Régulation* to characterize the successive stages of capitalism that he investigates.

4. However, like Freeman and Perez, we also stress the "*emergence of giant firms, cartels, trusts and mergers* [...]" or the emergence of specialized "*middle management*" within large firms.
5. An evolutionary model of long waves is presented in G. Silverberg, D. Lehnert, "Long Waves and 'Evolutionary Chaos' in a Simple Shumpeterian Model of Embodied Technical Change", *Structural Change and Economic Dynamics*, IV (1993) p. 9-37.

Concerning the modeling of technical change, we share with evolutionary economics the rejection of the *production function*.[6] As is well known, since the papers of Robert Solow ("The Theory of Capitalist Development, A Contribution to the Theory of Economic Growth", *Quarterly Journal of Economics*, LXX (1956) p. 65-94 and "Technical Change and the Aggregate Production Function", *Review of Economics and Statistics*, XXXIX (1957) p. 312-320), the production function has become the conventional framework in which to study growth and technical change. In the last few years, an important literature (beginning with P. Romer, "Endogenous Technological Change", *Journal of Political Economy*, XCVIII (1990) Part 2, p. S71-S102) has questioned the exogenous character conferred on growth and technical change. However, the theory of endogenous growth still requires the production function, and remains, in many respects, less radical than earlier attacks which fundamentally questioned the production function (see, for example, N. Kaldor, *Essays on Economic Stability and Growth*, London: Gerald Duckworth, 1960 and H.A. Simon, "On Parsimonious Explanations of Production Relations", *Scandinavian Journal of Economics*, LXXXI (1979) p. 459-474). This resilience of the production function is striking, and probably due to its ability to account for a number of well-known "stylized facts" and, in particular, the relationship between factor prices and factor substitution.

This rejection of the production function should not be confused with the denial of the role of prices (basically wages) in connection with technical change, which we judge to be of prominent importance. There is, actually, no unique point of view, in this respect, within evolutionary economics:

1. The acknowledgement of this dependency of technical change on prices is also present in Nelson's and Winter's work ("Factor Prices Changes and Factor Substitution in an Evolutionary Model", *Bell Journal of Economics*, VI (1975) p. 466-486 and *An Evolutionary Theory of Economic Change*, Cambridge: Harvard University Press, 1982). An important aspect of their analysis is the investigation of the reasons for a "*negative association between the wage rate and the labor-capital ratio, and a positive association of the wage rate with output per worker*" R.R. Nelson, S.G. Winter, "Factor Prices Changes and Factor Substitution in an Evolutionary Model", *Bell Journal of Economics*, VI (1975) p. 466-486 p. 469. The relationship between prices and technical change follows in their analysis from the use of a profitability criterion: "*Firms that are profitable at prevailing prices expand relative to less profitable and unprofitable firms.*" (p. 469).
2. The vision of Dosi and Orsenigo (G. Dosi, L. Orsenigo, "Coordination and Transformation: An Overview of Structures Behaviours and Changes in Evolutionary Environment", *in* G. Dosi, C. Freeman, R. Nelson, G. Silverberg, L. Soete (eds.), *Technical Change and Economic Theory*, London: Pinter, 1988, p. 13-37) is different. They contend that innovations are "naturally" profitable: "*These new techniques and new products in turn are likely to be or become superior to the old one irrespective of relative prices.*" (p. 17), or, in more "classical" formulation: "*The new wage-profit frontiers associated with the new techniques do not intersect for any positive value the 'old' one.*" (p. 227). We disagree with this view. The reference to prices is, indeed, necessary to account for the simultaneous decline of the productivity of capital and rise of labor productivity.

6. By "production function", we mean here a traditional function, such as a Cobb-Douglas, or a CES function, along which factors can be substituted. Our model, uses a description of technology with fixed input coefficients (*i.e.*, a "production function" of a particular type).

The *random* and *local* characters of innovation seem widely accepted. They correspond to the first and fifth stylized facts concerning innovation listed in G. Dosi, "The nature of the Innovative Process", *in* G. Dosi, C. Freeman, R. Nelson, G. Silverberg, L. Soete (eds.), *Technical Change and Economic Theory*, London: Pinter, 1988, p. 221-238, p. 222-223.

One unique aspect of our approach is that our model analyzes the transition between two paradigms, with their specific historical dynamics, rather than the transition between two given states of technology. (A number of models exist which account for the transition between two techniques, see, for example, the review in J.S. Metcalfe, "The Diffusion of Innovations: An Interpretative Survey", *in* G. Dosi, C. Freeman, R. Nelson, G. Silverberg, L. Soete (eds.), *Technical Change and Economic Theory*, London: Pinter, 1988, p. 560-589 or R.R. Nelson, S.G. Winter, *An Evolutionary Theory, op. cit.* note 3, 10.1.)

2 - THE MODELING OF TECHNICAL CHANGE

The stochastic emergence of new techniques (innovation), within one paradigm, is described in section 2.1, and their selection, based on a profitability criterion, in section 2.2. Then, section 2.3 introduces a deterministic approximation of the model in which some of its property can be made explicit. Finally, section 2.4 presents the general model in which two paradigms coexist, with particular emphasis on the central mechanism in this study, *viz.* the transition between two paradigms.

