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CHAPTER 3

REMODELLING STRUCTURAL CHANGE

JUSTIN YIFU LIN AND YONG WANG

3.1 Introduction

Economic development is a continuous process of economic growth accompanied by structural change, including technology, industry, hard infrastructure, and institution (or soft infrastructure) (Kuznets 1966). The existing growth literature focuses mainly on the process of resource reallocation across the three sectors (agriculture, industry, and service) in the process of structural transformation (see, for example, Herrendorf et al. 2014). Following Kuznets, throughout this chapter, structural change covers a much broader range of changes in economic structures including endowment structure, industrial structure, financial structure, and governance structure, etc. We believe that a deep understanding of the nature of economic development requires thorough analyses and explicit characterizations of the determinants, evolution, and various development implications of each of these structures, which is the research agenda of New Structural Economics (NSE) proposed by Justin Yifu Lin (Lin 2012a, 2013a).

The primary goal of this chapter is to introduce the key ideas and hypotheses of NSE, and, more importantly, to demonstrate by concrete examples the way structural change can be formally modelled in NSE. We argue that structural changes should be remodelled to highlight the central roles of endowment structure and firm viability, which deserve much more attention in the pertinent literature.

The rest of the chapter is organized as follows. In Section 3.2, we briefly review the current dominant framework for macro-development analysis, which is almost structureless. In Section 3.3, we explain why structures are important for an understanding of economic development. In Section 3.4, we introduce a benchmark model of new structural economics. In Section 3.5, we discuss several theoretical extensions to the benchmark model. Section 3.6 concludes.

3.2 Structureless Framework

Most existing macroeconomic theories (including economic growth) have largely ignored structural differences between countries at different stages of development. The benchmark model for modern macroeconomics is the one-sector growth model with the following exogenous aggregate production function:

$$Y = AK^{\alpha}H^{\beta}L^{1-\alpha-\beta}, \tag{1}$$

where Y denotes total output, A denotes total factor productivity (TFP), K denotes physical capital, H denotes human capital, L denotes raw labour hours (often normalized to the head count of workers), α and β are parameters that measure the shares of contribution of physical capital and human capital to total output, respectively. Equation (1) is used to organize thinking on what explains the aggregate output difference across countries. To understand different levels of living standard across countries, one can derive the following per capita production function from (1):

$$y = Ak^{\alpha}h^{\beta}, \tag{2}$$

where $y \equiv \frac{Y}{L}$, $k \equiv \frac{K}{L}$, $h \equiv \frac{H}{L}$ denote output per worker, physical capital per worker and human capital per worker, respectively. Equation (3), derived from (2), explains differences in growth rates across countries:

$$g_y = g_A + \alpha g_k + \beta g_h, \tag{3}$$

where $g_x \equiv \frac{d\log x}{dt}$ denotes the growth rate of x for $x \in \{A, k, h\}$.

This one-sector growth model is popular not only because it provides a simple conceptual framework of economic growth but also because it can successfully generate the Kaldor facts observed in the data of advanced economies. Moreover, it proves to be a useful quantitative framework for growth accounting, which decomposes economic growth into the contributions from the accumulation of each of the tangible and intangible inputs and TFP using (1)-(3). In addition, the obtained Solow residual term A plays a critical role in all kinds of macro-development analyses including, for example, economic fluctuations.

However, when this one-sector framework is applied to address the fundamental question why some countries are richer (higher y) or growing faster (higher g_y) than others, investigators are easily induced to only focus on the quantitative difference in A,k,h or their growth rates without seriously considering structural differences across countries at different development stages. For example, endowment structure, defined as the composition of different factor endowment (including land, labour, human capital, physical capital, etc.), is different for a country at a different stage of development. The composition of agriculture, industry, and service is also different at different income levels. Even within the manufacturing sector, the composition of sub-industries with different capital intensities (ranging from labour-intensive apparel industry to

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capital-intensive precision equipment), or industrial structure, is also different at different income levels. Moreover, financial structure, defined as the composition of different forms of financial intermediaries (including banks of different sizes, stock market, and venture capital, etc.), is also likely to be different at different income levels; the composition, stock, and quality of public goods (such as infrastructure) and public services (such as property rights protections, human security protections, supervision of public health and financial risks, etc.) are also generally different at different income levels. Clearly, none of these structural differences and entailed policy implications can be effectively explored in the one-sector growth model.

3.3 Why Structures Matter for Development

Why do these different economic structures matter? Because negligence of these structural differences and their determinants could easily result in misleading policy suggestions that hamper economic development.

In retrospect, the first wave of dominant thinking in development economics is the structuralism prevailing in the 1950s and 1960s. The proponents of structuralism observed that industrial structures are different between rich and poor countries. Industries in rich countries are generally more capital-intensive than in poor countries and the terms of trade are also in favour of rich countries. They argue that it is imperative for developing countries to establish the same industries as those in developed countries as quickly as possible, and that market failure prevents those heavy (capital-intensive) industries from emerging quickly enough in developing countries. The policy implication is, therefore, that government should provide large enough subsidies to capital-intensive industries together with import-substitution protectionist trade policies to give a big push to those 'modern industries'. Unfortunately, it turns out that such development strategies have failed in practice. The key reason is the failure of these structuralists to understand that the optimal industrial structure is endogenous and should be consistent with the endowment structure of the economy at a given stage of development (Lin 2012a, 2013a). Promoting capital-intensive industries prematurely violates the comparative advantage in factor endowment of poor countries. It would result in the need to protect non-viable firms, encouraging rent seeking, deteriorating resource misallocation, triggering price regulations or even large scale nationalization, all of which lead to slow economic growth. The failure of the structuralism policy in practice became increasingly clear and it gradually lost favour by the 1970s. Meanwhile, Keynesian macroeconomics, which advocates active government intervention, was also increasingly challenged by the neoclassical school of macro-economists who had been formally introducing rational expectation and criticizing the ineffectiveness of Keynesian interventionist policies, especially when the Keynesian theory failed to explain stagflation in the 1970s.

Ever since the 1980s, a new wave of social thought in development economics, namely, neo-liberalism, had gradually became dominant. The most representative policy advice of neo-liberalism is the so-called Washington Consensus, which emphasizes the fundamental role of the market rather than the state and highlights the importance of privatization, liberalization, and stabilization. Whereas this approach helps to initiate market-oriented reforms and deregulation, which are important in helping to improve the micro-incentives of individual households and firms, ameliorate efficiency of resource allocation, and create market environment that is more conducive to economic growth, the limitations of this approach are also enormous. Neo-liberalism sets the market institution of developed countries as the uniform target of reforms for all developing countries and advocates spontaneous structural transformation without a role for the state other than protecting private property rights and maintaining social order.

One manifestation of the failure of the neo-liberalist approach is the 'shock therapy', which proposes that all market reforms (especially privatization) should be completed as rapidly as possible because all institutions and policies are interrelated, presumably making partial and gradual reforms more distorting and harmful than a thorough and once-and-for-all grand reform (Murphy et al. 1992). The former Soviet Union is the stereotype of a country that adopts the shock therapy, but it turned out to be a disaster: the state became too weak and society became unstable, the unemployment rate skyrocketed, and GDP growth plunged immediately due to the collapse of non-viable firms in previously protected industries. In fact, even today the Russian economy has not yet fully recovered since the reform began more than 25 years ago. Other East European countries that adopted the shock therapy also suffered similar problems. A further symptom of neo-liberalism is the low feasibility of implementing all the prescribed comprehensive reforms. Governments in poor countries are usually tightly constrained in terms of the fiscal resources, manpower, and political support necessary to allow them to complete radical and comprehensive across-the-board reform unless sufficient foreign support is freely available. However, foreign backing is not always available, and even when it is available, there is often a long list of preconditions that require comprehensive reforms beyond the capacity of the administration, especially when leaders have fixed incumbency terms and face tight time constraints. As a consequence, a reform agenda of this type is often tabled or poorly implemented.

