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CROSS-INDUSTRY TFP GROWTH DIFFERENCES WITH ASYMMETRIC INDUSTRIES AND THE ENDOGENOUS MARKET STRUCTURE

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Abstract

I develop a multi-industry endogenous growth model with the endogenous market structure. Industries are heterogeneous in production unit costs, research and development (R&D) productivities, fixed operating costs and *industry level* market sizes. The endogenous market structure allows an empirically realistic and theoretically important determination of the individual firms' market sizes and distinguishes the model from the previous literatures. There are two sets of results. First, the balanced growth rate depends positively on R&D productivities and *firm* market size of both industries but not *industry* market size. Surprisingly, the steady state total factor productivity (TFP) level ratio between industry 1 and 2 depends negatively on R&D productivity and fixed costs in industry 1 and positively on those parameters in industry 2. Second, industry differences in both TFP growth and R&D intensity mainly reflect differences in quality-adjusted gross profits and R&D productivities. Such differences depend on R&D productivities and fixed operating cost parameters in general equilibrium. The industry with a higher R&D productivity and fixed cost has a lower TFP growth and research intensity compared to the other industry. Differences in production unit costs and industry level market sizes do not to contribute to cross-industry TFP growth differences. These results are substantially different from what is found in the existing literature. Model also offers novel explanations for directed technical change and structural change, and it offers a structure for analyzing the interaction between trade and growth.

Keywords: Cross-industry TFP growth differences, endogenous growth, asymmetric industries, endogenous market structure

1 Introduction

The paper develops an endogenous growth model with two characteristics present in the data but usually absent from previous models: the endogenous market structure and asymmetric industry behavior. The model can explain important observed phenomena and provides a basic for exploring others. Some of the results obtained are surprising and interesting.

Productivity growth rates differ widely across U.S industries. In a sample of 37 industries during 1958-1996, average annual productivity growth rangs from -0.52% in government enterprises, to 1.98% in electronic and electric equipment, highlighting fundamental differences in technology and productivity growth across industries[1]. Why do industries differ in their rates of TFP growth? The IO literature suggests that differences in R&D intensity (the ratio between R&D expensiture and sales) underlie differences in TFP growth. However, as mentioned by Jones (1995) and Klenow (1996), the causal relation between the *level* of R&D intensity and TFP growth is not clear. Rather, both of R&D intensity and TFP growth differences result from deeper industry differences. I explore the nature of those underlying differences with a growth model based on Peretto (Oct. 1999 and 2007) in which the industries are asymmetric and the market structure is endogenous. The model is designed to be consistent with important facts about technical progress and what drives it and with the IO structure of the economy. This is the first time a growth model with both the endogenous market structure and asymmetric industries has been used to study the industry variations in TFP growth and R&D intensity.

My analysis of industry TFP difference is based on a variant of the growth models pioneered by Peretto (Dec. 1998). The model is built to be consistent with four major sets of facts. First, quality improvement is driven by research and development (R&D) that is done predominately by incumbent firms (Dosi, 1988; NSF, 2010). Second, fixed operating costs put an upper bound on the number of varieties so that long-run growth of income per person is driven by quality improvement of existing products rather than creation of new products through variety expansion (Peretto and Connolly, 2007). Third, technology spillovers happen at both the intra-industry and inter-industry levels (Bernstein and Nadiri, 1988; Nadiri, 1993)[2]. Fourth, market structure, including the size and number of firm, is endogenously determined. More specifically, the market size of individual firm in an industry changes with market and technology conditions and is endogenously regulated by entry and exit in response to the profitability of operations (Laincz and Peretto, 2006; Pagano and Schivardi, 2003). Growth depends on the *individual firm's market size*. The larger the firm's market size, the greater its profit and so the greater the return to R&D. *Aggregate* market size is irrelevant. An increase in the size of the aggregate market is matched by an increase in entry, which keeps constant the market size of the individual firm. This endogenous market structure eliminates not

[1]See Table 1 in Jorgenson and Stiroh (2000).

[2]The model without inter-industry knowlege spillover does not alter the main resuls. See the appendix for detail.

only the scale effect[3], but also the underlying reason for it. Models in which each firm's market size is exogenous and equal to the entire industry size do not correspond with the realities of industrial organization (Cohen and Klepper, 1996a, 1996b; Adams and Jaffe, 1996). The endogenous market structure is the key to this model. Based on it, the model provides surprising and interesting results on cross-industry TFP growth differences and R&D intensity differences.

In light of these facts, I construct a model in which quality-improving R&D is done by incumbents with both inter- and intra-industry technology spillovers. Each industry's market structure is determined endogenously by entry and exit. Industries are asymmetric in their fundamentals, with heterogeneous in unit costs, R&D productivities, fixed operating costs, and industry-level market size. As a result, firms in different industries are different in their product prices, research and development decisions, product quality levels, and market sizes. Those differences underlie the cross-industry differences in the growth rates of TFP. The asymmetry and the endogenous market structure provide a substantially different explanation for cross-industry TFP growth differences than what is offered in the existing literature.

I get two sets of main results. One concerns the growth of the aggregate economy on the balanced growth path (BGP), and the TFP *level* differences across industries on the BGP. The other concerns the R&D intensity and TFP growth differences across industries on the transition path. Both sets of the results have surprising and interesting elements that arise from the endogenous market structure.

First, the aggregate TFP growth rate on the BGP is positively related with R&D productivity and firm market size. The latter element is consistent with empirical findings, e.g., Laincz and Peretto (2006). Firm size affects the balanced growth rate through fixed operating cost. A higher fixed operating cost causes a higher market concentration and a larger market size for the individual firm. See Sutton (1992). Thus the balanced growth rate is positively related with fixed operating cost parameters and R&D productivities of both industries. Fixed operating cost generally has been ignored by the growth literature. It has an important effect here because of the mechanics of the endogenous market structure adjustment. The balanced growth rate does not depend on aggregate market size, or on the unit production costs. On the BGP, the two industries grow at the same rate, but the TFP *levels* across industries are different. Surprisingly, the ratio of the two industries' TFP in the steady state depends negatively on R&D productivity and the fixed cost parameter for industry 1 and positively on those parameters of industry 2.

Second, TFP growth rates are different across industries during the transition to the BGP. The differences mainly reflect differences in quality-adjusted gross profits. In equilibrium, the differences in quality-adjusted gross profits depend on R&D productivities and fixed operating costs. An increase in one industry's fixed cost reduces that industry's TFP growth relative to that of the other industry. The surprising result is that an increase in an industry's R&D productivity also reduces its TFP growth relative to that of the

[3]The scale effect is the positive relation between long run growth and aggregate scale in many growth literature. It is rejected by empirical findings, e.g., Backus, Kehoe, and Kehoe (1992).

other industry.. The key to understanding this result is once again the endogeneity of the market structure. Firms that are more productive at R&D tend to have greater profit as their advantage in R&D begins to bring in higher sales. The greater profit induces entry to the point where profit is equalized across firms and industries. The larger number of firms reduces average firm size, which in turn reduces the return to R&D to the same level as the other industry. The differences in fixed cost then enter the picture and result in lower R&D relative to the other industry in equilibrium. The same elements also affect the R&D intensity differences across industries.

This model provides a substantially different explanation of cross-industry TFP growth differences and research intensity differences from what has been offered in the previous literature. For example, Klenow (1996), Giordani and Zamparelli (2008), Ngai and Samaniego (2009) discuss cross-industry TFP growth differences through three channels: technology opportunity (the efficiency of research), market size, and appropriability (the extent that a firm benefits from its own knowledge). In these models, each firm faces the whole industry as its market. By construction, the models do not address the components of market structure, such as concentration and firm size, which the IO literature argues are important determinants of the R&D activity of profit-seeking firms[4]. The implicit assumptions of these models are not supported by the data[5]. In contrast, with its endogenous market structure, my model provides very different results. Technology opportunity in this model is R&D productivity. If firm size were fixed, the industry with a better technology opportunity enjoys a higher TFP growth just as in existing models. However, the firm size here is *not* fixed. Instead, it changes in response to market and technology conditions. With the endogenous market structure, the industry with better technology opportunity in fact ends up with a lower TFP growth compared to the other industry, assuming other parameters and variables are the same across industries. This result is surprising. The mechanism is complicated, so the details must await the full development of the model below. As for market size, the existing literature connects the TFP growth with industry size rather than firm size. However, the R&D incentive of the individual firm depends on the *firm's* size not the industry size. The industry's size is irrelevant. See Schumpeter (1950), Laincz and Peretto (2006). The present model captures those properties. Firm-level size is endogenously determined by a no-arbitrage condition. This model assumes at least partial appropriability[6] by restricting knowledge spillovers to be incomplete, which captures the idea that firms are successful in keeping part of the innovation secrets. In addition to discussing technology opportunity and market size, I introduce the differences in unit costs of production across industries, which

[4]See, e.g. Kamien and Schwartz (1982), Baldwin and Scott (1987), Dosi (1988), Tirole (1988, Ch. 10), Cohen and Levin (1989), and Scherer and Ross (1990, Ch. 17); more recently, Cohen and Klepper (1996a, 1996b), Adams and Jaffe (1996).