2.1 INNOVATION (WITHIN A SINGLE PARADIGM)

Consider a very simple economy in which only one good is produced by a single firm. The production of one unit of this good uses A units of itself and L units of labor as inputs. Thus, the productivity of capital is $P_K = 1/A$, and labor productivity is $P_L = 1/L$. Consider now a new technique (A_+, L_+). We define, a and l, the rates of saving on each input, by:

$$A_+ = A/(1+a) \quad \textit{and} \quad L_+ = L/(1+l)$$

Variables a and l are also equal to the growth rates of the productivities of the two inputs:

$$\rho(P_K) = a \quad \text{and} \quad \rho(P_L) = l \tag{1}$$

The comparison between the two techniques can be symbolically described as in panels (a) and (b) of diagram 1. A new technique is represented by a point, and the black dot (•) corresponds to the old technique. Within region [1], the new technique economizes on each input. Conversely, both inputs are increased within region [4]. Regions [2] and [3] describe situations in which the economy on one input is obtained at the cost of an increased utilization of the other.[7]

7. The point of view of Dosi and Orsenigo concerning the "natural" profitability of innovation (see section 1.3) can be interpreted in reference to this framework: most innovations fall within region [1].

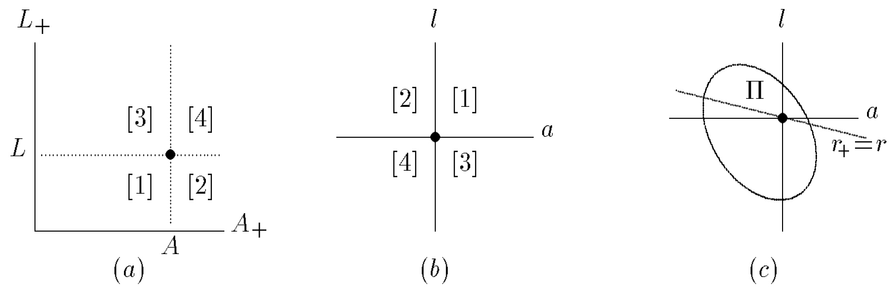


Diagram 1

Innovation expresses the random outcome of R&D activities. When a project is initiated, it is not possible to predict its outcome. Firms search on the basis of the previously existing technique, and the size of innovation is limited (innovation is local). As shown in panel (c) of the diagram, we assume that innovation can be represented by a *probability law*, $\pi(a, l)$, whose support is bounded and denoted as the *innovation set*. It includes the existing technique.

2.2 THE SELECTION OF PROFITABLE INNOVATIONS (WITHIN A SINGLE PARADIGM)

New techniques within region [1] in diagram 1 save on each input, and will always be adopted, and all techniques in region [4] will be rejected. This section discusses the decision to adopt a technique corresponding to regions [2] or [3], which saves on a single input at the cost of an increased utilization of the other.

The *profit rate* is the criterion in the selection of new techniques. If the profit rate (computed with the same wage rate) of the new technique is larger than that of the previous one, the innovation is selected, and it is rejected if it is lower. The borderline between selected and rejected techniques, corresponding to the condition $r_+ = r$, can be represented by a downward sloping line crossing the origin in the plane (a, l) (see panel (c) in diagram 1). We denote this line as the *selection frontier*. Thus, only the new techniques which fall within the innovation set and above the selection frontier are selected. This region, Π, will be called the *profitable innovation set*.

Using w to denote the exogenous *labor cost*, *i.e.*, the unit wage deflated by the price of the good (also called "wages" for short), the profit rate can be expressed as:

$$r = \frac{1 - Lw}{A} \tag{2}$$

Under the assumption that the innovation set is small, the new profit rate, r_+, can be developed linearly in the vicinity of the prevailing profit rate r:

$$r_+ = r\left(1 + \frac{\mu a + l}{\mu}\right) \tag{3}$$

In this equation, $\mu = (1 - \omega)/\omega$ is the ratio of profit to wages, with $\omega = Lw$ denoting the wage share. The equation of the selection frontier is $\mu a + l = 0$ (and its slope is μ).

This concludes the construction of the stochastic dynamical model for the two variables A and L (or P_K and P_L), with labor cost, w, as the only exogenous variable. On this basis, it is possible to generate "technical trajectories" within one paradigm. To this end, one only needs to specify the probability law which accounts for the emergence of new techniques, the initial values of A and L, and to follow the procedure indicated in this section and the preceding, which allows for the derivation of A and L in $t+1$ from their value in t.[8] Along such technical trajectories, any trend may prevail: capital productivity and the profit rate may rise or decline, labor productivity may grow rapidly or slowly, etc.

2.3 A DETERMINISTIC APPROXIMATION OF THE MODEL

In order to shed some light on the ability of this model to account for a broad variety of technical patterns, this section studies a *deterministic approximation* of the model. In this approximation, the stochastic values of the growth rates of the two productivities are replaced by their *average values*.

Section 2.3.1 is devoted to the average values of the variables and some of their properties. When these average values are considered, a deterministic dynamical model is obtained. Section 2.3.2 presents this model, and its asymptotic trajectories are determined. Last, section 2.3.3 summarizes the main results of this investigation.

2.3.1 The Average Values of Labor Productivity and the Productivity of Capital

In the deterministic approximation of the model, the stochastic values of the growth rates of the two productivities are replaced by, $\overline{a}$ and $\overline{l}$, their average values:

$$\overline{a} = \iint_{\Pi} a\, d\pi(a,l) \quad \textit{and} \quad \overline{l} = \iint_{\Pi} l\, d\pi(a,l)$$

in which the integrals are limited to selected innovations, *i.e.*, the profitable innovation set Π. They are functions of the probability law (which is given) and of the slope of the selection frontier, μ, and, thus, of the wage share ω: $\overline{a} = \overline{a}(\omega)$ and $\overline{l} = \overline{l}(\omega)$.