To summarize, the old structuralism fails because it mistakenly takes optimal industrial structures as exogenous and independent of the stage of development, and neo-liberalism fails because it erroneously takes optimal institutions as exogenous and independent of the stage of development. As a result, for any developing economy, the policy prescription from the old structuralism is an immediate and thorough imitation of the same industrial structures observed in the developed countries regardless of its own current endowment structure and stage of development. In constrast, the policy prescription from the neo-liberalism is an immediate and thorough transplantation of the same economic, political, and legal institutions prevailing in developed countries regardless of its own current stage of development and institutional history. The common mistake of these two approaches is a failure to recognize that the optimal economic structures and institutions are both endogenously different for countries at different stages of development. In other words, we should not take the structures, including industries and institutions, of developed countries as the unique and time-invariant optimal choice for all countries regardless of their stage of development.

These two waves of problematic social thoughts have significantly influenced policy makers. As a consequence, most countries that have faithfully adopted these approaches do not achieve what was expected according to the theories. In fact, in the past sixty years, among more than 200 developing economies, only two economies (South Korea and Taiwan Province of China) have successfully upgraded from a low-income status to a high-income status (Lin and Rosenblatt 2012), and only thirteen out of 101 middle-income economies have moved up the ladder and become high-income economies by 2008 (Agenor et al. 2012).

Strikingly, among all the economies that have successfully escaped the low-income trap or the middle-income trap in the past eighty years, none has strictly followed either the structuralism approach or the neo-liberalism approach. Instead, each has adopted a more pragmatic approach by developing industries that are consistent with the endowment structures and by continuously upgrading their industries as their endowment structures change. Meanwhile, fast-growing transitional economies such as China have adopted a gradualist approach to institutional reform instead of overnight privatization and radical institutional transplanting as prescribed by neo-liberalism (Lin 2009).

Such a huge discrepancy between mainstream theoretical prescriptions and real-world performance cannot be resolved without a new theory in development economics. This is where New Structural Economics enters the field.

3.4 A Benchmark Model of New Structural Economics

A hallmark technical feature of NSE is that the aggregate production function is no longer taken as exogenous and time-invariant, as in (1). Instead, it is derived from the compositions of underlying industries which are in turn determined by the endowment structure. Moreover, when the endowment structure evolves over time, the optimal composition of industries also changes accordingly, which further implies that the functional form of the aggregate production function may also change over time.

The key economic idea of NSE behind this technical feature is that endowment structure determines optimal industrial structures and that capital accumulation (improvement of endowment structure) serves as a fundamental mechanism that drives changes in industrial structures.

An important technical challenge for such formal models is to characterize the dynamic optimization problem in the presence of many industries, each of which evolves nonlinearly. More precisely, first, the model predictions should not only be consistent with the stylized facts at the disaggregated industry level (to be discussed in more details below), but should also be consistent with the Kaldor facts at the aggregate level.[1] Second, to keep track of the life-cycle dynamics of each industry along the whole path of aggregate growth, we must fully characterize transitional dynamics, which is well recognized to be difficult even for a two-sector model, but now we have infinite industries with an infinite time horizon.[2] Third, it turns out that endogenous structural change in the underlying industries eventually forces us to characterize a Hamiltonian system with endogenously switching state equations instead of a time-invariant state equation as in the Ramsey model.

To be more concrete, we will illustrate how we model this dynamic evolution in industrial structures on the growth path. This part is mainly taken from Ju et al. (2015). We show that, despite of all these technical challenges, the Ju, Lin, and Wang (JLW hereafter) model is still highly tractable: We obtain closed-form solutions to fully characterize the whole process of the hump-shaped industrial dynamics for each of the infinite industries along the aggregate growth path. The model predictions are qualitatively consistent with all the stylized facts about the industrial dynamics at the micro industry level and the Kaldor facts at the aggregate level.

We first develop a static model with infinite industries (or goods, interchangeably) and two factors (labour and capital). With a general CES production function for the final commodity, we obtain a version of the *Generalized Rybczynski Theorem*: for any given endowment of capital and labour, there exists a cut-off industry such that, when the capital endowment increases, the output will increase in every industry that is more capital intensive than this cut-off industry, while the output in all the industries that are less capital intensive than this cut-off industry will decrease. Moreover, the cut-off industry moves toward the more capital-intensive direction as the capital endowment increases. As a special case, when the CES substitution elasticity is infinity, generically only two industries are active in equilibrium and the capital–labour ratios of the active industries are the closest to the capital–labour ratio of the economy. The model implies that the structures of underlying industries are endogenously different at different stages of economic development.

Then the model is extended to a dynamic environment where capital accumulates endogenously. The dynamic decision is decomposed into two steps. First, the social planner optimizes the inter-temporal allocation of capital for the production of consumption goods, which determines the evolution of the endowment structure. Then, at each time point the resource allocation across different industries is determined by the capital and labour endowments in the same way as the static model. Endogenous changes in the industrial composition of an economy translate into different functional

[1] Kaldor facts refer to the relative constancy of the growth rate of total output, the capital–output ratio, the real interest rate, and the share of labour income in GDP.

[2] See King and Rebelo (1993), Mulligan and Sala-i-Martin (1993), Bond et al. (2003), and Mehlum (2005).

forms of the endogenous aggregate production function and the capital accumulation function; therefore, we must solve a Hamiltonian system with endogenously switching state equations because of the endogenous structural change.

3.4.1 Model Environment

Consider a closed economy with a unit mass of identical households and infinite industries. Each household is endowed with L units of labour and E units of physical capital, which can be easily extended to incorporate intangible capital as well. A representative household consumes a composite final commodity C, which is produced by combining all the intermediate goods c_n, where $n \in \{0, 1, 2, \dots\}$. Each intermediate good should be interpreted as an industry, although we will use 'good' and 'industry' interchangeably throughout the chapter.

For simplicity, assume that the production function of the final commodity is

$$C = \Sigma_{n=0}^{\infty} \lambda_n c_n, \tag{4}$$

where λ_n represents the marginal productivity of good n in the final good production.[3] We require $c_n \geq 0$ for any n. The final commodity serves as the numeraire. The utility function is *CRRA*:

$$U = \frac{C^{1-\sigma} - 1}{1 - \sigma}, \text{where } \sigma \in (0, 1]. \tag{5}$$

All the technologies exhibit constant returns to scale. In particular, good 0 is produced with labour only. One unit of labour produces one unit of good 0. To produce any good $n \geq 1$, both labor and capital are required and the production functions are Leontief:[4]

$$F_n(k, l) = \min\left\{\frac{k}{a_n}, l\right\}, \tag{6}$$

where a_n measures the capital intensity of good n. All the markets are perfectly competitive. Let p_n denote the price of good n. Let r denote the rental price of capital and w denote the wage rate. The zero profit condition for a firm implies that $p_0 = w$ and $p_n = w + a_n r$ for $n \geq 1$.