[5]For example, Klenow (1996) is a first generation growth model with scale effect. It's rejected by empirical findings, notably, Jones (1995). Ngai and Samaniego (2009) is a Semi-endogenous model which is widely rejected by the data. See Laincz and Peretto (2006), Ha and Howitt (2007), Madsen (2008).

[6]This model assumes appropriablity degrees are the same across industries. In my extended work, I allow different appropriability across industries, but the main implications of the model do not change. See the appendix.

again seems realistic. Although production cost differences do have some effects in the model, I show that they do not affect cross-industry growth differences, again because of the endogenous market structure.

The key element of the model is the endogenous market structure. Market structure determines the behavior of profit-seeking firms by affecting the returns to innovation, and the size and number of firms change in response to market and technology conditions. The endogenous market structure induces feed-backs that are a crucial determinant of the difference performances across industries. Ignoring the endogeneity of the market structure misses those feedbacks and leads to suspect results.

The model leads naturally to analysis of issues besides cross-industry TFP growth differences. I show that the combination of the endogenous market structure and asymmetry across industries offers explanations for both directed technical change and structural change of the economy. This model also provides a basis for examining the relation between international trade and economic growth.

The rest of the paper proceeds as follows. Section 2 constructs an asymmetric growth model with the endogenous market structure based on Peretto (Oct. 1999 and 2007), highlighting the role of technological opportunity, market size and unit costs in determining industry research intensity, and productivity growth. The main differences between this model and the existing literature are explained. Section 3 discusses the implications of this model for other issues including directed technical change, structural change and international trade. Section 4 concludes.

2 A Muti-industry Endogenous Growth Model

In this sector, I first set up the model, then discuss how industry characteristics affect (1) the balanced growth rate of the whole economy; (2) the difference between industry productivity growth and research intensity. Two industries are compared without loss of generality.

There are three productive sectors in the model: final goods, processed goods and intermediate goods. One representive firm produces final goods Y with two types of processed goods, X_1 and X_2. Final goods can be used for consumption; to produce intermediate goods G_{ij}; and to improve the quality inside intermediate goods Z_{ij}. Intermediate goods G_{ij} and the quality inside it are used to produce processed goods, X_i. The structure of the model is shown in figure 1.

Models with this type usually have two sectors, one for final good and one for intermediate goods. In this model, I have two different classes of intermediate goods, which also means two heterogeneous industries. Adding a third sector (the processed good sector) facilitates the discussion.

2.1 Final Goods Sector

One representive firm produces a single homogeneous final good Y using two non-durable processed goods X_1 and X_2 as inputs. The final goods can be consumed, used to produce intermediate goods, and invested in R&D that improves the quality of existing intermediate goods. The final goods sector is perfectly competitive with Cobb-Douglas production:

$$Y = X_1^{\epsilon} X_2^{1-\epsilon} \tag{1}$$

I take the final good as the numeraire, so $P_Y = 1$. The representative firm's profit is

$$\pi_Y = Y - P_{X_1} X_1 - P_{X_2} X_2 \tag{2}$$

from which I obtain the indirect demand functions

$$P_{X_1} = \epsilon \left(X_2 / X_1 \right)^{1-\epsilon} \tag{3}$$
$$P_{X_2} = \epsilon \left(X_1 / X_2 \right)^{\epsilon} \tag{4}$$

where P_{X_1} and P_{X_2} are the prices of X_1 and X_2.

The competitive final-good producer pays compensation ϵY and $(1-\epsilon)Y$ to the processed-good 1 and processed-good 2. So I get

$$\epsilon Y = P_{X_1} X_1 \quad and \quad (1-\epsilon) Y = P_{X_2} X_2. \tag{5}$$

2.2 Processed Goods Sector

The processed goods sector is also perfectly competitive. This sector comprises of two industries, each producing a single homogeneous good. The representative firms in the two industries use non-durable intermediate goods and labor to produce their respective processed goods. Borrowed from Aghion and Howitt (2005) and Peretto (2007), their production functions are,

$$X_1 = \int_0^{N_1} G_{1j}^{\lambda} \left(Z_{1j}^{\delta} Z_1^{\gamma} Z_2^{1-(\delta+\gamma)} l_{1j} \right)^{1-\lambda} dj, \quad 0 < \lambda, \gamma, \delta < 1 \tag{6}$$
$$X_2 = \int_0^{N_2} G_{2j}^{\lambda} \left(Z_{2j}^{\delta} Z_2^{\gamma} Z_1^{1-(\delta+\gamma)} l_{2j} \right)^{1-\lambda} dj, \quad 0 < \lambda, \gamma, \delta < 1 \tag{7}$$

where G_{ij}, $i = 1, 2$ are intermediate goods, Z_{ij} is the quality of good G_{ij}, $Z_i \equiv (1/N_i) \int_0^{N_i} Z_{ij} dj$ is the average quality of class-i intermediate goods, l_{ij} is the number of workers working with intermediate good G_{ij}, and N_i is the number of varieties of intermediate goods used in each industry. The quality Z_{ij} of intermediate good G_{ij} is embodied in the good itself, but augments the workers l_{ij} who use that good.

Define L_1 and L_2 as the total amount of workers allocated to industry 1 and 2 respectively. So, $L_1 \equiv \int_0^{N_1} l_{1j} dj$ and $L_2 \equiv \int_0^{N_2} l_{2j} dj$. Note that each intermediate good G_{ij} is used by only a fraction of the industry labor force, l_{ij}, but not the whole industry labor force, L_i. This is one of the key differences between this model and existing growth models. The latter assumes G_{ij} is used by L_i.

There are two classes of intermediate goods, $\{G_{1j}\}_{j=0}^{N_1}$ and $\{G_{2j}\}_{j=0}^{N_2}$, with one class providing inputs for the X_1 industry and the other class providing inputs for the X_2 industry. Each intermediate good is in one and only one class, so the sets of intermediate goods used by the X_1 and X_2 industries are disjointed, and generally have different numbers of elements (i.e., in general $N_1 \neq N_2$). Each intermediate good G_{ij} has its own quality Z_{ij}, determined by the R&D that has been done by the firm that produces G_{ij}. I discuss the industrial structure and R&D of the intermediate goods sector in the next section. Labor productivity depends on the quality of the intermediate good it works with. To allow for knowledge spillovers, I let labor productivity in industry X_1 also depend on both the average quality $Z_1 = (1/N_1)\int_0^{N_1} Z_{1j}dj$ of the $\{G_{1j}\}$ goods used in industry X_1, and $Z_2 = (1/N_2)\int_0^{N_2} Z_{2j}dj$ of the $\{G_{2j}\}$ goods used in industry X_2. Industry X_2's situation is symmetric. The importance of knowledge spillovers is governed by the magnitude of the parameters δ and γ. Setting $\delta + \gamma = 1$ would exclude knowledge spillovers across industries. Getting rid of the inter-industry spillover from the model doesn't change the main implications. See the appendix for details.

Processed goods firms choose quantities of intermediate goods and labor to maximize their profit:

$$\max_{\{G_{ij}, l_{ij}\}} \pi_{X_i} = P_{Xi}X_i - \int_0^{N_i} P_{G_{ij}}G_{ij}dj - \int_0^{N_i} wl_{ij}dj \tag{8}$$

where $P_{G_{ij}}$ is the price of G_{ij}, w is the wage rate, and the firm takes all prices as given. The demand functions for intermediate goods and labor are[7]

$$G_{1j} = \left(\frac{\lambda P_{X_1}}{P_{G_{1j}}}\right)^{\frac{1}{1-\lambda}} Z_{1j}^{\delta} Z_1^{\gamma} Z_2^{1-(\delta+\gamma)} l_{1j} \tag{9}$$

$$G_{2j} = \left(\frac{\lambda P_{X_2}}{P_{G_{2j}}}\right)^{\frac{1}{1-\lambda}} Z_{2j}^{\delta} Z_2^{\gamma} Z_1^{1-(\delta+\gamma)} l_{2j} \tag{10}$$

$$l_{1j} = (P_{X_1}\frac{1-\lambda}{w})^{\frac{1}{\lambda}} G_{1j}(Z_{1j}^{\delta} Z_1^{\gamma} Z_2^{1-(\delta+\gamma)})^{\frac{1-\lambda}{\lambda}} \tag{11}$$

$$l_{2j} = (P_{X_2}\frac{1-\lambda}{w})^{\frac{1}{\lambda}} G_{2j}(Z_{2j}^{\delta} Z_2^{\gamma} Z_1^{1-(\delta+\gamma)})^{\frac{1-\lambda}{\lambda}} \tag{12}$$

From the demand functions, we see that an increase in qualities $Z'_{ij}s$ and the spillovers Z_1, Z_2 cause the increases in the demand of intermediate goods and labors. This is the reason why intermediate good firms do research to increase their qualities – in order to get a higher demand.