The following properties of $\overline{a}$ and $\overline{l}$ can be easily derived geometrically:

Theorem 1: (i) *The average growth rate of the productivity of capital, $\overline{a}(\omega)$, is a decreasing function of ω.* (ii) *The average growth rate of labor productivity, $\overline{l}(\omega)$, is an increasing function of ω.*

Consider panel (c) of diagram 1. A small wage share, ω, corresponds to a rather vertical selection frontier, and a large wage share to a frontier close to horizontal. A rising wage share is associated with a counterclockwise rotation of the frontier. This rotation of the frontier entails, in a similar direction, that of the point whose coordinates correspond to the average values of the two productivities, diminishing $\overline{a}$ and increasing $\overline{l}$.

The economic meaning of these properties is straightforward. With a given technology, the rise of labor cost increases ω. As a result of the rotation of the selection frontier, the

8. The issue of the *endogenous* nature of technical change in our model can, obviously, be raised. The selection of new techniques is clearly endogenous, since it is based on profitability. The case of innovation is different. The probability law which governs innovation has been considered as given. There would, of course, be no objection to endogenizing this law.

average growth rate of the productivity of capital, $\overline{a}$, is smaller, the average growth rate of labor productivity, $\overline{l}$, is larger and, thus, the speed of the substitution of capital for labor is faster. In other words, the rise of labor cost causes that of the growth rate of the capital-labor ratio. One difference with the production function model is, however, that technology is *path-dependent*: The characteristics of today's technology are functions, not only of the present value of wages, but of the entire sequence of labor costs in the past, and not only of its present value.

Even if innovation is neutral, *i.e.*, if the innovation set is symmetrical with respect to the first bisector, the profitable innovation set, Π, is not symmetrical, and imparts a bias to technical change. Accordingly, this effect of distribution on technical change must be distinguished from a possible *a priori* bias of the innovation set.

2.3.2 The Deterministic Dynamical System for a Given growth Rate of Wages, and its Asymptotic Trajectories

After substituting the average values of innovation, $\overline{a}$ and $\overline{l}$, for their stochastic values, a and l, into equations 1, a deterministic dynamical system is obtained for the two variables which describe technology, A and L (or equivalently P_K and P_L). This section focuses on the asymptotic trajectories of the model, which provide a framework for the interpretation of the historical trends of the variables.

The only exogenous variable is labor cost. We assume that its growth rate is constant and denoted ρ_w. With this assumption, and replacing L (or P_L) by the wage share $\omega = Lw$, the dynamical system can be written as:

$$\begin{aligned} \rho(\omega) &= \rho_w - \overline{l}(\omega) \\ \rho(P_K) &= \overline{a}(\omega) \end{aligned} \tag{4}$$

The first equation can be studied independently of the second. As stated in theorem 1, $\overline{l}(\omega)$ is a monotonically increasing function of ω. Therefore, if ρ_w belongs to the interval $[\overline{l}(0), \overline{l}(1)]$, a unique fixed point, $\omega^\star$, exists. At the fixed point, the wage share is constant and, thus, the growth rate of labor productivity is also constant and equal to that of wages:

$$\rho(P_L) = \overline{l}(\omega^\star) = \rho_w \quad \textit{or} \quad P_L = \frac{w}{\omega^\star} = P_L(0)e^{\rho_w t} \quad \textit{with} \quad P_L(0) = \frac{w(0)}{\omega^\star} \tag{5}$$

In continuous time, the local stability of this fixed point is easy to prove. It follows from the second item in theorem 1 which determines the sign of the derivative of $\overline{l}(\omega)$, and proves that the sign of the (unique) eigenvalue of the Jacobian matrix is negative.

These properties are rather intuitive. If labor productivity grows at a slower rate than the exogenous labor cost, ($\overline{l}(\omega) < \rho_w$), a rising labor share follows. The rotation of the selection frontier provokes, in turn, a larger growth rate of labor productivity, as shown above. Conversely, a labor productivity growing at a larger rate than labor cost rotates the selection frontier toward a more vertical position, and initiates a decline in the growth rate of labor productivity. Equilibrium is reached when the two growth rates are equal.

Consider now the second equation (equations 4). The fixed point of the first equation corresponds to an asymptotic trajectory in which the productivity of capital, P_K increases or diminishes at a constant rate:

$$P_K = P_K(0)e^{\overline{a}(\omega^\star)t}$$

Since $r = (1-\omega)P_K$, the same is true for the profit rate, $\rho(r) = \rho(P_K)$, and, since $\rho(K/L) = \rho(P_L) - \rho(P_K)$, the capital-labor ratio also grows at a constant (positive or negative) rate.

The following results have, thus, been obtained:

Theorem 2: *For a given probability law and a given growth rate of labor cost within the interval* $[\bar{l}(0), \bar{l}(1)]$, *the variables converge toward an asymptotic trajectory. On this trajectory, the wage share is constant (or labor productivity grows at the same constant rate as labor cost). The productivity of capital and profit rate grow at the same positive or negative constant rate. The capital-labor ratio also grows at a positive or negative constant rate.*

One should notice that, on an asymptotic trajectory, labor productivity is entirely determined (its level and growth rate are both given), whereas only the growth rate of the productivity of capital is determined. Its value in t depends on its initial value in 0. These distinct properties echo the fact that labor cost is given exogenously, when the profit rate is determined endogenously.