[3] It is not unusual in the growth literature to assume perfect substitutability for the output across different production activities; see Hansen and Prescott (2002). This assumption is relaxed and the general CES function is discussed in Section 5 of Ju et al. (2015).

[4] Leontief functions are also used in Luttmer (2007) and Buera and Kaboski (2012a, 2012b). It can be easily shown that our key qualitative results will remain valid when the production function is Cobb–Douglas, but that will enormously increase the nonlinearity of the problem in the multiple-sector environment, making it much harder to obtain closed-form solutions, especially for the dynamic analysis.

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Without loss of generality, the industries are ordered such that a_n is increasing in n. Empirical evidences suggest that a more capital-intensive technology is generally more productive, we assume that λ_n is increasing in n. To obtain analytical solutions, we assume

$$\lambda_n = \lambda^n, a_n = a^n, \tag{7}$$

$$a - 1 > \lambda > 1. \tag{8}$$

$a > \lambda$ must be imposed to rule out the trivial case that only the most capital-intensive good is produced in the static equilibrium, and we strengthen the assumption further to $a - 1 > \lambda$ to simplify the analysis as good 0 requires no capital.[5]

The household problem is to maximize (1) subject to the following budget constraint:

$$C = wL + rE. \tag{9}$$

3.4.2 Market Equilibrium

It is shown that at most two goods are simultaneously produced in the equilibrium and that these two goods have to be adjacent in the capital intensities. Suppose goods n and $n + 1$ are produced for some $n \geq 1$, then the marginal rate of transformation (MRT) between the two intermediate goods must be equal to their price ratio: $MRT_{n+1,n} = \lambda = \frac{p_{n+1}}{p_n} = \frac{w+a^{n+1}r}{w+a^n r}$, which yields

$$\frac{r}{w} = \frac{\lambda - 1}{a^n(a - \lambda)}. \tag{10}$$

In addition, condition (8) ensures that good 0 is not produced.

The market clearing conditions for labour and capital are given respectively by:

$$c_n + c_{n+1} = L, \tag{11}$$

$$c_n a^n + c_{n+1} a^{n+1} = E. \tag{12}$$

The market equilibrium can be illustrated in Figure 3.1, where the horizontal and vertical axes are labor and capital, respectively. Point O is the origin and Point $W = (L,E)$ denotes the endowment of the economy. When $a^n L < E < a^{n+1} L$, as shown in the current case, only goods n and $n + 1$ are produced. The factor market clearing conditions, (11) and (12), determine the equilibrium allocation of labour and capital in industries n and $n + 1$, which are represented respectively by vector OA and vector OB in the parallelogram $OAWB$. $\overleftarrow{Oa^n} = (1, a^n)c_n$ and $\overleftarrow{Oa^{n+1}} = (1, a^{n+1})c_{n+1}$ are the vectors

[5] If $\lambda = 1$, the equilibrium would be trivial because only good 0 is produced in this linear case. In section 5 of Ju et al. (2015), $\lambda = 1$ is allowed when (4) is replaced by a general CES function.

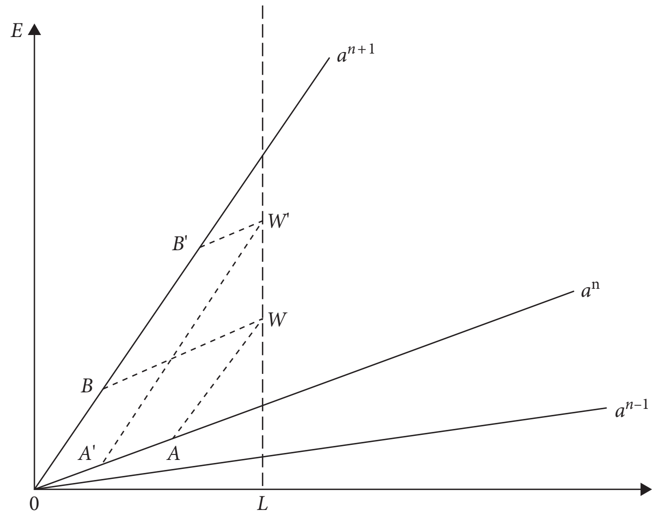

FIGURE 3.1 How industrial structures are determined by endowment structures

of factors used in producing c_n and c_{n+1} in the equilibrium. If the capital increases so the endowment point moves from W to W', the new equilibrium becomes parallelogram $OA'W'B'$ so that c_n decreases but c_{n+1} increases. When $E = a^n L$, only good n is produced. Similarly, if $E = a^{n+1}L$, only good n+1 is produced.[6]

More precisely, the equilibrium output of each good c_n, the relative factor prices $\frac{r}{w}$, and the corresponding aggregate output C are summarized in Table 3.1.

The static equilibrium is summarized verbally in the following proposition.

Proposition 1 *Generically, there exist only two industries whose capital intensities are the most adjacent to the aggregate capital–labour ratio,* $\frac{E}{L}$. *As* $\frac{E}{L}$ *increases, each industry* n ($n \geq 1$) *exhibits a hump shape: the output first remains zero, then increases and reaches its peak and then declines, and finally returns to zero and is fully replaced by the industry with the next higher capital intensity.*

The equilibrium outcome, as summarized in the above proposition and Table 3.1, shows that the aggregate production function (C as a function of L and E) has different forms when the endowment structures are different, reflecting the endogenous structural change in the underlying industries. Accordingly, the coefficient right before E in the endogenous aggregate production function is the rental price of capital, and the coefficient before L is the wage rate. So the relative factor price is $\frac{r}{w} = \frac{\lambda-1}{a^n(a-\lambda)}$ when $E \in a^n L, a^{n+1}L)$, and it declines in a stair-shaped fashion as E increases. This discontinuity results from the Leontief assumption. Observe that the capital income share in the total output is given by

[6] This graph may appear similar to the Lerner diagram in the H-O trade models with multiple diversification cones (see Leamer (1987). However, the mechanism in our autarky model is different from the international specialization mechanism in the trade literature.

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Table 3.1 Static Equilibrium

$0 \leq E < aL$	$a^n L \leq E < a^{n+1} L$ for $n \geq 1$
$c_0 = L - \frac{E}{a}$	$c_n = \frac{La^{n+1} - E}{a^{n+1} - a^n}$
$c_1 = \frac{E_i}{a}$	$c_{n+1} = \frac{E_i - a^n L_i}{a^{n+1} - a^n}$
$c_j = 0$ for $\forall j \neq 0, 1$	$c_j = 0$ for $\forall j \neq n, n+1$
$\frac{r}{w} = \frac{\lambda - 1}{a}$	$\frac{r}{w} = \frac{\lambda - 1}{a^n(a - \lambda)}$
$C = L + (\lambda - 1)\frac{E}{a}$	$C = \frac{\lambda^{n+1} - \lambda^n}{a^{n+1} - a^n} E + \frac{\lambda^n(a - \lambda)}{a - 1} L$
$\Leftrightarrow E_{0,1} = \frac{a}{\lambda - 1}(C - L)$	$\Leftrightarrow E_{n,n+1} = \left[C - \frac{\lambda^n(a - \lambda)}{a - 1} L\right] \frac{a^{n+1} - a^n}{\lambda^{n+1} - \lambda^n}.$

$$\frac{rE}{rE + wL} = \frac{\left(\frac{\lambda-1}{a-1}\right)E}{\frac{\lambda-1}{a-1}E + \frac{a^n(a-\lambda)}{a-1}L} \tag{13}$$

when $E \in a^n L, a^{n+1} L)$ for any $n \geq 1$. So the capital income share monotonically increases with capital within each diversification cone and then suddenly drops to $\frac{(\lambda-1)}{a-1}$ as the economy enters a different diversification cone, but the capital income share always stays within the interval $[\frac{\lambda-1}{a-1}, \frac{(\lambda-1)a}{(a-1)\lambda}]$ for any $n \geq 1$. This is consistent with the Kaldor fact that the capital income share is fairly stable over time.[7]

3.4.3 Dynamics

Now we extend the above static model to a dynamic setting to fully characterize the industrial dynamics along the growth path of the aggregate economy, where the capital changes endogenously over time.