The processed goods industries are competitive with Cobb-Douglas production. Combine the resource allocation in final good sector, (5), we can see that the intermediate goods firms in class 1 (i.e., those in the set $\{G_{1j}\}$) together receive a total payment of

[7] See derivations in the appendix.

$\lambda P_{X1}X_1 = \lambda\epsilon Y$, and the workers in processed goods industry 1 receive total compensation of $wL_1 = (1-\lambda) P_{X1}X_1 = (1-\lambda)\epsilon Y$. Similarly, the payments to intermediates and workers employed in processed goods industry 2 are $\lambda P_{X2}X_2 = \lambda(1-\epsilon) Y$ and $wL_2 = (1-\lambda) P_{X2}X_2 = (1-\lambda)(1-\epsilon) Y$. Based on that, I can get the labor allocation across industries to,

$$\frac{L_1}{L_2} = \frac{wL_1}{wL_2} = \frac{\epsilon}{1-\epsilon} \tag{13}$$

Total compensation paid to intermediate good producers and labor is $\int_0^{N_1} G_{1j}P_{G1j}\,dj + \int_0^{N_2} G_{2j}P_{G2j}\,dj = \lambda Y$ and $w(L_1+L_2) = (1-\lambda) Y$. Quality Z_{ij} does not get paid directly from the final goods sector. The return to Z_i is generated indirectly by increasing the demand for the intermediate G_{ij} in which it is embodied, as shown in equations (9) and (10).

2.3 Intermediate Goods Sector

The intermediate sector is the core of the model. There are two dimensions of technology change in this sector – vertical (quality improvement) dimension and horizontal (variety) dimension. In vertical dimension, incumbents perform innovation to improve the quality of its own product in order to get a larger individual market size – thus, a higher profit. In horizontal dimension, assuming Bertrand Competition, if entrepreneurs observe an incipient profit, they enter the market with a new variety, and share the market with existing firms. Thus, the market structure is endogenous. Fixed operating costs make horizontal expansion eventually stop[8]. So, the key to long run growth is the quality improvement.

The intermediate goods sector, like the processed goods sector, comprises of two heterogeneous industries. In each industry, all firms face identical production, R&D production and demand function. But those differ across industries. I prove that in the same industry all firms make the same decisions on prices and the investments in R&D, thus all firms within the same industry have the same individual market size and are symmetric. However, firms in different industries are heterogeneous. To simplify the analysis, I assume entry and exit involve zero costs[9]. Thus, the number of firms is free to jump to its equilibrium level, as in Peretto (1996, Oct 1999). I construct an equilibrium where at time t, firms commit to time-path strategies, while simultaneously, free entry and exit determine the number of firms in the market. A transitional dynamics of quality accumulation is shown.

I construct this equilibrium in three steps. First, I focus on the determination of the price and investment in R&D of the firms that are already active in the market (incumbent). Next, I focus on the endogenous market structure, which is the free entry

[8] See Peretto and Connolly (2007) for more discussion.

[9] This is the assumption in Peretto (1996) and (Oct 1999). For the discussion of costly entry in a similar framework but with symmetric industries, see Peretto (2007).

and exit decisions and the determination of the number of firms in the market. Finally, I prove the incumbents make symmetric decisions within the same industry, but asymmetric decisions across industries.

2.3.1 Incumbents

Each intermediate goods industry comprises of a continuum of monopolistically competitive incumbents, each of which produces a single intermediate good G_{ij} and also undertakes R&D to improve the quality Z_{ij} of the good it produces. An increase in quality raises the demand for the goods, as shown above, and thus raises profit.

Production, technologies, R&D technologies, and costs are the same for all firms within a given industry but differ across industries. Thus, the industrial structure is symmetrical within each intermediate goods industry, but is asymmetrical across two industries. All firms in industry i have a linear technology that converts A_i units of the final good into one unit of intermediate good G_{ij}:

$$A_i G_{ij} = Y_{ij} \tag{14}$$

where Y_{ij} is the amount of the final good used by firm j in industry i. Similarly, the R&D production functions are the same within an industry but differ across them:

$$\dot{Z}_{ij} = \alpha_i R_{ij} \tag{15}$$

where R_{ij} is the amount of the final good Y spent on R&D. The firm obtains the resources for R from retained earnings.

Firms face a fixed operating cost ϕ_{ij} that depends on the average quality of the firm's own industry Z_i, and of the other industry Z_k. There are two channels of influence. First, the operating cost depends positively on own industry quality. A more sophisticated industry is more complex and requires more sophisticated inputs, so the demand for operating cost inputs is increasing in industry quality. On the reasonable assumption, commonly made in the literature, that the cost of producing those inputs rises with their sophistication, higher industry quality then implies a higher price for the factors that are used to run the firms' operations. I borrow a page from the adjustment cost literature and assume that fixed operating costs are convex in the level of industry sophistication. Second, operating costs are reduced by advances in knowledge, which in our model is captured by quality. I suppose that all knowledge is useful in reducing operating costs; that is, that knowledge spillovers from both an intermediate goods firm's own industry and also from the other industry lower operating costs. Thus, both own industry knowledge Z_i and other industry knowledge Z_j help reduce costs. The general form of the operating cost function is thus $\phi_{ij} = \Phi_{ij}\left(Z_i; Z_i, Z_k\right)$ with $\Phi'_1 > 0$, $\Phi'_{11} > 0$, $\Phi'_2 < 0$, and $\Phi'_3 < 0$. To keep the analysis tractable, I assume that all firms in a given industry have the same cost function, which takes the analytically convenient form

$$\Phi_{ij}\left(Z_i; Z_i, Z_k\right) = \theta_i \frac{Z_i^3}{Z_i Z_k} = \theta_i \frac{Z_i^2}{Z_k}$$

The cubic term in the numerator captures the convexity of cost in complexity[10], and the two terms in the denominator capture the effect of knowledge in reducing costs. Thus, I have

$$\phi_1 \equiv \phi_{1j} = \theta_1 \frac{Z_1^2}{Z_2}; \qquad \phi_2 \equiv \phi_{2j} = \theta_2 \frac{Z_2^2}{Z_1} \tag{16}$$

Dependence of cost on only industry averages and not the firm's own quality level is not restrictive because, as I show later, firms within a given industry behave symmetrically so that each firm's quality equals the average quality of the industry.

The intermediate goods firm's *gross profit* is revenue substracted by production costs:

$$F_{ij} = P_{G_{ij}} G_{ij} - A_i G_{ij} - \phi_i \tag{17}$$

The firm retains some amount R_{ij} of its gross profit for investment purposes and distributes the rest to its owners. Gross profit net of retained earnings is the net profit:

$$\Pi_{ij} = F_{ij} - R_{ij} \tag{18}$$

The present discounted value $V_{ij}(t)$ of this net profit is

$$\begin{aligned} V_{ij}(t) &= \int_t^\infty \Pi_{ij}\, e^{-\int_t^\tau r(s)ds} d\tau \\ &= \int_t^\infty \left[G_{ij}\left(P_{G_{ij}} - A_i\right) - \phi_i - R_{ij}\right] e^{-\int_t^\tau r(s)ds}\, d\tau \end{aligned} \tag{19}$$

The firm chooses the paths of its product price $P_{G_{ij}}$ and its R&D expenditure R_{ij} to maximize (19) subject to the demand function (9), the R&D production function (15), and the average qualities, Z_1 and Z_2, which the firm takes as given. So the firm's current-value Hamiltonian is

$$CVH_{ij} = G_{ij}(P_{Gij} - A_i) - \phi_i - R_{ij} + q_{ij}(\alpha_i R_{ij})$$

where i denotes the industry, and q_{ij} is the co-state variable. Taking the first order direvative subject to $P_{G_{ij}}$, the solutions for the prices are mark-ups over variable cost:

$$P_{G1} \equiv P_{G_{1j}} = \frac{A_1}{\lambda} \tag{20}$$

$$P_{G2} \equiv P_{G_{2j}} = \frac{A_2}{\lambda} \tag{21}$$

The Hamiltonian is linear in R&D expenditure, so the solution for investment expenditure R_{1j} is bang-bang:

$$R_{ij} \begin{cases} = \infty & \text{if } 1/\alpha > q_{ij} \\ > 0 & \text{if } 1/\alpha = q_{ij} \\ = 0 & \text{if } 1/\alpha < q_{ij} \end{cases}$$

[10] I choose a cubic functional form for the tractability of the model.

I rule out the first possibility of $R_{ij} = \infty$ because it is inconsistent with market equilibrium. I also rule out the other corner solution, $1/\alpha < q_{ij}$, because it implies no economic growth, and I am interested here in the case where perpetual growth occurs. I thus have the interior solution

$$\frac{1}{\alpha_i} = q_{ij} \tag{22}$$

The left side of eq. (22) is the same for all j, so all firms in industry i choose the same level of R&D, which I denote R_i.