In what follows, we will assume that these results can be extended to the case of a growth rate of labor cost changing slowly over time.

2.3.3 Technical Change Within One Paradigm: A Summing Up

A given *paradigm* is defined by the initial values of labor productivity and of the productivity of capital, and the probability law governing innovation.

Two categories of properties of a paradigm have been demonstrated in the previous sections:

1. In any situation, *i.e.*, not necessarily on an asymptotic trajectory, the value of the labor cost has an impact on the choice of new techniques and, therefore, on the substitution of capital for labor. However, technology is a function of the entire sequence of wages, *i.e.*, technical change is *path-dependent*.
2. For a given growth rate of labor cost, technology converges to an asymptotic trajectory in which the wage share is given, as well as the growth rates of labor productivity, of the productivity of capital, and of the profit rate. Labor productivity grows at the same rate as labor cost. The growth rates of the productivity of capital or profit rate are equal, and can be positive or negative.

The existence and stability of this asymptotic path does not imply that technology always gravitates around such a path. We believe that this situation is characteristic of a paradigm which has reached a form of "maturity". When a new paradigm is introduced, there is no reason to assume that such maturity has been attained.

2.4 THE TRANSITION BETWEEN TWO PARADIGMS

If two paradigms exist, both of them can be represented using the model in the previous sections, with their own characteristic features (the probability law and the initial values of the productivities). The values of the variables for the total economy can be obtained by averaging for the two paradigms, weighting by the amounts of capital invested in each segment of the productive system.

We denote as K^i the capital stock for each paradigm (with $i = 1$ for the older paradigm, and $i = 2$ for the new one), and $y = K^1/K^2$, the ratio between the two capital stocks. One paradigm produces $K^i P_K^i$, and consumes $K^i P_K^i L^i$ units of labor. The average productivity of capital and labor productivity are:

$$P_K = \frac{K^1 P_K^1 + K^2 P_K^2}{K^1 + K^2} = \frac{y P_K^1 + P_K^2}{y+1}$$

$$P_L = \frac{K^1 P_K^1 + K^2 P_K^2}{K^1 P_K^1 L^1 + K^2 P_K^2 L^2} = \frac{\left(y \frac{L^1}{A^1}\right) P_L^1 + \left(\frac{L^2}{A^2}\right) P_L^2}{\left(y \frac{L^1}{A^1}\right) + \frac{L^2}{A^2}}$$

One also has: $r = \dfrac{y r^1 + r^2}{y+1}$ and $\omega = \dfrac{w}{P_L}$.

We assume that the diffusion of the new paradigm throughout the entire productive system — from its mere appearance to its generalization and, therefore, the vanishing of the former paradigm — is steady, and can be represented by a declining function of time, $y(t)$.

The modeling of the diffusion of the new paradigm is treated in the appendix. In this analysis the profit rate is the central variable. (The profitability differential accounts for the growth differential of the capital stocks in the two paradigms.)

The transition can be depicted as in diagram 2, where each paradigm has reached its asymptotic trajectory. Each figure in this diagram depicts the two asymptotic trajectories (⋯⋯) and the average for the total economy (——), for the productivity of capital (a), labor productivity (b), and the profit rate (c). These figures point to the following two properties:

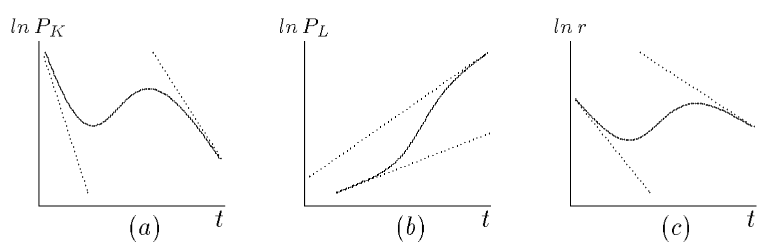


Diagram 2

1. The asymptotic trajectories of the two paradigms differ.
2. In spite of the declining trends observed for both the asymptotic trajectories of the productivity of capital and the profit rate, the average for the total productive system can be rising during the transition period.

3 - A MODEL FOR THE US

The model introduced in section 2.4 remains very general, and could be applied to several distinct problems. The present section applies this framework to the analysis of technical and distributional changes in the US economy since the Civil War. As shown in section 3.1, an examination of the series suggests additional assumptions concerning the two paradigms. Section 3.2 specifies the probability law accounting for the emergence of new techniques. The reconstruction of the series is presented in section 3.3. In this analysis, labor cost is still considered as an exogenous variable. Its modeling is, finally, introduced in section 3.4.

3.1 A REVOLUTION IN TECHNOLOGY RATHER THAN IN TECHNICAL CHANGE

This section discusses the nature of the metamorphosis between the first and second paradigms. We locate the main difference between the two paradigms in the distinct initial values of the two variables, whereas, on the contrary, the features of technical change (the probability law) remained *unchanged*. In other words, the major metamorphosis brought about by the new paradigm concerns a new set of values of the two productivities and not the parameters governing technical change : *a revolution in the organization of production and technology, rather than a revolution in technical change.* (More technically, there is a change in the levels, but not in the trends of the variables.)