3.4.3.1 Environment

There are two sectors in the economy: a sector producing capital goods and a sector producing consumption goods. Capital goods and consumption goods are distinct in nature and not substitutable. Moreover, they are produced with different technologies. Capital goods are produced using an AK technology: One unit of capital good produces A units of new capital goods, where A captures the effect of learning by doing. It also

[7] See Barro and Sala-i-Martin (2003) for more discussion on the robustness of the Kaldor facts.

highlights the feature that the technology progress is investment-specific, so it occurs in the capital (investment) goods sector rather than in the consumption goods sector (see Greenwood et al. 1997).[8] Let $K(t)$ denote the capital *stock* available at the beginning of time *t*, so the output *flow* coming out of the capital good sector is *AK(t)*, which is then split between two different usages:

$$AK(t) = X(t) + E(t), \tag{14}$$

where *X(t)* denotes capital investment and *E(t)* denotes the *flow* of capital used to produce consumption goods at *t*. *E(t)* fully depreciates, so capital in the whole economy accumulates as follows:

$$\dot{K}(t) = X(t) - \delta K(t), \tag{15}$$

where δ is the depreciation rate in the capital goods sector. Substituting (14) into the above equation and defining $\xi = A - \delta$, we obtain

$$\dot{K}(t) = \xi K(t) - E(t).$$

At time *t*, capital *E(t)* and labour *L* (assumed to be constant) produce all the intermediate goods $\{c_n(t)\}_{n=0}^{\infty}$ with technologies specified by (6), which are ultimately combined to produce the final consumption good *C(t)* according to (4). Based on Table 3.1, define

$$F(E, L) \equiv \begin{cases} \frac{(\lambda - 1)}{a} E + L & \text{if} \quad 0 \leq E < aL \\ \frac{\lambda^{n+1} - \lambda^n}{a^{n+1} - a^n} E + \frac{\lambda^n (a - \lambda)}{a - 1} L & \text{if} \quad a^n L \leq E < a^{n+1} L \text{for} n \geq 1 \end{cases}, \tag{16}$$

which is the endogenous aggregate production function derived in Table 3.1. Therefore,

$$C(t) = F(E(t), L) = r(t)E(t) + w(t)L, \tag{17}$$

where *r(t)* and *w(t)* are the rental price for capital and the wage rate at time *t*, respectively. With some abuse of notation, let *E(C(t))* denote the total amount of capital goods needed to produce final consumption goods *C(t)*, so $F(E(C(t), L) \equiv C(t)$. Final consumption goods *C* and all the intermediate goods $\{c_n\}_{n=0}^{\infty}$ are non-storable.

By the second welfare theorem, we can characterize the competitive equilibrium by resorting to the following social planner problem:

$$\max_{c(t)} \int_0^{\infty} \frac{c\,(t)^{1-\sigma} - 1}{1 - \sigma} e^{-\rho t} dt \tag{18}$$

[8] Notice that this dynamic setting differs from the most standard setting where capital goods and consumption goods are identical goods. Detailed comparisons and justifications are provided in subsection 4.1.3 and section 5 of Ju et al. (2015).

subject to

$$\dot{K}(t) = \xi K(t) - E(C(t)), \tag{19}$$
$$K(0) = K_0 \text{ is given,}$$

where ρ is the time discount rate. We assume $\xi - \rho > 0$ to ensure positive consumption growth and, to exclude the explosive solution, we also assume $\frac{\xi-\rho}{\sigma}(1-\sigma) < \rho$. Putting them together, we impose

$$0 < \xi - \rho < \sigma\xi. \tag{20}$$

The social planner decides the inter-termporal consumption flow *C(t)* and makes optimal investment decisions *X(t)*, which in turn determine the evolution of the endowment structure $\frac{K(t)}{L}$ and the optimal amount of capital allocated for consumption goods production *E(t)*. Note that, at any given time *t*, once *E(t)* is determined, the optimization problem for the whole consumption goods sector is exactly the same as the static problem as in the previous subsection. From the bottom row of Table 3.1, we know that *E(C)* is a strictly increasing, continuous, piece-wise linear function of *C*. It is not differentiable at $C = \lambda^i L$, for any $i = 0, 1, \ldots$. Therefore, the above dynamic problem may involve changes in the functional form of the state equation: (19) can be explicitly rewritten as

$$\dot{K} = \begin{cases} \xi K, & \text{when} \quad C < L \\ \xi K - E_{0,1}(C), & \text{when} \quad L \leq C < \lambda L \\ \xi K - E_{n,n+1}(C), & \text{when} \quad \lambda^n L \leq C < \lambda^{n+1} L, \text{for} n \geq 1 \end{cases},$$

where $E_{n,n+1}(C)$ is defined in the bottom row of Table 3.1 for any $n \geq 0$.

3.4.3.2 *Equilibrium Characterization*

We can verify that the objective function is strictly increasing, differentiable, and strictly concave while the constraint set forms a continuous convex-valued correspondence, hence the equilibrium must exist and also be unique. Let t_0 denote the *last* time point when aggregate consumption equals L (that is, only good 0 is produced), and t_n denote the *first* time point when $C = \lambda^n L$ (that is, only good n is produced) for $n \geq 1$. As can be verified later, aggregate consumption C is monotonically increasing over time in equilibrium, hence the problem can also be written as

$$\max_{c(t)} \int_0^{t_0} \frac{C(t)^{1-\sigma} - 1}{1-\sigma} e^{-\rho t} dt + \sum_{n=0}^{\infty} \int_{t_n}^{t_{n+1}} \frac{C(t)^{1-\sigma} - 1}{1-\sigma} e^{-\rho t} dt$$

subject to

$$\dot{K} = \begin{cases} \xi K & \text{when} \quad 0 \leq t \leq t_0 \\ \xi K - E_{0,1}(C), & \text{when} \quad t_0 \leq t \leq t_1 \\ \xi K - E_{n,n+1}(C), & \text{when} \quad t_n \leq t \leq t_{n+1}, \text{for} n \geq 1 \end{cases},$$

$$K(0) = K_0 \text{ is given,}$$

where t_n is to be endogenously determined for any $n \geq 0$.