The Maximum Principle gives the necessary condition for the evolution of the co-state variable q_1, which I can rearrange as

$$r_{ij} = \frac{\partial F_{ij}}{\partial Z_{ij}} \frac{1}{q_{ij}} + \frac{\dot{q_{ij}}}{q_{ij}} \tag{23}$$

This equation defines the rate of return to R&D (i.e., to quality innovation), with r_{ij} as the percentage marginal revenue from R&D plus the capital gain (percentage change in the shadow price). Because $1/\alpha_i = q_{ij}$, I also have $\dot{q}_{ij}/q_{ij} = 0$. As with intermediate goods prices, the expressions for the rates of return differ across the two industries. The rate of return for industry 1 is obtained by substituting (9), (17), (20), and (22) into (23):

$$r_{1j} = \delta \alpha_1 A_1 \frac{1-\lambda}{\lambda} \left(\frac{\lambda P_{X_1}}{A_1/\lambda} \right)^{\frac{1}{1-\lambda}} \left(\frac{Z_{1j}}{Z_2} \right)^{(\delta+\gamma)-1} l_{1j} \tag{24}$$

Following the same steps as in industry 1, I get the rate of return to R&D in industry 2:

$$r_{2j} = \delta \alpha_2 A_2 \frac{1-\lambda}{\lambda} \left(\frac{\lambda P_{X_2}}{A_2/\lambda} \right)^{\frac{1}{1-\lambda}} \left(\frac{Z_{2j}}{Z_1} \right)^{(\delta+\gamma)-1} l_{2j} \tag{25}$$

The return in R&D positively depends on the market size of individual firm, l_{ij}. Given the spillover from the other industry, return in R&D is diminishing in its own quality level, since $\delta + \gamma$ is between 0 and 1. Thus, a balanced growth requires the qualities from both industries to grow together. [11]

The return in R&D has a convenient property that,

$$r_{ij} = \delta \alpha_i \frac{(P_{ij} - A_i) G_{ij}}{Z_{ij}} \tag{26}$$

Keep this convenient property in mind. It provides clear intuition for cross-industry differences in section (2.7) and (2.8).

[11] Without inter-industry spillover, industries grow at different rates on BGP. However, this does not alter the main results of this paper. See the appendix for detail.

2.3.2 Entrants

The value of the firm V_{ij} $(i = 1, 2)$ is defined by equation (19). To determine the entry and exit of the firm, this value V_{ij} has to be compared with the cost of entry and exit. I assume that entry and exit are costless. For simplicity, I refer only to entry. I explored an extension of the model with costly entry, but I was unable to obtain closed-form solutions.[12] Costless entry implies that N_i is a jumping variable. Whenever the net present value of a new firm V_{ij} differs from the entry cost of zero, new firms jump in or out to restore equality between the value of the firm and the entry cost. I thus have at all times

$$V_{ij} = 0 \tag{27}$$

Differentiating Eq.(19) with respect to time gives the firm's rate of return to equity (i.e., entry):

$$r_{ij}^E = \frac{\Pi_{ij}}{V_{ij}} + \frac{\dot{V}_{ij}}{V_{ij}} \tag{28}$$

This is a usual perfect-foresight, no-arbitrage condition for the equilibrium of the captial market. It requires two conditions. First, the returns in R&D in all firms in both industries should be the same, otherwise all investment goes to the firms with higher R&D returns. We are going to revisit this condition again in general equilibrium. Second, the return to firm ownership should be equal to the rate of return to a riskless loan of size V_{ij}. The return to firm ownership is given by the ratio between profit $(\prod_{ij})$ and the firm's stock market value (V_{ij}), plus the capital gain (loss) from the stock appreciation (depreciation). As a result, I also have $\dot{V}_{ij} = 0$. Multiplying both sides of (28) by V_i and imposing $V_{ij} = 0$ and $\dot{V}_{ij} = 0$ implies the *Zero (net) Profit Condition.*

$$\Pi_{ij} = 0 \tag{29}$$

as in Peretto (Oct 1999).

Based on zero profit condition (29) and (18), incumbents denote all the retaining gross profits for R&D. The level of R&D expenditure can be written as

$$R_{ij} = F_{ij} = P_{G_{ij}} G_{ij} - A_i G_{ij} - \phi_i \tag{30}$$

And the growth rates of qualities can be written as the quality-adjusted gross profit $\frac{F_{ij}}{Z_{ij}}$, times the R&D productivity α_i

$$\frac{\dot{Z}_{ij}}{Z_{ij}} = \frac{\alpha_i R_{ij}}{Z_{ij}} = \frac{\alpha_i F_{ij}}{Z_{ij}} = \frac{\alpha_i [(P_{ij} - A_i) G_{ij} - \phi_i]}{Z_{ij}} \tag{31}$$

[12] See Peretto (2007) for discussions of costly entry in a framework similar to mine.

2.3.3 Symmetry and Asymmetry

As my interest is in industry comparisons, I focus on equilibrium where the distribution of productivity within sectors is symmetric and stable.

I follow Peretto (Oct. 1999) and impose a simplification that avoids technical complications and has no effect on the analysis or results. I assume that (1) at the initial time all firms in industry i have the same level of quality $Z_{ij} = Z_i$; and (2) new firms enter with the average quality level Z_i of the industry. These two assumptions plus a zero-cost entry/exit condition lead directly to an equilibrium that is symmetric within each industry, with all firms in an industry always making the same decisions on pricing, R&D expenditures, and market size. See Appendix for detail.

I should clarify one point about the stability of the equilibrium. Consider the general situation in which firms have different quality levels. A firm with below-average quality might be tempted to set R&D expenditures to zero and get a free ride to the average level of quality simply by leaving the market and then immediately re-entering with the average quality. If that strategy were profitable, the market equilibrium would be one in which no firms do R&D. However, the strategy is not profitable. Once an incumbent entrepreneur leaves the market, he loses all claim on the niche he just vacated. That is the meaning of exit, after all. If he wants to re-enter the market, even in the instant after he leaves, he must join the pool of other potential entrants vying for the vacated niche. There are an uncountable number of potential entrants, so the probability that the former incumbent will reclaim the vacated niche is zero. The strategy of exit and immediate re-entry therefore has an expected value of zero, rendering it unprofitable. Thus an incumbent with below-average quality will not leave the market and then try to re-enter, and the equilibrium is stable with respect to such possible behavior. For a complete discussion of market equilibrium and its stability in these types of R&D models, see Peretto (1996, 1999, 2007) and the references cited therein.

All firms in industry i choose the same prices and sell the same quantity of goods, all of which have the same quality. Because the intermediate goods G_{ij} have the same price and quality, the processed goods industry allocates the same amount of labor to each of them. I henceforth drop the firm subscript except where clarity demands otherwise.

The internal symmetry of each industry leads (24) and (25) to simplified expressions for the rates of return

$$r_1 \equiv r_{1j} = \delta\alpha_1 A_1 \frac{1-\lambda}{\lambda}\left(\frac{\lambda P_{X_1}}{A_1/\lambda}\right)^{\frac{1}{1-\lambda}}\left(\frac{Z_1}{Z_2}\right)^{(\delta+\gamma)-1} l_1 \tag{32}$$

$$r_2 \equiv r_{2j} = \delta\alpha_2 A_2 \frac{1-\lambda}{\lambda}\left(\frac{\lambda P_{X_2}}{A_2/\lambda}\right)^{\frac{1}{1-\lambda}}\left(\frac{Z_2}{Z_1}\right)^{(\delta+\gamma)-1} l_2 \tag{33}$$

$$l_1 = L_1/N_1 \tag{34}$$

$$l_2 = L_2/N_2 \tag{35}$$

The growth rates of quality innovation, (31) can be written as

$$\begin{aligned} g_1 &\equiv \frac{\dot{Z}_1}{Z_1} = \frac{\alpha_1 R_1}{Z_1} = \frac{\alpha_1 F_1}{Z_1} \qquad (36) \\ &= \alpha_1 \left[A_1 \frac{1-\lambda}{\lambda} \left(\frac{\lambda P_{X_1}}{A_1/\lambda} \right)^{\frac{1}{1-\lambda}} \left(\frac{Z_1}{Z_2} \right)^{(\delta+\gamma)-1} l_1 - \theta_1 \frac{Z_1}{Z_2} \right] \\ g_2 &= \frac{\dot{Z}_2}{Z_2} = \frac{\alpha_2 R_2}{Z_2} = \frac{\alpha_2 F_2}{Z_2} \qquad (37) \\ &= \alpha_2 \left[A_2 \frac{1-\lambda}{\lambda} \left(\frac{\lambda P_{X_2}}{A_2/\lambda} \right)^{\frac{1}{1-\lambda}} \left(\frac{Z_2}{Z_1} \right)^{(\delta+\gamma)-1} l_2 - \theta_2 \frac{Z_2}{Z_1} \right] \end{aligned}$$

As we have seen, firms in industry 1 are all alike, and firms in industry 2 are all alike, but this model is not entirely symmetric. Firms in industry 1 differ from firms in industry 2. In general, $P_{G1} \neq P_{G2}$ because, in general, $A_1 \neq A_2$; $R_1 \neq R_2$ because, in general, $\alpha_1 \neq \alpha_2$; and also $l_1 \neq l_2$ as we will see later. Thus, firms differ across industries. This element of asymmetry increases the realism of the model and, more importantly, provides the basis for cross-industry TFP growth differences and other applications, e.g., directed technical change, structural change, comparative advantage and dynamic trade.