This hypothesis is based on the striking similarity, observed in section 1.1 (see table 1), between the trends prevailing during the first and third periods (late 19th century and second half of the 20th century). First, similar (negative) growth rates of the productivity of capital obtain. Second, nearly identical growth rates of labor cost result in approximately equal labor shares. An examination of equations 4 and 5 shows that these two observations follow in a straightforward manner from the assumption that *the probability law is identical for the two paradigms.*[9]

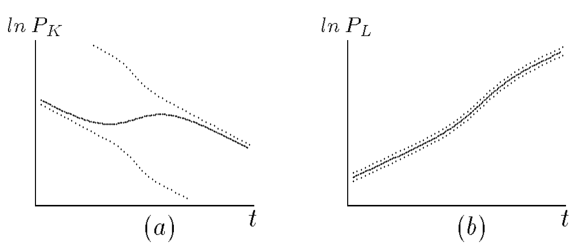


Diagram 3

9. This interpretation further assumes that the first paradigm is old and has reached its asymptotic position from the beginning of the period covered, and the new paradigm reaches its asymptotic position during the third period (but not necessarily during the first period which coincides with its emergence).

Assuming that the two paradigms remained in the vicinity of their asymptotic trajectories, and taking account of the fact that labor cost varied historically according to the pattern *Slower / Faster / Slower* (see table 1), the following interpretation of historical trends in the US clearly emerges (see diagram 3):

1. Two consequences follow From the assumption of an unchanged probability law. First, the *growth rates* of the productivity of capital in the two paradigms are equal. This is reflected in the fact that the two doted lines (········) in the diagram are parallel. Second, the *values* of labor productivity are equal in the two paradigms, and the two doted lines are merged into a single one in the diagram.
2. The rise of the productivity of capital during the intermediate period is the effect of the transition from the first paradigm to the second.
3. The larger growth rate of labor cost during the intermediate period is associated with a larger share of wages. From this it follows that (see theorem 1):

- The growth rate of labor productivity rises during the intermediate period.
- The growth rate of the capital-labor ratio diminishes during this period.

3.2 THE PROBABILITY LAW

The entire specification of the model requires the determination of the probability law. In this connection, we choose *a uniform probability distribution within a circle*. This circle, the innovation set, is centered in (δ_a, δ_l), and its radius is R (with $\delta_a^2 + \delta_l^2 < R^2$). Under these assumptions, one can explicitly compute the average values of a and l:

$$\rho(P_K) = \overline{a} = R\mu g(\beta) - \delta_a f(\beta) \quad \textit{and} \quad \rho(P_L) = \overline{l} = Rg(\beta) - \delta_l f(\beta) \quad \textit{with:}$$

$$\beta = -\frac{1}{R}\frac{\mu\delta_a + \delta_l}{\sqrt{1+\mu^2}}, \quad g(\beta) = \frac{2}{3\pi}\frac{(1-\beta^2)^{3/2}}{\sqrt{1+\mu^2}}, \quad \textit{and } f(\beta) = \frac{1}{\pi}\left(\beta\sqrt{1-\beta^2} - \textit{arccos}\,\beta\right)$$

The difference between the growth rates of labor and capital productivities, that is the growth rate of the capital-labor ratio, can be written as:

$$\rho(K/L) = \overline{l} - \overline{a} = \underbrace{R(1-\mu)g(\beta)}_{\textit{Substitution}} - \underbrace{(\delta_l - \delta_a)f(\beta)}_{\text{A priori } \textit{bias}}$$

The first term expresses the effect of distribution on technical change. It is equal to zero if the wage share is equal to 1/2 (*i.e.*, if, μ, the slope of the selection frontier is equal to 1). Under such circumstances, distribution does not impart any bias in technical change. If the wage share is larger than 1/2, capital is substituted for labor (and conversely if $\omega < 1/2$). The second term refers to the bias in technical change independent of distribution. It is equal to zero if $\delta_a = \delta_l$, and the center of the circle belongs to the first bisector (*i.e.*, if innovation is neutral). Capital-saving or labor-saving changes may be favored depending on the coordinates of the center.

3.3 RECONSTRUCTION

We now turn to the reconstruction of the series. The methodology is, first, introduced in section 3.3.1. The results and their interpretation are presented in section 3.3.2. Last, section 3.3.3 discusses the robustness of the estimation, by presenting a confidence interval.

3.3.1 Methodology

In order to reconstruct the variables, the model is used in simulation. The exact procedure is the following:

1. A set of values of parameters is chosen, R, δ_a, and δ_l, to describe the innovation set (the same values for the two paradigms).
2. At each period a new technique is determined randomly for the first paradigm. The profit rate of this technique is computed and compared to that obtained assuming that the previous technique is maintained. The technique yielding the largest profit rate is adopted. The procedure is initiated choosing values of the variables, A and L, which describe the technique in 1868. This procedure is repeated period after period, and a technical trajectory generated (the elementary period used in the model is not the year, but the month).
3. The same procedure is then applied to the second paradigm.
4. Finally, we compute the average values of P_K, P_L, and r[10], under the assumption that, y, the ratio between the two capital stocks varies exponentially.

The model includes 9 parameters: (R, δ_a, δ_l) for the innovation set, (A, L) in 1868 for the two paradigms, and y in 1868 and its growth rate ρ_y.

3.3.2 Results and Interpretation

It is not too difficult to choose a set of nine parameters allowing for the reproduction of the two productivities and the profit rate. The results of this reconstruction are presented in figures 1, 2, and 3 (-----). In spite of the simple features of the model, these reconstructions are quite satisfactory.