Table 3.1 indicates that goods 0 and 1 are produced during the time period $[t_0,t_1]$ and $E(C) = E_{0,1}(C) \equiv \frac{a}{\lambda-1}(C - L)$. When $t_n \le t \le t_{n+1}$ for $n \ge 1$, goods n and n+1 are produced. Correspondingly, $E(C) = E_{n,n+1}(C) \equiv [C - \frac{\lambda^n(a-\lambda)}{a-1}L]\frac{a^{n+1}-a^n}{\lambda^{n+1}-\lambda^n}$. If K_0 is sufficiently small (this is more precisely shown in Proposition 3), then there exists a time period $[0,t_0]$ in which only good 0 is produced and all the working capital is saved for the future, so $E = 0$ when $0 \le t \le t_0$. If K_0 is large, on the other hand, the economy may start by producing goods h and h+1 for some $h \ge 1$, so $t_0 = t_1 = \ldots = t_h = 0$ in equilibrium.

To solve the above dynamic problem, following Kamien and Schwartz (1991), we set the *discounted-value* Hamiltonian in the interval $t_n \le t \le t_{n+1}$, and use subscripts 'n,n+1' to denote all the variables during this time interval:

$$H_{n,n+1} = \frac{C(t)^{1-\sigma} - 1}{1-\sigma} e^{-\rho t} + \eta_{n,n+1}[\xi K(t) - E_{n,n+1}(C(t))]$$
$$+\zeta_{n,n+1}^{n+1}(\lambda^{n+1}L - C(t)) + \zeta_{n,n+1}^{n}(C(t) - \lambda^n L) \tag{21}$$

where $\eta_{n,n+1}$ is the co-state variable, $\zeta_{n,n+1}^{n+1}$ and $\zeta_{n,n+1}^{n}$ are the Lagrangian multipliers for the two constraints $\lambda^{n+1}L - C(t) \ge 0$ and $C(t) - \lambda^n L \ge 0$, respectively. The first-order condition and Kuhn-Tucker conditions are

$$\frac{\partial H_{n,n+1}}{\partial C} = C(t)^{-\sigma} e^{-\rho t} - \eta_{n,n+1}\frac{a^{n+1} - a^n}{\lambda^{n+1} - \lambda^n} - \zeta_{n,n+1}^{n+1} + \zeta_{n,n+1}^{n} = 0, \tag{22}$$
$$\zeta_{n,n+1}^{n+1}(\lambda^{n+1}L - C(t)) = 0, \zeta_{n,n+1}^{n+1} \ge 0, \lambda^{n+1}L - C(t) > 0,$$
$$\zeta_{n,n+1}^{n}(C(t) - \lambda^n L) = 0, \zeta_{n,n+1}^{n} \ge 0, C(t) - \lambda^n L \ge 0.$$

We also have

$$\eta'_{n,n+1}(t) = -\frac{\partial H_{n,n+1}}{\partial K} = -\eta_{n,n+1}\xi. \tag{23}$$

In particular, when $C(t) \in (\lambda^n L, \lambda^{n+1}L)$, $\zeta_{n,n+1}^{n+1} = \zeta_{n,n+1}^{n} = 0$, and equation (22) becomes

$$C(t)^{-\sigma} e^{-\rho t} = \eta_{n,n+1}\frac{a^{n+1} - a^n}{\lambda^{n+1} - \lambda^n}. \tag{24}$$

The left hand side is the marginal utility gain from increasing one unit of aggregate consumption, while the right hand side is the marginal utility loss due to the decrease in capital because of that additional unit of consumption, which by the Chain's Rule can be decomposed into two multiplicative terms: the marginal utility of capital $\eta_{n,n+1}$ and the marginal capital requirement for each additional unit of aggregate consumption $\frac{a^{n+1}-a^n}{\lambda^{n+1}-\lambda^n}$ (see Table 3.1). Taking the logarithm on both sides of equation (24) and differentiating with respect to t, we obtain the consumption growth rate from the regular Euler equation:

$$g_c \equiv \frac{\dot{C}(t)}{C(t)} = \frac{\xi - \rho}{\sigma}, \tag{25}$$

for $t_n \leq t \leq t_{n+1}$ for any $n \geq 0$. The strictly concave utility function implies that the optimal consumption flow $C(t)$ must be continuous and sufficiently smooth (without kinks); hence from (25) we obtain:

$$C(t) = C(t_0)\ e^{g_c(t-t_0)} \text{ for any } t \geq t_0 > 0. \tag{26}$$

Following Kamien and Schwartz (1991), we have two additional necessary conditions at $t = t_{n+1}$:

$$H_{n,\ n+1}(t_{n+1}) = H_{n+1,n+2}(t_{n+1}), \tag{27}$$

$$\eta_{n,n+1}(t_{n+1}) = \eta_{n+1,n+2}(t_{n+1}). \tag{28}$$

Substituting equations (27) and (28) into (21), we can verify that $K^-(t_{n+1}) = K^+(t_{n+1})$. In other words, $K(t)$ is also continuous. Observe that

$$C(t_0)e^{g_c(t_n-t_0)} = C(t_n) = \lambda^n L \text{ when } t_0 > 0, \tag{29}$$

which implies

$$t_n = \frac{\log\frac{\lambda^n L}{C(t_0)} + \frac{\xi-\rho}{\sigma}t_0}{g_c}, \text{when } t_0 > 0. \tag{30}$$

Define $m_n \equiv t_{n+1} - t_n$, which measures the length of the time period during which both good n and good n+1 are produced (that is, the duration of the diversification cone for good n and good n+1). We must have

$$m_n = m \equiv \frac{\log\lambda}{g_c}. \tag{31}$$

The comparative statics for equation (31) is summarized in the following proposition.

Proposition 2 *The full life span of each industry $n \geq 1$ is equal to 2m. The speed of industrial upgrading (measured by frequency $\frac{1}{2m}$) decreases with the productivity parameter λ but increases with the aggregate growth rate g_c. More precisely,the industrial upgrading is faster when technological efficiency ξ increases, or the inter—temporal elasticity of substitution $\frac{1}{\sigma}$ increases, or the time discount rate ρ decreases.*

The intuition for the proposition is the following. Suppose good n and good n+1 are produced. When the productivity parameter λ is larger, the marginal productivity of good n (λ^n) becomes bigger, making it pay to stay at good n longer; but the marginal productivity of good n+1 (λ^{n+1}) also becomes bigger, making it optimal to leave good n and move to good n+1 more quickly. It turns out that the first effect dominates the second effect because (8) implies that, by climbing up the industrial ladder, the productivity gain l is sufficiently small relative to the additional capital cost reflected by the cost parameter a. Thus the net effect is that industrial upgrading slows down. On the other hand, industrial upgrading is faster when the consumption growth rate g_c increases because larger consumption is supported by more capital-intensive industries, as implied by Table 3.1.

When the household is more impatient (larger ρ), it will consume more and save less and hence capital accumulation becomes slower and thus the endowment-driven industrial upgrading also becomes slower. When the production of the capital good becomes more efficient (ξ), capital can be accumulated faster, so the upgrading speed is increased. When the aggregate consumption is more substitutable across time (larger $\frac{1}{\sigma}$), the household is more willing to substitute current consumption for future consumption, which also boosts saving and then causes quicker industrial upgrading.