In this section, I discuss the decisions of both incumbents and entry in the intermediate goods sector. I first derived the firm's price and R&D decision in both industries, given the market structure, the interest rate, and the demand. Next, I imposed the instantaneous zero-profit condition, given the price, R&D decision, interest rate and demand. Then I show that the equilibrium within an industry is symmetric with all firms in that industry choosing the same values for their control variables; but, across the industries the equilibrium is asymmetric with firms in industry 1 making different decisions from firms in industry 2.

To determine the dynamic of the economy, I now look at the household decision and the general equilibrium.

2.4 Households

The economy is populated by a representative household that supplies labor inelastically in a perfectly competitive market and purchases assets (corporate equity). I assume for simplicity that there is no population growth. The utility function of the representative household is

$$U(t) = \int_t^{\infty} log(c)\, e^{-\rho t} \qquad (38)$$

where c is consumption per capita and ρ is the rate of time preference.

The only assets that the household can accumulate are firms that it owns. The household's lifetime budget constraint therefore is

$$0 = \int_0^\infty \left(\int_0^{N_1} \Pi_{1j} dj + \int_0^{N_2} \Pi_{2j} dj + wL - C \right) e^{-\int_t^\tau r(s)ds} dt \tag{39}$$

where C is aggregate consumption and L is population. The intertemporal consumption plan that maximizes discounted utility (38) is given by the consumption Euler equation, which, as usual, can be written as

$$r = \rho + \frac{\dot{C}}{C} \tag{40}$$

2.5 General Equilibrium

In general equilibrium, all markets clear.

In the labor market, the quantity labor demanded, eqn (11) and (12), equals to the quantity labor supplied. The supply of labor in each industry is given by the labor constraint, $L_1 + L_2 = L$, and the labor allocation (13). Thus, $L_1 = \epsilon L$, and $L_2 = (1-\epsilon)L$. Note that *Industry-level* market sizes are different across industries. Such market size difference doesn't determine the cross-industry TFP growth differences. This is because the R&D incentive of an individual firm does not depend on industry-level market size, but on the firm's market size. These growth rates in (36) and (37), and the returns in R&D from (32) and (33) depend positively on L_i/N_i, which is the individual firm size l_i, not with L_i itself, which is the industry market size. That distinction is one of the main differences between second-generation growth models like this and first-generation models. In this model, an increase in L_i raises demand by the processed goods sector for intermediate goods and thereby raises profit of the existing intermediate goods firms. The increase in profit induces entry of new firms and raises N_i to keep L_i/N_i constant. An increase in aggregate market size L_i will not cause an increase in growth rate of R&D.

In the credit market, the no-arbitrage condition requires that all rates of return are equal: $r_1 = r_2 = r$. So the right sides of (32) and (33) must be equal. If one return is higher, then all resources go to accumulate that quality. The numbers of firms N_1 and N_2 jump up or down, which lowers or raises firm size l_1 and l_2. From (32) and (33), instantaneous changes in firm size lower or raise the rates of return r_1 and r_2. Those changes continue until the arbitrage opportunity has been eliminated. Until this point, we see market structure is endogenous. It is determined by endogenous firm entry based on the no-arbitrage condition. This is the most important difference between this model and exisiting literature, and it plays an important role in cross-industry TFP growth differences. Further detail will be given in section (2.8).

Given that all markets are clear, and with the solutions for the intermediate goods sector in hand, I can solve the rest of the model. As noted earlier, the prices P_{Gi} determine the quantities G_i from the demand equations (9) and (10). The values of the Z_i are the solutions to the differential equations (36) and (37), subject to the initial values of the Z_i. I describe those solutions below. I also have derived the labor demands (11) and (12). I use those solutions to solve the processed goods sector's production functions (6) and (7) for X_1 and X_2. I then substitute the solutions for X_1 and X_2 into the final goods sector's production function (1) to get Y and into the indirect demand functions for processed goods (3) and (4) to get the prices P_{X1} and P_{X2}. Using the solutions for P_{X1}, P_{X2}, X_1, and X_2, I can write the rates of return in (32), (33), (36) and (37) entirely as functions of parameters, the state variables Z_1 and Z_2, and the number of firms in each intermediate goods industry N_1 and N_2.

Now I have two remaining unknowns: N_1 and N_2. I get one equation for determining them by imposing the no-arbitrage condition where rates of return must be equal which allows us to set the two expressions on the right sides of (32) and (33) equal to each other and get a function of N_1, N_2 and $\frac{Z_1}{Z_2}$ only.

The remaining equation is the Euler equation. I've shown that market clearing conditions guarantee the same growth rates for C and Y,

$$\frac{\dot{Y}}{Y} = \frac{\dot{C}}{C} = r - \rho \tag{41}$$

Combining the demand functions of intermediate goods (9) and (10) in the final goods production (1) to eliminate G_i, I get

$$Y = \kappa Z_1^{\Gamma} Z_2^{1-\Gamma} L \tag{42}$$

where κ and Γ are some constants.[13]. The growth rate of Y is a weighted average of the growth rates of the Z_i:

$$\frac{\dot{Y}}{Y} = \Gamma g_1 + (1 - \Gamma) g_2 \tag{43}$$

The growth rates g_1 and g_2 are given by equations (36) and (37) and are functions of model parameters, the current values of the state variables Z_1 and Z_2, and of N_1 and N_2. Thus, the Euler equation also provides an equation of the two unknowns N_1 and N_2, giving us the second equation that I need to solve for N_1 and N_2.

2.6 Balanced Growth Path

On the BGP, the growth rates of Z_1 and Z_2 are equal, and the ratio Z_1/Z_2 is constant. Then the following growth rates, including growth rates of both industries, are equal:

$$g^{\star} = \frac{\dot{Z}_1}{Z_1} = \frac{\dot{Z}_2}{Z_2} = \frac{\dot{Y}}{Y} = \frac{\dot{C}}{C} = \frac{\dot{X}_1}{X_1} = \frac{\dot{X}_2}{X_2} = \frac{\dot{G}_1}{G_1} = \frac{\dot{G}_2}{G_2} = \frac{\dot{w}}{w} \tag{44}$$

[13]See the appendix for detail.

I get the quality ratio $(Z_1/Z_2)^\star$ on the BGP by noting that $g_1 = g_2 = g^*$, $r_1 = r_2 \equiv r$, and, from the Euler equation, $r = g^* + \rho$. From those relations, I obtain the following quadratic form:

$$\alpha_1\theta_1 \left(\frac{Z_1}{Z_2}\right)^2 - \alpha_2\theta_2 = 0 \tag{45}$$

The two roots are

$$\left(\frac{Z_1}{Z_2}\right)^\star = \sqrt{\frac{\alpha_2\theta_2}{\alpha_1\theta_1}} > 0 \tag{46}$$
$$\left(\frac{Z_1}{Z_2}\right)^\star = -\sqrt{\frac{\alpha_2\theta_2}{\alpha_1\theta_1}} < 0$$

I discard the negative solution because it is economically meaningless, so the balanced growth rate is

$$g^* = \frac{\delta}{1-\delta}\sqrt{\alpha_1\theta_1\alpha_2\theta_2} - \frac{1}{1-\delta}\rho \tag{47}$$

(46) shows that the steady state ratio of Z_1 and Z_2 is negatively related with $\alpha_1\theta_1$, and positively related with $\alpha_2\theta_2$. People tend to think the industry with a higher R&D productivity should enjoy a relatively higher technology level compared with the other industry, while this model predicts the opposite. The reason is the endogenous market structure. Further detail will be discussed in section (2.7).

(47) shows two classes of results. First, the R&D productivities and fixed operating cost parameters of both industries are positively related with the balanced growth rate. The impact of fixed operating costs on balanced growth rate was unusual in other literature. I will explain this in section (2.6.1). Second, other factors, such as the scale effect, and the unit costs do not affect the balanced growth. See intuition in section (2.6.2). For both results, the endogenous market structure plays a crucial role, which is explained in section (2.6.3).

2.6.1 The effects of α_i and θ_i on g^*

The growth rate depends positively on the R&D productivities α_1 and α_2 and on the fixed operating cost parameters θ_1 and θ_2. The higher the productivity of R&D with others fixed, the higher the return to R&D, which implies a higher growth rate. See (32). This is a usual result in literature.