In 1868, the ratio of the capital stock in the two paradigms is equal to $y = 32$ (*i.e.*, the capital stock in the new paradigm amounts to 3.3% of the total capital stock). This ratio declines rather fast, since $\rho_y = 10.9\%$ (per year).

The initial values of the variables (for 1868) are as follows:

First Paradigm:	$A = 2.65$	*i.e.*,	$P_K = 0.377$
	$L = 0.369$	*i.e.*,	$P_L = 2.71$
Second Paradigm:	$A = 1.62$	*i.e.*,	$P_K = 0.617$
	$L = 0.116$	*i.e.*,	$P_L = 8.60$

These figures emphasize the more efficient performances of the second paradigm whose productivities are considerably larger. One should be careful, however, concerning the precision of the above figures, since the productivities for the still embryonic second paradigm are not well defined for the first years.

The three parameters which define the innovation set are as follows (in % per month):

$$R = 0.734, \quad \delta_a = -0.392 \quad \textit{and} \quad \delta_l = -0.048$$

10. In the reconstruction of the profit rate, we do not attempt to reproduce the relative price of GNP *vis-à-vis* capital, and the ratio of gross capital to net capital. These ratios vary in connection to the diminishing service life of fixed capital and the variations of accumulation. Instead of equation 2, we use the formula, $N_1 N_2(1 - Lw)/A$, in which N_1 and N_2 correct for the two above effects and are determined empirically. (Note that this problem is not met in the reconstruction of the productivity of capital.)

These results show that nearly no bias exists on labor productivity, whereas a significant bias obtains for the productivity of capital. It is possible to decompose the growth rate of the capital-labor ratio into its two components, a "substitution" effect due to the growth of the labor cost and an *a priori* bias on innovation.[11] With the average share of wages prevailing in the US ($\omega = 66.4\%$), the average growth rate of the capital-labor ratio, which is equal to 1.39% in the model (for an actual value of 1.48%), can be decomposed into 0.50% for the substitution effect, and 0.89% for the *a priori* bias on innovation.

3.3.3 Confidence Interval

The reconstruction of the variables results from a single random set of values of the variables. It is possible to estimate the confidence intervals for the estimations by varying only the stochastic variables, for the same set of parameters (including those characteristic of stochastic distributions). 1000 such trajectories have been computed.

The doted lines in figure 2 represent the upper and lower bounds within which 95% of the resulting sample runs lie. As can be expected all paths originate from the same initial value, and progressively the distance between the bounds increases with time. In 1992, an interval of approximately 24% is obtained for the productivity of capital. These observations confirm the view that the trajectories depend on the exact drawing, but that this dependency is limited and does not compromise the basic properties of the model.

3.4 THE ENDOGENOUS TREATMENT OF LABOR COST

The interpretation in the previous section provides two distinct explanations for the profile of the *productivity of capital* and *labor productivity* during the intermediate period. The variation of P_K mirrors the transition between the two paradigms, and that of P_L corresponds to the larger growth rate of labor cost. *This difference relates to the still exogenous treatment of labor cost.*

It is not the purpose of this study to analyze the determination of labor cost (or the real wage rate), which is a complex issue in which various time frames are involved. Concerning the point of view of the very long term in this study, we will adopt the model presented in G. Duménil, D. Lévy, *The Economics of the Profit Rate : Competition, Crises, and Historical Tendencies in Capitalism*, Aldershot : Edward Elgar, 1993 (Section 15.4), in which the growth rate of the labor cost is expressed as a function of the growth rate of the profit rate and its value in each year :

$$\rho(w) = \beta_0 + \beta_1 \rho(1+r) + \beta_2 \, ln(1+r)$$

This relationship expresses the view that increasing or larger profit rates are favorable to the rise of wages, and conversely for declining or lower profit rates. This link is quite obvious in the recent decades (since approximately the 1970s), when the downward trend of the profit rate induced slower growth rates of the labor cost. The term $\beta_2 \, ln(1+r)$ in the above equation accounts for the lag which can be observed in the variation of labor cost vis-à-vis that of the profit rate. For example, the larger growth rate of the labor cost during the 1960s were, to a certain extent, prolonged into the 1970s.

11. It is easier to find new capital-consuming rather than capital-saving innovations.

The model can be estimated including this new equation and, thus, treating labor cost endogenously. The results are as satisfactory as those obtained with the exogenous labor cost. For simplicity, we only present the reconstruction of the labor cost (figure 4). (As could be expected, the short-term fluctuations are not reproduced.)

In this framework, the following conclusions are obtained :

1. The transition between the two paradigms explains now *the two aspects* of the intermediate period. It accounts in a straightforward manner for the rise of the productivity of capital. It also indirectly explains the larger growth rate of labor productivity : The rising productivity of capital induces the rise of the profit rate, which, in turns, allows for the larger growth rate of the labor cost, which finally provokes the larger growth rates of labor productivity.
2. The fact that the growth rate of labor productivity reaches its maximum later than the productivity of capital, as noted at the end of section 1.1, is explained by the lag of the labor cost on the profit rate.
3. It is the decline of the profit rate which explains the lower growth rates of labor productivity, and not the *productivity slowdown* which accounts for the decline of the profit rate.