We are now ready to derive the industrial dynamics for the entire time period. The industrial dynamics depend on the initial capital stock, $K(0)$ We show in the Appendix of Ju et al. (2015) that there exists a series of increasing constants, $\vartheta_0, \vartheta_1, \cdots, \vartheta_n, \vartheta_{n+1}, \cdots$, such that if $0 < K(0) \leq \vartheta_0$, the economy will start by producing good 0 only until the capital stock reaches ϑ_0; if $\vartheta_n < K(0) \leq \vartheta_{n+1}$, the economy will start by producing goods n and n+1 for any $n \geq 0$. Furthermore, we can show that $K(t_n) \equiv \vartheta_n$ for any $K(0) < \vartheta_n$. That is, irrespective of the level of initial capital stock, the economy always starts to produce good n+1 whenever its capital stock reaches ϑ_n.

To be more concrete, consider the case when $\vartheta_0 < K(0) \leq \vartheta_1$, where the threshold values ϑ_0 and ϑ_1 can be explicitly solved. That is, the economy will start by producing goods 0 and 1. Equation (26) and Table 3.1 jointly implies that when $t \in 0,t_1]$,

$$E(t) = \frac{a}{\lambda - 1}(C(t) - L) = \frac{a}{\lambda - 1}(C(0)e^{\frac{\xi-\rho}{\sigma}t} - L).$$

Correspondingly,

$$\dot{K} = \xi K(t) - \frac{a}{\lambda - 1}(C(0)e^{\frac{\xi-\rho}{\sigma}t} - L).$$

Solving this first-order differential equation with the condition $K(0) = K_0$, we obtain

$$K(t) = \frac{-\frac{aC(0)}{\lambda-1}}{\frac{\xi-\rho}{\sigma} - \xi}e^{\frac{\xi-\rho}{\sigma}t} + \frac{-aL}{\xi(\lambda - 1)} + \left[K_0 + \frac{\frac{aC(0)}{\lambda-1}}{\frac{\xi-\rho}{\sigma} - \xi} + \frac{aL}{\xi(\lambda - 1)}\right]e^{\xi t},$$

which yields

$$\vartheta_1 \equiv K(t_1) = \frac{-\frac{a\lambda L}{\lambda-1}}{\frac{\xi-\rho}{\sigma} - \xi} + \frac{-aL}{\xi(\lambda - 1)} + \left[K_0 + \frac{\frac{aC(0)}{\lambda-1}}{\frac{\xi-\rho}{\sigma} - \xi} + \frac{aL}{\xi(\lambda - 1)}\right]\left(\frac{\lambda L}{C(0)}\right)^{\frac{\xi\sigma}{\xi-\rho}}.$$

When $t \in t_n, t_{n+1}]$, for any $n \geq 1$, the transition equation of capital stock (19) becomes

$$\dot{K} = \xi K(t) - \left[C(0)e^{\frac{\xi-\rho}{\sigma}t} - \frac{\lambda^n(a - \lambda)}{a - 1}L\right]\frac{a^{n+1} - a^n}{\lambda^{n+1} - \lambda^n} \text{when } t \in t_n, t_{n+1}], \text{ for any } n \geq 1.$$

Solving the above differential equation, we obtain:

$$K(t) = \alpha_n + \beta_n e^{\frac{\xi-\rho}{\sigma}t} + \gamma_n e^{\xi t} \text{ when } t \in t_n, t_{n+1}], \text{ for any } n \geq 1 \tag{32}$$

where

$$\alpha_n = -\left(\frac{a^{n+1} - a^n}{\lambda^{n+1} - \lambda^n}\right) \frac{\lambda^n (a-\lambda) L}{\xi(a-1)},$$

$$\beta_n = -\left(\frac{a^{n+1} - a^n}{\lambda^{n+1} - \lambda^n}\right) \frac{C(0)}{\left(\frac{\xi-\rho}{\sigma} - \xi\right)},$$

$$\gamma_n = \left[\frac{\lambda^n L}{C(0)}\right]^{\frac{-\xi\sigma}{\xi-\rho}} \left\{ \vartheta_n + \frac{(a^{n+1} - a^n)L}{\lambda - 1} \left[\frac{1}{\left(\frac{\xi-\rho}{\sigma} - \xi\right)} + \frac{(a-\lambda)}{\xi(a-1)} \right] \right\}.$$

Again the endogenous change in the functional form of the capital accumulation path (32) reflects the structural changes that underlie the aggregate economic growth. Note that $\{\vartheta_n\}_{n=2}^{\infty}$ are all constants, which can be sequentially pinned down: $\vartheta_n \equiv K(t_n)$ can be computed from equation (32) with $K(t_{n-1})$ known.

For each individual industry, using equation (26) and Table 3.1, we obtain

$$c_n^*(t) = \begin{cases} \frac{C(0)e^{\frac{\xi-\rho}{\sigma}t}}{\lambda^n - \lambda^{n-1}} - \frac{L}{\lambda - 1} & \text{when } t \in t_{n-1}, t_n] \\ -\frac{C(0)e^{\frac{\xi-\rho}{\sigma}t}}{\lambda^{n+1} - \lambda^n} + \frac{\lambda L}{\lambda - 1}, & \text{when } t \in t_n, t_{n+1}] \\ 0, & \text{otherwise} \end{cases}, \text{for all } n \geq 2$$

$$c_1^*(t) = \begin{cases} \frac{C(0)e^{\frac{\xi-\rho}{\sigma}t} - L}{\lambda - 1}, & \text{when } t \in 0, t_1] \\ -\frac{C(0)e^{\frac{\xi-\rho}{\sigma}t}}{\lambda^2 - \lambda} + \frac{\lambda L}{\lambda - 1}, & \text{when } t \in t_1, t_2] \\ 0, & \text{otherwise} \end{cases},$$

$$c_0^*(t) = \begin{cases} L - \frac{C(0)e^{\frac{\xi-\rho}{\sigma}t} - L}{\lambda - 1}, & \text{when } t \in 0, t_1] \\ 0, & \text{otherwise} \end{cases},$$

where $C(0)$ can be uniquely determined by the transversality condition and the endogenous time points t_n are given by (30) for any $n \geq 1$. Recall $t_0 = 0$ in this case. The above mathematical equations fully characterize the industrial dynamics for each industry over the whole life cycle while aggregate consumption growth is still given by (25). If the initial capital stock is sufficiently small such that $K_0 < \vartheta_0$, then the economy will first have a constant output level equal to L (Malthusian regime) until the capital stock $K(t) = \vartheta_0$, which occurs at $t_0 > 0$, after which the aggregate consumption growth

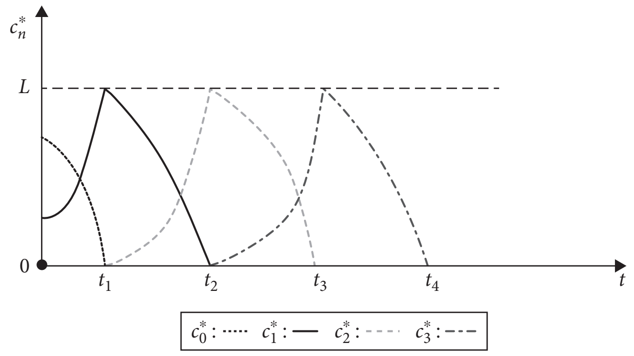

FIGURE 3.2 How different industries evolve over time

rate permanently changes to $\frac{\xi-\rho}{\sigma}$ (Solow regime). All these mathematical results can be read as follows:

Proposition 3 *There exists a unique and strictly increasing sequence of endogenous threshold values for capital stock,* $\{\vartheta_i\}_{i=0}^{\infty}$, *which are independent of the initial capital stock K(0).The economy starts to produce good n when its capital stock K(t) reaches* ϑ_{n-1} *for any* $n \geq 1$*.K(t) evolves following equation (32),while total consumption C(t) remains constant at L until* t_0*, after which it grows exponentially at the constant rat* $\frac{\xi-\rho}{\sigma}$. The output of each industry follows a hump-shaped pattern: When capital stock $K(t)$ reaches ϑ_{n-1}, industry n enters the market and booms until capital stock $K(t)$ reaches ϑ_n; its output then declines and finally exits from the market at the time when $K(t)$ reaches ϑ_{n+1}.