The unusual result is the positive effect of fixed operating cost parameters on the growth rate. The higher the fixed operating cost parameters, the lower the profit for incumbents and thus the smaller the number of firms in the market, which drives up the individual market size of firms L_i/N_i. From eqs. (32) and (33), we see that the larger the individual firm market size, the higher return in R&D. Consequently, the growth rate on BGP is positively related to fixed operating costs. Peretto (2007) obtains the same result for the same reason. Much of the earlier literature ignores the long run effects of fixed operating costs. (47) shows it very important on balanced growth rate. I will show that, with the endogenous market structure, fixed operating costs also play a crucial role on cross-industry TFP growth differences in section (2.8).

2.6.2 The Effects of $A_i's$ on g^*

The growth rate is unrelated to unit costs of production A_1 and A_2. A change in unit costs has two opposite effects that exactly cancel. One effect is a positive "direct effect": eq (32) shows that a decrease in unit costs directly causes an increase in the return of R&D and hence also in the growth rate. The other effect is a negative "indirect effect": a decrease in unit costs causes a higher incipient profit and induces entry, which reduces firm size L_i/N_i and hence reduces the return to R&D. We can see this indirect effect from (48) later. These two effects cancel out each other, so the growth rate is not affected by unit costs.

2.6.3 The Endogenous Market Structure and The Number of Firms on BGP

Now we will see how the endogenous market structure drives the previous results on BGP. We can see this point more clearly by looking at the number of firms on BGP.

We can get the number of firms N_1^* by plugging $(\frac{Z_1}{Z_2})^*$ back to growth rate (36) and return in R&D (32) and combining the Euler equation.

$$N_1^* = \frac{\alpha_1 \delta^{\frac{1-\lambda}{\lambda}} [\lambda^2 \epsilon]^{\frac{1}{1-\lambda}} (\frac{\epsilon}{1-\epsilon})^{\frac{\epsilon-1}{1-\lambda}}}{\frac{\delta}{1-\delta}\sqrt{\alpha_1\theta_1\alpha_2\theta_2} - \frac{\delta}{1-\delta}\rho} (\sqrt{\frac{\alpha_2\theta_2}{\alpha_1\theta_1}})^{\Gamma-1} A_1^{\frac{-\lambda\epsilon}{1-\lambda}} A_2^{\frac{-\lambda(1-\epsilon)}{1-\lambda}} (\epsilon L) \tag{48}$$

First, $\partial N_1^*/\partial\theta_1 < 0$.[14] A higher fixed operating cost parameter implies a higher barrier to entry. Therefore, the number of firms in the market is smaller, and the firm size, $\frac{L_1}{N_1}$ is larger, given that $L_1 = \epsilon L$. A higher firm size implies a higher return in R&D and therefore a higher growth rate, as discussed in section (2.6.1).

Second, $\partial N_1^*/\partial A_1 < 0$.[15] A lower A_1 causes an incipient increase in profit. That induces firms to enter instantaneously without any cost (N_1 increases). As a result, firm size decreases, which has a negative effect on r_1 according to (32). This is the "indirect" effect of a lower A_1, as discussed in section (2.6.2). A lower A_1 also directly increases r_1 (direct effect), but it is offset by the firm entry (indirect effect). Thus, unit costs do not affect return in R&D and the growth rate.

Third, Eqn (48) also shows the reason why this model does not show a scale effect. Firm size $\epsilon L/N_1^*$ is constant on the BGP. If L increases, N_1 jumps (zero entry cost) to keep the ratio constant. Consequently, entry kills the scale effect at the aggregate level. Thus, the growth rate (47) does not contain L (scale effect).

[14]See Derivation in the appendix.

[15](48) indicates $\partial N_1^*/\partial A_2 < 0$. See derivations and intuitions in the appendix.

The solution of the number of firms in the other industry, N_2^*, and the intuition are in the appendix.

In this section, we have seen two important results. First, balanced growth rate positively depends on R&D productivity and fixed operating cost parameters. Fixed operating cost parameters affect growth rate through the endogenous firm entry. Second, unit costs and aggregate market size do not affect balanced growth due to endogenous firm entry. The endogenous market structure plays an important role to drive these results. It make the model distinct from those growth models with scale effect and semi-endogenous growth models.

The endogenous market structure is also the crucial element that determines cross-industry TFP differences. See section (2.7) and (2.8). Next, I will present the full transition dynamics, which is stable. I will also provide the reason why in (46), $(\frac{Z_1}{Z_2})^*$is negatively related with $\alpha_1\theta_1$, while positively related with $\alpha_2\theta_2$.

2.7 Transition Dynamics

The model permits a full characterization of the economy's transition dynamics. In this section, I will first show the intuition why $(\frac{Z_1}{Z_2})^*$ is negatively related with $\alpha_1\theta_1$. Then, I will describe the full transition dynamics. Notice how the endogenous market drives the results.

Recall that R&D production function in industry i is (15); and zero entry cost requires zero (net) profit condition. Thus firm uses its retaining gross profit for R&D, which is $R_i = F_i$ in (30). Therefore,

$$\dot{Z}_1 = \alpha_1[(P_1 - A_1)G_1 - \phi_1] \quad (49)$$

$$= \alpha_1 \frac{(P_1 - A_1)G_1}{Z_1} Z_1 - \alpha_1\theta_1 \frac{Z_1^2}{Z_2} \quad (50)$$

$$\dot{Z}_2 = \alpha_2[(P_2 - A_2)G_2 - \phi_2]$$

$$= \alpha_2 \frac{(P_2 - A_2)G_2}{Z_2} Z_2 - \alpha_2\theta_2 \frac{Z_2^2}{Z_1}$$

From (49) it *seems* that $\dot{Z}_1$ is positively related with α_1 as other literature predicts. It is true with the exogenous market structure. But in this model, the market structure is endogenous. (9) shows that G_1 includes individual market size, which is endogenously determined by firm entry, N_1 and N_2. The no-arbitrage condition with zero entry cost requires that the number of firms, N_1 and N_2 adjust instantly to equalize the returns to R&D across the two industries. Thus, the right sides of (24) and (25) are always equal. According to (26), this means

$$r_1 = r_2 \Longleftrightarrow \delta\alpha_1 \frac{(P_1 - A_1)G_1}{Z_1} = \delta\alpha_2 \frac{(P_2 - A_2)G_2}{Z_2} \tag{51}$$

$$\Longleftrightarrow \alpha_1 \frac{(P_1 - A_1)G_1}{Z_1} = \alpha_2 \frac{(P_2 - A_2)G_2}{Z_2} \tag{52}$$

Now assume the economy is on BGP, so Z_1 and Z_2 grow at the same rates. When α_1 increases, at that instance, the first term in (50) does not change for two reasons. First, instantaneous entry makes $\alpha_1 \frac{(P_1-A_1)G_1}{Z_1} = \alpha_2 \frac{(P_2-A_2)G_2}{Z_2}$ due to the no-arbitrage condition (51). Second, Z_1 has not changed yet at that instance. The second term in (50) increases because of a higher α_1. An increase in α_1 instantaneously decreases $\dot{Z}_1$ while keeps $\dot{Z}_2$ unchanged at that moment, so Z_1 grows slower than Z_2 until the quality ratio goes to a new steady state. Therefore, the steady state of $\frac{Z_1}{Z_2}$ is negatively related with α_1. Similar reasons apply to the effects of fixed operating costs and α_2 on $(\frac{Z_1}{Z_2})^*$.

We have seen how the endogenous market structure and the no-arbitrage condition cause the steady state of quality negatively depends on $\alpha_1\theta_1$, and positively depends on $\alpha_2\theta_2$. In the rest of the paper, readers must keep in mind that the market structure is endogenous, and the no-arbitrage condition always holds due to the endogenous firm entry. Most of the results in the rest of the paper are driven by the endogenous market structure.

Now, I show the full transition dynamics of the model. The growth rates of qualities are quality-adjusted gross profits times R&D productivity (36) and (37). They can also be organized as

$$\frac{\dot{Z}_1}{Z_1} = \alpha_1 \frac{(P_1 - A_1)G_1}{Z_1} - \alpha_1\theta_1 \frac{Z_1}{Z_2} \tag{53}$$

$$\frac{\dot{Z}_2}{Z_2} = \alpha_2 \frac{(P_2 - A_2)G_2}{Z_2} - \alpha_2\theta_2 \frac{Z_2}{Z_1} \tag{54}$$

According to the no-arbitrage condition (51), the first terms of (53) and (54) are equal due to the endogenous entry. The difference of TFP growth across industries becomes [16]

$$\frac{\dot{(Z_1/Z_2)}}{Z_1/Z_2} = \frac{\dot{Z}_1}{Z_1} - \frac{\dot{Z}_2}{Z_2} = -\alpha_1\theta_1(\frac{Z_1}{Z_2}) + \alpha_2\theta_2(\frac{Z_2}{Z_1}) \tag{55}$$

Multiplying (55) through by Z_1/Z_2 gives

$$\dot{(Z_1/Z_2)} = -\alpha_1\theta_1(Z_1/Z_2)^2 + \alpha_2\theta_2 \tag{56}$$

[16] If $\delta' s$ in (51) are not equal across industries, the main results of this model are still robust. See the appendix.