4 - DISCUSSION AND RELATIONSHIP TO EARLIER STUDIES

The model in section 2 is based on rather drastic assumptions. This option echoes the major emphasis in this study, which is placed on the *transition* between two paradigms, not on the *modeling of technical change within a single paradigm* as in previous studies (G. Duménil, D. Lévy, "Complexity and Stylization", *op. cit.* note 3 and "A Stochastic Model of Technical Change, Application to the US Economy (1869-1989)", *Metroeconomica*, XLVI (1995) p. 213-245). In particular, the model abstracts from all forms of heterogeneity and disequilibrium within the economy.

In G. Duménil, D. Lévy, "Complexity and Stylization", *op. cit.* note 3, we consider the three following sources of complexity, in a model in which a single paradigm is considered :

1. A first source of heterogeneity is linked to the coexistence of *various vintages of fixed capital*, in which distinct techniques are embodied. The model in section 2 of the present paper describes the "average" technology by two input coefficients, and analyzes technical change as the variation with time of these coefficients. Actually, technology is, to a large extent, *putty-clay*, *i.e.*, once fixed capital has been installed, it is difficult to modify its technical features, and several vintages with different features exist simultaneously.[12]

12. See G. Duménil, D. Lévy, "Stylized Facts about Technical Progress since the Civil War : A Vintage Model", *Structural Change and Economic Dynamics*, V (1994) p. 1-23 for the details of the construction of a vintage model. This paper also discusses the issue of economic obsolescence and premature discards of older vintages.

2. A second aspect of heterogeneity relates to the existence of *several goods and enterprises*. It is possible to generalize the model in this paper to the consideration of such diversity. (When a same good is produced by distinct producers, there is no need to assume a single price.)
3. In the model in this paper, commodity markets are implicitly assumed to be in equilibrium, and productive capacities are supposed to be used at "normal" levels. The same approach to technical change can be embodied within a *general disequilibrium model*, in which decisions are made within disequilibrium, firms are price and quantity makers, supplies differ from demands, stocks of unsold commodities exist, capacity utilization rates differ from normal, etc.[13] In this framework, where radical uncertainty prevails, behaviors are modeled in terms of adjustment to disequilibrium (and not maximizing).

The overall conclusion of the investigation in G. Duménil, D. Lévy, "Complexity and Stylization", *op. cit.* note 3 is that, from the point of view of the explanation of the macro profile of technical change and distribution, these additional sources of complexity are not essential.

In both G. Duménil, D. Lévy, *ibid.* and "A Stochastic Model of Technical Change, Application to the US Economy (1869-1989)", *Metroeconomica*, XLVI (1995) p. 213-245, only a single paradigm is considered, and the historical profile of the variables is reproduced by *varying the parameters defining the innovation set* (R, δ_a, and δ_l). The hypothesis in these earlier studies is that the difficulty to innovate was relaxed during the intermediate period, shifting the innovation set along the first bisector to the North-East. The present paper substitutes to this approach a different vision, in which two paradigms are distinguished, but with invariant features. The path and rapidity of technical change are now the effect of the different rhythms of accumulation in the two segments of the economy governed by the two paradigms. This new interpretation has different advantages over the previous one :

1. It moves one step further toward the endogenous treatment of technical change, in a more disaggregated model.
2. The vanishing of the favorable profile of the intermediate period is built in, "programmed" in a sense, since it corresponds to the completion of a transition and there is no notion of exogenous exhaustion of a paradigm.
3. It is more in line with our understanding of the economic history of the US in general.

APPENDIX : MODELING THE TRANSITION BETWEEN THE TWO PARADIGMS

This appendix discusses four models of the transition between the two paradigms. The first model leads to an exponential variation of the ratio, y, between the two capital stocks in the two paradigms, *i.e.*, the function actually used in this paper.

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13. This framework would allow for the discussion of the Schumpeterian relationship between the business cycle and technical change.

The overall idea is that the profit rate is the key variable which governs accumulation. This view is central to the *classical perspective*, in particular in the analysis of the formation of prices of production, accumulation, and historical tendencies (G. Duménil, D. Lévy, *The Economics of the Profit Rate: Competition, Crises, and Historical Tendencies in Capitalism*, Aldershot: Edward Elgar, 1993). It is also widely accepted within evolutionary economics (E. Mansfield, "Technical change and the rate of imitation", *Econometrica*, XXIX (1961)p. 741-766, R.R. Nelson, S.G. Winter, *An Evolutionary Theory of Economic Change*, Cambridge: Harvard University Press, 1982, S. Oster, "The diffusion of innovations among steel firms: the basic oxygen process", *Bell Journal of Economics*, XIII (1982) p. 45-56, J.S. Metcalfe, "The Diffusion of Innovations: An Interpretative Survey", *in* G. Dosi, C. Freeman, R. Nelson, G. Silverberg, L. Soete (eds.), *Technical Change and Economic Theory*, London: Pinter, 1988, p. 560-589, p. 572-576 and G. Silverberg, G. Dosi, L. Orsenigo, "Innovation, Diversity and Diffusion: A Self-Organizing Model", *The Economic Journal*, XCVIII (1988) p. 1032-1054).