The industrial dynamics characterized in Proposition 3 are depicted in Figure 3.2.

3.4.4 Empirical Relevance

Sustainable economic growth relies on the healthy development of underlying industries, yet many important aspects still remain imperfectly understood within the context of economic growth, especially at the high-digit disaggregated industry level. Consider, for example, the automobile industry and the apparel industry. How different are the evolution patterns of two industries along the growth path of the whole economy? Which industry should we expect to expand or decline earlier than the other and why? How long, if at all, does a leading industry maintain its predominant position? What fundamental forces drive these dynamics? What is the relationship between individual industrial dynamics and aggregate GDP growth? These questions are interesting to economists, policy makers, and private investors.

The JLW model is designed to shed some light on these issues by studying the dynamics of all high-digit industries simultaneously within a growth framework.

In Ju et al. (2015), we establish four stylized facts about industrial dynamics using the NBER-CES data set of the US manufacturing sector, which covers 473 industries at the 6-digit NAICS level from 1958 to 2005:

Fact 1 (cross-industry heterogeneity): There exists tremendous cross-industry heterogeneity in capital–labour ratios, capital expenditure shares, and labour productivity.

Fact 2 (hump-shaped dynamics): An industry typically exhibits a hump-shaped dynamic pattern: its value-added share first increases, reaches a peak, and then declines.

Fact 3 (timing fact): The more capital intensive an industry is, the later its value-added share reaches its peak.

Fact 4 (congruence fact): The further an industry's capital–labour ratio deviates from the economy's aggregate capital–labour ratio, the smaller is the industry's employment share.

Similar patterns are also found in the UNIDO data set, which covers 166 countries from 1963 to 2009 at the two-digit level (23 sectors). In fact, documentation and analyses of a subset of the above-mentioned patterns of industrial dynamics can be dated at least back to the 1960s. For example, Chenery and Taylor (1968) show that the major products in the manufacturing sector gradually shift from the labour-intensive ones to more capital-intensive ones as an economy develops.

In the JLW model, we take Fact 1 as exogenously given and the model is able to simultaneously explain Facts 2, 3, and 4. Meanwhile, the theoretical results are also consistent with the Kaldor facts that the growth rate of total consumption remains constant and the capital income share is relatively stable, as shown in equation (13).

3.4.5 Related Literature

The JLW model is most closely related to the growth literature on structural change. This literature mainly tries to match the Kuznets facts, namely, that the agricultural share in GDP has a secular decline, the industry (manufacturing) share demonstrates a hump shape, and the service share increases. However, such sectors are too aggregated to address questions such as those raised earlier. Insufficient effort is devoted to reconciling Kaldor facts with the aforementioned stylized facts about industrial dynamics at the disaggregated levels.

The JLW model has two theoretical contributions to the literature. First, we develop a highly tractable growth model with infinite industries to fully characterize the industrial dynamics, which are qualitatively consistent with the four motivating facts. Second, more importantly, we show how capital accumulation serves as a new independent mechanism that drives the structural change. The existing literature mainly discusses two mechanisms of structural change in autarky. One is the preference-driven mechanism, in which the demand for different goods shift asymmetrically as income increases due to the non-homothetic preferences.[9] A weakness of this approach is that the change of income is treated exogenously. However, one of the main purposes of development economics is to explain income change. The second mechanism is that unbalanced productivity growth rates across sectors drive resource reallocation.[10] However, for developing countries the technologies are mostly exogenously given to them due to the latecomer's advantage. Therefore, the unbalanced productivity growth rates across sectors cannot be the main drive of resource reallocation.

Unlike these two mechanisms, we propose that improvement of endowment structure (capital accumulation) itself is a new and fundamental mechanism that can independently drive industrial dynamics, which we refer to as endowment-driven structural change. To highlight the theoretical sufficiency and distinction of this new mechanism, we assume a homothetic preference to shut down the preference-driven mechanism. We also assume that productivity is constant over time in all the industries to shut down the productivity-driven mechanism. Instead, the model, as motivated by Fact 1, assumes that industries differ in their capital intensities, which deviates from the standard assumption that different sectors have equal capital intensity, including models without capital.[11]

An important exception is Acemoglu and Guerrieri (2008), who study structural change in a two-sector growth model with different capital intensities, but their model does not explain or generate the repetitive hump-shaped industrial dynamics because the life cycle of each sector in their model is truncated. In fact, their analytical focus is on the *asymptotic* aggregate growth rate in the long run, by which time one industry dominates the economy in terms of employment share and structural change virtually ends. In contrast, we have infinite sectors so the structural change goes on endlessly and this setting allows us to analyse the complete life-cycle dynamics of *every* industry at the disaggregated levels *during* the whole growth process.

Ngai and Pissarides (2007) study structural change in a growth model with an arbitrary but finite number of sectors, which potentially allows for the life-cycle analysis of disaggregated industries. However, they do not treat capital accumulation as a major driving force for structural change, even in their appendix where they introduce different capital intensities across different sectors. Nor do they attempt to keep track of the life cycles of each industry to explain their dynamics along the growth

[9] For instance, the Stone-Geary function is used in Laitner (2000), Caselli and Colemen (2001), Kongsamut et al. (2001), Gollin et al. (2007). Hierarchic utility functions are adopted in Matsuyama (2002), Foellmi and Zweimuller (2008), Buera and Kaboski (2012a), among others.

[10] See, e.g., Hansen and Prescott (2002), Ngai and Pissarides (2007), Duarte and Restuccia (2010), Uy et al. (2013).

[11] Ngai and Samaneigo (2011) study how R&D differs across industries and contributes to industry-specific TFP growth. Acemoglu (2007) argues that technology progress is endogenously biased toward utilizing the more abundant production factors, which indicates that endowment structure is also fundamentally important even in accounting for TFP growth itself.

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path. Moreover, structural change will disappear in the long run because there are finite sectors in their model.

Ju et al. (2015) is also closely related to the strand of growth literature that studies the life cycle dynamics of industries, firms, establishments, or products. The key mechanisms that drive the life-cycle dynamics are different in different models. For example, some highlight the role of innovation and creative destruction (see Stokey 1988; Grossman and Helpman 1991; Aghion and Howitt 1992; Jovanovic and MacDonald 1994); some highlight the role of specific intangible capital such as organizational capital (see Atkeson and Kehoe 2005) or technology-specific or industry-specific human capital (see Chari and Hopenhayn 1991; Rossi-Hansberg and Wright 2007); some focus on productivity change and destruction shocks (see Hopenhayn 1992; Luttmer 2007; Samaniego 2010)), still others highlight demand shift due to consumers' heterogeneous preferences together with product awareness (Perla 2013) or non-homothetic preferences (Matsuyama 2002). Ju et al. (2015) differ from and complement these approaches by focusing on the role of endowment structure via the endogenous relative factor prices.