The steady state is the value of Z_1/Z_2 that makes $(\dot{Z_1/Z_2}) = 0$, which is equivlent to making $\left(\dot{Z_1/Z_2}\right)/(Z_1/Z_2) = 0$, which, in turn, is equivalent to making $\dot{Z}_1/Z_1 = \dot{Z}_2/Z_2$. Setting $(\dot{Z_1/Z_2}) = 0$ in (56) and rearranging gives the quadratic form

$$(Z_1/Z_2)^2 = \alpha_2\theta_2/\alpha_1\theta_1$$

One root is $\sqrt{\alpha_2\theta_2/\alpha_1\theta_1} > 0$, which is stable. When $Z_1/Z_2 > \sqrt{\alpha_2\theta_2/\alpha_1\theta_1}$, eq. (56) implies $(\dot{Z_1/Z_2}) < 0$, so Z_1 decreases relative to Z_2, and Z_1/Z_2 returns to $\sqrt{\alpha_2\theta_2/\alpha_1\theta_1}$. When $0 < Z_1/Z_2 < \alpha_2\theta_2/\alpha_1\theta_1$, eq. (56) implies $(\dot{Z_1/Z_2}) > 0$ so that Z_1 rises relative to Z_2 and again Z_1/Z_2 returns to $\sqrt{\alpha_2\theta_2/\alpha_1\theta_1}$. The other root is $-\sqrt{\alpha_2\theta_2/\alpha_1\theta_1} < 0$ and is unstable. Figure 2 shows the transitional dynamics. Thus, the positive root is the unique globally stable equilibrium value for the quality ratio Z_1/Z_2. At that equilibrium ratio, Z_1 and Z_2 grow at the same rate, and the economy is on the balanced growth path.

Note that all growth rates depend on quality improvement alone, while variety expansion plays no role. This is due to two reasons: (1) Fixed operating costs make the variety expansions eventually stop (see Peretto and Connolly (2007) for a detail discussion); and (2) with zero entry cost, the number of firms jumps instantaneously to eliminate the incipient profits. As a result, variety expansion has no effect on growth even along the transition path. See Peretto (Oct. 1999).

In this section, I show that, the steady state TFP level ratio between industry 1 and 2 depends negatively on R&D productivity and fixed cost parameter of industry 1; while it depends positively on those parameters of industry 2 due to the endogenous market structure. On BGP, the TFP growth rates across industries are the same. During transition, the TFP growth rates across industries are different. The transition dynamics is stable. In the next section, I will show the factors that determine the cross-industry TFP growth differences and research intensity differences on the transition path. We are going to see, again, how the endogenous market structure leads to surprising results.

2.8 TFP Growth Differences Across Industries

This section examines the determinants of the differences of research intensity and TFP growth across industries. This model provides substantially different implications on across-industry TFP growth differences and research intensity from other literature. Those variations depend on the quality-adjusted gross profits and R&D productivities in (53) and (54), which in general equilibrium, only depend on the differences in R&D productivities and fixed operating costs, but not on the differences in unit costs and industry level market sizes.

Eqn (55) shows that the *difference* between the growth rates of Z_1 and Z_2 negatively depends on $\alpha_1\theta_1$, and positively depends on $\alpha_2\theta_2$.

$$\frac{\partial\,[\frac{\dot{Z}_1}{Z_1} - \frac{\dot{Z}_2}{Z_2}]}{\partial\,\alpha_1\theta_1} = -\frac{Z_1}{Z_2} < 0; \tag{57}$$

$$\frac{\partial\,[\frac{\dot{Z}_1}{Z_1}-\frac{\dot{Z}_2}{Z_2}]}{\partial\,\alpha_2\theta_2}=\frac{Z_2}{Z_1}>0 \tag{58}$$

This means that, if $\alpha_1\theta_1$ increases, then the difference between $\frac{\dot{Z}_1}{Z_1}$ and $\frac{\dot{Z}_2}{Z_2}$ becomes smaller. This result is suprising and substantially different from other literature. Why does a higher R&D productivity α_1 (and fixed cost parameter θ_1) imply a smaller difference between the growth rates of Z_1 and Z_2? The key is, again, the endogenous market structure.

To emphasize the endogenous market structure, which is the main difference between this model and the other literature, let's imagine if the market size is exogenous first. Given an exogenous individual market size, in the expressions of TFP growth, (36) and (37), l_1 and l_2 are exogenous and fixed. Assume initially $g_1 = g_2$, then a raise in R&D productivity α_1 implies a higher TFP growth in industry 1. This is exactly what is implied by the literature without the endogenous market structure. However, in this model, entry is endogenously determined. The no-arbitrage condition induces new firms to enter the market to make the return in R&D equal across industries. Since firms can enter the market instantanously with zero cost, it means the no-arbitrage condition always holds. See (51). Therefore, the first terms in the the TFP growth for both industries, (53) and (54), are always equal due to the endogenous firm entry, and the second term determines the growth differences. See (55). It leads to the result that the industry with a higher R&D productivity and a fixed cost parameter has a lower TFP growth compared to the other industry, given the same initial TFP levels across industries. More specifically, in (53) and (54), given $Z_1 = Z_2$, if $\alpha_1\theta_1 > \alpha_2\theta_2$, then the growth rate of Z_1 is lower than the growth rate of Z_2. The endogenous market size predicts a dramatically different result from the other literature.

The cross-industry TFP growth differences do not depend on the differences on unit costs and industry level market sizes. From the no-arbitrage condition (51), we can see that the endogenous entry also absorbs the differences in production unit costs and market sizes across industries, which are included in the term $(P_i - A_i)G_i$. Therefore, unit cost and industry market size differences do not affect the cross-industry quality growth differences. The differences in growth rates of Z_1 and Z_2 only depend on R&D productivities and fixed operating cost parameters , given $\frac{Z_1}{Z_2}$.

The initial quality ratio $\frac{Z_1}{Z_2}$ also affects the quality growth difference, as shown in (55). If $Z_1/Z_2 > \sqrt{\alpha_2\theta_2/\alpha_1\theta_1}$, then the second term of $\frac{\dot{Z}_1}{Z_1}$ in (53) is lower than the second term of $\frac{\dot{Z}_2}{Z_2}$ in (54). The first term of the growth rates are always equal due to the no-arbitrage condition and the endogenous entry. Therefore, $\frac{\dot{Z}_1}{Z_1} > \frac{\dot{Z}_2}{Z_2}$; and vice versa. See the detail in section (2.7).

What about the differences in R&D intensity across industries? Define industry research intensity as R&D/Sale, which is $RND_i \equiv \frac{R_i}{P_iG_i}$, as in Klenow (1996) and IO literature. After some simple calculation and taking the endogenous market structure into account (see Appendix), the research intensity ratio across industries is

$$\frac{RND_1}{RND_2} = \frac{\frac{\dot{Z}_1}{Z_1}}{\frac{\dot{Z}_2}{Z_2}} \tag{59}$$

If $\frac{\dot{Z}_1}{Z_1} > \frac{\dot{Z}_2}{Z_2}$, then $RND_1 > RND_2$; and vice versa. The factors that affect the difference between $\frac{\dot{Z}_1}{Z_1}$ and $\frac{\dot{Z}_2}{Z_2}$ also affect the difference in industry research intensity by the same direction.

This model provides substantially different implications on research intensity and across-industry TFP growth differences, compared with other literature. The key is the endogenous market structure. First, differences between the growth rates of Z_1 and Z_2 negatively depend on $\alpha_1\theta_1$, and positively depend on $\alpha_2\theta_2$. The reason is that, the endogenous firm entry under the no-arbitrage condition drives the first part of TFP growth in (53) and (54) equally across industries. The industry with a higher fixed operating cost and R&D productivity (in the second term) ends up devoting a smaller amount of resource in R&D relative to the other industry. Second, unit cost and industry market size differences do not affect the cross-industry TFP growth differences. The reason is also the endogenous market structure under the no-arbitrage condition. Finally, the differences in research intensity across industries depend on the same factors that affect cross-industry TFP growth differences.

3 Applications and Extensions

This model incorporates two characteristics to the endogenous growth model – the endogenous market structure and asymmetric industry behavior. The model leads naturally to analysis of issues besides cross-industry TFP growth differences. I show that the combination of the endogenous market structure and asymmetry across industries offers explanations for both directed technical change and structural change of the economy. They also provide a basis for examining the relation between international trade and economic growth.