In the classical analysis, the emphasis is placed on the "comparison" between various activities, or capital mobility. In addition to self-financing, external sources of finance, such as loans, bonds, or shares, are considered, and funds are channelled within holdings and firms themselves (actually a hierarchy of parent companies and subsidiaries) toward various fields of activity. Profitability differential is supposed to play a prominent role in all these relationships.[14]

The first three models below adopt the point of view of capital mobility, and the fourth one that of self-financing. We assume that each paradigm has reached its asymptotic trajectory. It is, therefore, possible to use the results of section 2.3.2 and, in particular, the expression of the profit rate:

$$r = r_0 e^{-bt} \quad \textit{with} \quad r_0 = (1-\omega^\star)P_K(0) \quad \textit{and} \quad b = -\overline{a}(\omega^\star) \tag{6}$$

• *Model I:*

This model is based on two additional assumptions: (1) The two innovation sets are identical, and (2) The equations which account for capital mobility are:

$$\rho(K^1) = \overline{\rho} + \gamma \frac{r^1 - r^2}{r^1 + r^2}$$
$$\rho(K^2) = \overline{\rho} - \gamma \frac{r^1 - r^2}{r^1 + r^2}$$

in which $\overline{\rho}$ denotes the average growth rate of the capital stock. If $r^2 > r^1$, growth is faster within the second paradigm, and conversely if $r^1 > r^2$.[15] From these equations, one can

14. The frontier between the various trends of thought is often difficult to draw. J. Stanley Metcalfe, who approaches these issues "*from a number of different theoretical perspectives*" (p. 560), writes, for example, that the growth rate of productive capacity is determined by the profit rate: "*Given the product price, firms with different technologies earn differential profits (rents) which they invest in further capacity expansion.* (p. 573)". This statement could be interpreted in terms of self-financing: profits realized in a given enterprise are invested within this firm. However, Metcalfe goes on as follows: "*Moreover, it is the relative profitability of competing technologies, not their absolute profitability, which is important (p. 562)*".

15. The profitability differential, $r^1 - r^2$, is divided by $r^1 + r^2$, *i.e.*, "normalized", since a differential of 1% is not supposed to lead to the same adjustment of capital stocks if the profit rates are, for example, 5% and 6%, or 35% and 36%.

derive the growth rate, $\rho(y)$, of the relative capital stock $y = K^1/K^2$:

$$\rho(y) = -2\gamma \frac{r^2 - r^1}{r^1 + r^2}$$

From equation 6 and the assumption that the two innovation sets are identical, it follows that a same parameter b prevails for the two paradigms. After eliminating e^{-bt}, one obtains $\rho(y) = \rho_y$, where the constant ρ_y is defined as $\rho_y = -2\gamma \frac{r_0^2 - r_0^1}{r_0^1 + r_0^2}$. Thus, one has:

$$y = y_0 \, exp(-\rho_y t)$$

This first model is a particular case of the two following.

- *Model II:*

This second model is based on the same assumptions, with the exception that the innovation sets may differ. Therefore, the growth rates of the two profit rates differ, and the normalized profitability differential is not constant. One has now:

$$\rho(y) = -2\gamma \frac{r_0^2 - r_0^1 \, exp(-(b^1 - b^2)t)}{r_0^2 + r_0^1 \, exp(-(b^1 - b^2)t)}$$

We further assume that $r_0^1 < r_0^2$ and $b^1 > b^2$ to express that the old paradigm is less profitable that the new one ($r^1 < r^2$). Solving the above equation, one obtains:

$$y = y_0 e^{-2\gamma t} \left(\frac{r_0^2 + r_0^1 \, exp(-(b^1 - b^2)t)}{r_0^2 + r_0^1} \right)^{-\frac{4\gamma}{b^1 - b^2}}$$

This function is always decreasing, since $\rho(y)$ is negative.

- *Model III:*

This model is identical to model I, but capital accumulation is modeled as:

$$\rho(K^i) = \overline{\rho} + \gamma \frac{r^i - \overline{r}}{\overline{r}}$$

with $\overline{r}$ denoting the average profit rate. The basic idea is the same as in model I, but the model is improved. First, this latter model can be generalized to the case of more than two commodities. Second, the normalization takes accounts of the relative values of the capital stock in each industry, instead of the unweigthed sum $r^1 + r^2$. Additional complexity follows from the fact that $\overline{r}$ depends on y:

$$\overline{r} = \frac{y r_0^1 + r_0^2}{y + 1} e^{-bt}$$

One can integrate the differential equation satisfied by y, but only an implicit equation in y obtains:

$$y = y_0 e^{-\gamma' t} \left(\frac{1 + y}{1 + y_0} \right)^{\delta} \quad with \quad \delta = \frac{r_0^2 - r_0^1}{r_0^2} \quad and \quad \gamma' = \gamma \delta$$

This equation has no exact explicit solution. It can be solved by successive approximations:

$$y^{(1)} = y_0 e^{-\gamma' t}$$

$$y^{(n)} = y^{(1)} \left(\frac{1 + y^{(n-1)}}{1 + y_0} \right)^{\delta}$$

Again, the exponential appears in $y^{(1)}$, the approximation to the first order.

• *Model IV:*

We now turn to the self-financing model. Capital accumulation within each paradigm is modeled as $\rho(K^i) = \gamma^i r^i$, meaning that the growth rate of fixed capital is proportional to the profit rate. We still assume that the innovation set is unchanged from the first to the second paradigm. The ratio between the two capital stocks satisfies the following relation:

$$\rho(y) = -(\gamma^2 r_0^2 - \gamma^1 r_0^1) e^{-bt}$$

whose integral is:

$$y = y_0 \, exp(A(e^{-bt} - 1)) \quad with \quad A = \frac{\gamma^2 r_0^2 - \gamma^1 r_0^1)}{b}$$

In the limit case where the profit rate declines slowly (parameter b is small), one can develop e^{-bt}. Conserving only the term of the first order, an exponential obtains.

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