3.4.6 Policy Implications

The JLW model shows that the optimal industrial structures are different when endowment structures are different and optimal growth is achieved only when the industrial development follows the comparative advantage of the endowment structures of the economy. If a country follows a comparative-advantage-defying development strategy by prematurely boosting industries whose capital intensity is too high for the endowment structures of that country, it would lower the GDP growth rates and hurt the social welfare. In other words, the industries and technologies that prevail in developed countries are not necessarily suitable for developing countries to support and imitate immediately, in sharp contrast with the prescriptions by the old structuralism in the 1950s.

This model also shows that aggregate GDP growth is synchronized with development of underlying industries with the appropriate capital intensities, which suggests that formulation or evaluation of sensible development strategies and macroeconomic policies must take into account the time-varying endowment structures, induced industrial structures and industrial dynamics. In particular, the fourth fact (congruence fact), which is explained in the JLW model, may provide a useful policy guidance for what kind of industries are most likely to be the dominant ones at each different stage of development. The fact that the model has infinite sectors potentially allows policy makers to take advantage of the increasingly available 'big data' for supply and demand information on products at the high-digit levels and formulate growth policies that are better micro-founded at the product or industry levels at each different stage of development.

3.5 Extensions of the JLW Model

The JLW model introduced in the previous section characterizes the first best scenario under the perfect market environment, so the first welfare theorem applies: Pareto efficiency is achieved by the market without any necessity of government intervention. While it serves as a useful benchmark, it must be further extended to incorporate all sorts of more realistic market imperfection before we can discuss the role of government more fruitfully. In this section, we show with several concrete examples how the JLW model could serve as a workhorse for NSE in various extensions.

3.5.1 International Trade

Ju et al. (2015) discuss a simple extension of their model to a small open economy and the key results remain unchanged. Wang (2014a) extends the benchmark autarky setting in Ju et al. (2015) to an environment with two large countries, so terms of trade are now endogenous. Closed-form characterizations are provided to show how international trade and dynamic trade policies affect industrial dynamics and economic growth. Two main results are obtained: (a) both industrial upgrading and the aggregate growth of an economy are facilitated by the investment-specific technology progress (ISTP) of the trade partner if and only if the inter-temporal elasticity of substitution exceeds unity; (s) accelerating trade liberalization has a non-monotonic impact on aggregate output growth and industrial dynamics, depending on the level of trade cost and the inter-temporal elasticity of substitution.

3.5.2 Non-Competitive Market Structure

Wang (2014b) relaxes the assumption of perfect competitive market structures in Ju et al. (2015) to capture a more realistic situation because the first adopters of a new (and also more capital intensive) technology in developing countries sometimes enjoy certain temporary *de facto* market power, which disappears after this technology is implemented for some time. It is shown that the temporary non-competitive market structure in the goods market indirectly distorts factor market price signals, which in turn affects the dynamic implementation decisions of the new technology through the general equilibrium effect, even though factor markets per se are perfect. In particular, under certain circumstances, an increase in initial capital endowment may delay rather than facilitate the adoption of a more-capital intensive technology because the monopoly profits are higher in the later period when capital becomes cheaper. The policy implication is that foreign aid may in some cases inefficiently delay rather than accelerate industrial upgrading in developing countries when the final goods market is imperfectly competitive.

3.5.3 Marshallian Externality and Industrial Policies

There is no role for industrial policies in the world of Ju et al. (2015) because there is no market failure. Ju, et al. (2011) explore optimal industrial policies by introducing Marshallian externality into the Ju et al. (2015) model. The model deviates from the standard setting in the existing literature of industrial policies on two important dimensions. The first deviation is that more than one sector exhibits Marshallian externality, so how to identify the right industrial target is an endogenous decision rather than taken as given. The second deviation is that both capital and labour are needed, not just labour, in the production of industries with different capital intensities, so relative price signals in factor markets change as the economy develops, which has an asymmetric impact on different industries. The model highlights the importance of factor market price signals in guiding the government to target the correct industries to support at each different stage of development. We show that the if government adopts an industrial policy to facilitate the growth of industries that is consistent with comparative advantages determined by endowment structures, the appropriate government intervention could overcome the coordination failure and create Pareto improvement over the laissez-faire market equilibrium allocation. However, if government targets an industry that violates the factor endowment-determined comparative advantage, such industrial policies would result in an outcome worse than the intervention-free market outcome, despite the existence of Marshallian externality. So NSE proposes a market-led-and-government-facilitated approach of industrial policies, which is different from both the old structuralism approach (ignoring the positive role of market) and the neo-liberalism approach (downplaying the positive role of state).

3.5.4 Frictional Labour Market

Li and Wang (2017) study how a frictional labour market affects industrial upgrading and how labour market dynamics are shaped by industrial upgrading in the context of structural change and economic growth. To do this, we relax the assumption of perfect labour market in the JLW model by introducing search and match processes both within and across industries. Labour reallocation across the capital-intensive sunrise and the labour-intensive sunset industries is plagued by a mismatch between heterogeneous workers and the jobs which are created and destructed asymmetrically and endogenously as the economy develops. Mismatch is shown to delay industrial upgrading and depress growth by preventing workers from smoothly moving into the sunrise industries. On the other hand, industrial upgrading amplifies the role of mismatch in affecting the dynamics of unemployment, wage inequality, and output volatility. Quantitative investigations suggest that those effects are significant.

3.5.5 Further Discussions

NSE highlights the endogeniety of various dimensions of economic structures for understanding economic development, which can be potentially applied to many research topics. For instance, NSE holds the view that the characteristics of the financial services needed by different industries can be different because of the difference in their capital sizes and risks. Therefore the optimal compositition of different forms of financial intermediaries (such as banks of different sizes, stock market, and venture capital) presumably differs when industrial structures change with the endowment structures, which in turns implies that optimal financial structures should be different at different stages of development (see Lin et al. 2013; Lin et al. 2015). Also, macroeconomic topics such as economic fluctuations, fiscal and monetary policies, infrastructure investment, and international capital flows can all be remodelled through the lens of NSE. See Lin (2012a, 2012b, 2013a, 2013b) for further elaborations.

To formalize those ideas, we could potentially follow an approach similar to the JLW model by examining heterogeneity in certain relevant dimensions across different sectors and exploring how this heterogeneity may evolve over time and its implications for economic structures, policies, and development outcomes. A hallmark feature of this NSE methodology is to stop assuming a time-invariant, development-stage-free exogenous economic structure, instead, we should pay sufficient attention to the endogenous differences in all dimensions of economic structures between countries at different economic stages of development.

3.6 Conclusion

In this chapter, we have introduced the key ideas of New Structural Economics and also shown in detail how various dimensions of structural changes can be formalized in NSE. A common feature of most NSE models is to highlight the role of endowment structures and capital accumulation in determining optimal industrial and other economic structures at each different stage of development in a multiple-factor and multi-sector environment. On the technical side, a common feature of NSE models is that the aggregate production function is often endogenously derived and may change over time, so we may have to solve a dynamic system with endogenously switching state equations. Moreover, for our purpose of understanding developing countries, the analysis on transitional dynamics is often more important than the long-run steady state. All of these features of modelling structural changes can be clearly seen in the benchmark JLW model. We believe that remodelling structural change in this way can be more promising and fruitful than many of the existing approaches, especially when exploring economic growth for developing countries.

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