3.1 Directed Technical Change

What determines the direction of technical change? Acemoglu (1998, 2002b) highlights the importance of industry market size on the direction of technical change. My model, as it stands, provides a theory of directed technical change. With the endogenous market structure, the industry size does not affect the direction of technical change. It is the differences between R&D productivity and fixed operating costs across industries that drive the directed technical change. We can see the detail on both BGP and transition dynamics.

On the BGP, growth rates across industries are the same, while the quality *levels* of different industries are different, as shown in (46). The type-1 technology Z_1 relative to Z_2 is negatively related with R&D productivity and fixed operating cost parameters of industry 1, $\alpha_1\theta_1$; and it is positively related with $\alpha_2\theta_2$. Neither unit costs nor the industry market size affect the quality ratio due to the endogenous market structure. The detail is in section (2.7).

During transition dynamics, different technologies grow at different rates. The growth rate of each type of technology depends on quality-adjusted gross profit times R&D productivity, which is the $\frac{\alpha_i(P_i-A_i)G_i}{Z_i}$, subtracted from $\alpha_i\theta_i\frac{Z_i}{Z_j}$, as seen in (53) and (54). The endogenous market structure, under the no-arbitrage condition, causes $\frac{\alpha_i(P_i-A_i)G_i}{Z_i}$ equal across industries. Therefore, the growth rate differences across industries are determined by $\alpha_i\theta_i\frac{Z_i}{Z_j}$ only. The industry with a higher value of $\alpha_i\theta_i\frac{Z_i}{Z_j}$ has a lower technological growth rate. See (55) and figure 2. Section (2.8) provides the detail. Again, with the endogenous market structure, the differences in unit costs and industry-level market size do not play roles in directed technical change.

This model can be extended to discuss the underlying reason for the biased technological change across different factors. With the endogenous market structure, the model provides a different prediction from Acemoglu (1998, 2000b). According to Acemolgu, technical change is biased towards the factor that ensures the larger returns, which is the factor facing a higher industry market size. Such result is based on the underlying assumption that, in each industry, each intermediate good firm faces the whole *industry* market as its *individual* market. However, as mentioned in the introduction, many contributions to the empirical IO literature show that the incentives for innovation are related to individual market size but not the industry level market size. Consistent with those empirical results, my model provides a framework to revisit the incentives for biased technological change. In a working paper, Ji (2011), I show that biased technological change does not depend on industry market size, and it could be a temporary phenomenon. All the implications in Acemoglu's model disappear. I also provide the transitional dynamics for such a change.

3.2 Economic Growth and Structural Change

In much of the literature, e.g., Acemoglu and Guerrieri (2006), and Ngai and Pissarides (2007), structural change is driven by an *exogenous* technological change[17]. But what drives the technological change? Those models cannot provide an answer. My model as it stands provides a theory of structural change, with the endogenous technological change, and the endogenous market structure. I show the underlying reason for structural change is technological change. The factors that affect the direction of technical change also affect the structural change. The previous literature ignores the endogenous technological change, and their results are not robust to introducing the endogenous market structure.

[17]The other reason for structural change, according to the literature, is the utility-based explanation, which requires different income elasticities for different goods and can yield structural change (defined as employment allocation) even with equal technological growth in all sectors.

I define the structural change as the difference on the growth rates of processed goods. The growth rates of processed goods, X_1 and X_2, are different until the economy converges to a BGP. I can rewrite X_1 and X_2 by combining the demand functions of intermediate goods (9) and (10) in the processed good productions (6) and (7) respectively,

$$X_1 = \zeta_1 Z_1^{\vartheta_1} Z_2^{1-\vartheta_1}(\epsilon L) \tag{60}$$

$$X_2 = \zeta_2 Z_1^{\vartheta_2} Z_2^{1-\vartheta_2}[(1-\epsilon)L] \tag{61}$$

The growth rate of X_i therefore depends on both TFP growth rates

$$\frac{\dot{X}_1}{X_1} = \vartheta_1 \frac{\dot{Z}_1}{Z_1} + (1-\vartheta_1)\frac{\dot{Z}_2}{Z_2} \tag{62}$$

$$\frac{\dot{X}_2}{X_2} = \vartheta_2 \frac{\dot{Z}_1}{Z_1} + (1-\vartheta_2)\frac{\dot{Z}_2}{Z_2} \tag{63}$$

where $\vartheta_i' s$ and $\zeta_i' s$ are constant, and $\vartheta_i \in (0,1)$. See the appendix for derivations.

Therefore, the difference of the processed goods growth rates across industries is

$$\frac{\dot{X}_1}{X_1} - \frac{\dot{X}_2}{X_2} = (1-\lambda)[2(\delta+\gamma)-1](\frac{\dot{Z}_1}{Z_1} - \frac{\dot{Z}_2}{Z_2}) \tag{64}$$

where $0 < \delta+\gamma < 1$; $0 < \lambda < 1$.

$(\frac{\dot{X}_1}{X_1} - \frac{\dot{X}_2}{X_2})$ depends on two elements. One is $2(\delta+\gamma)-1$, and the other one is the TFP growth difference, $(\frac{\dot{Z}_1}{Z_1} - \frac{\dot{Z}_2}{Z_2})$. $(\delta+\gamma)$ is the exponent of the industry's own knowledge which augments the workers, and $1-(\delta+\gamma)$ is the exponent of the knowledge spillover from the other industry. See (6) and (7). There are three critical cases. (1) If $\delta+\gamma = 1$, then there is no inter-industry spillover, so the growth rate of X_i only depends on its own quality growth rate Z_i, and $\frac{\dot{X}_1}{X_1} - \frac{\dot{X}_2}{X_2} = (1-\lambda)(\frac{\dot{Z}_1}{Z_1} - \frac{\dot{Z}_2}{Z_2})$. (2) If $\delta+\gamma = \frac{1}{2}$, then the knowledge spillover from both industries have the same weights for the growth of X_i, so $\frac{\dot{X}_1}{X_1} - \frac{\dot{X}_2}{X_2} = 0$. (3) If $\delta+\gamma = 0$, then it means the industry's own knowledge does not augment its own workers at all. It seems unrealistic.

Assume an industry's own knowledge contributes to its own TFP more, which seems more realistic. This then means that $\frac{1}{2} < \delta+\gamma \leq 1$. $(\frac{\dot{X}_1}{X_1} - \frac{\dot{X}_2}{X_2})$ is positively related with TFP growth difference $(\frac{\dot{Z}_1}{Z_1} - \frac{\dot{Z}_2}{Z_2})$. So, the factors that affect the TFP growth differences also affect industry output growth differences by the same direction. As discussed in section (2.8), due to the endogenous market structure, TFP growth difference, $(\frac{\dot{Z}_1}{Z_1} - \frac{\dot{Z}_2}{Z_2})$, negatively depends on $\alpha_1\theta_1$, and positively depends on $\alpha_2\theta_2$, as does the processed goods growth difference $(\frac{\dot{X}_1}{X_1} - \frac{\dot{X}_2}{X_2})$. Besides that, the differences on processed goods growth rates does not depend on unit costs and industry market size, as indicated by the differences on TFP growth.

The structure change essentially depends on the endogenous technological change with the endogenous market structure. Any factors that affect the direction of technical change affect structural change. The models with exogenous technological change and an exogenous market structure miss such important elements of structural change.

The model can be extended to discuss the other aspect of structural change – the shifts in industrial employment shares that take place over long periods of time. The current model uses Cobb Douglas production function and homothetic preference, which imply a constant allocation of employment across industries independent of their productivity. Such assumptions can be relaxed to generate a dynamic of allocations of labors. I could either use CES production function as in Acemoglu and Guerrieri (2006), and Ngai and Pissarides (2007); or use nonhomothetic preference as in Caselli and Coleman (2001), and Kongsamut el. (2010). Such a set up will allow the model to generate a dynamic allocation of labors across industries. This is my work in progress.

3.3 Comparative Advantage, trade and growth

With the asymmetric element, this model can be extended to discuss the interaction between trade and growth. The element of asymmetry allows us to determine comparative advantage and the trade pattern endogenously, which is unusual in studies of trade and growth. The endogenous market structure eliminates scale effect. Therefore, trade does not affect growth through a larger aggregate market size, which fits the empirical results and also allows me to focus on the pure effect of comparative advantage on growth. An "in-house" technical progress and the separation of production division and R&D division in this model lead to a possibility of dynamic inefficiency after trade. As traders purchase the cheaper goods, they ignore the effects of their purchasing decisions on the R&D activity of the firms making the products that the traders decide to buy. Choosing a good also chooses the R&D division associated with that good, but traders have no interest in the R&D division and ignore it in making their purchasing decision. The result is that today's purchasing decision affects tomorrow's quality, but traders today do not see the connection because they have no market incentive to see it. Therefore, trade could increase or decrease growth. In this model, quality is embodied inside the product, thus importing foreign goods also delivers their embodied quality characteristics, which leads to an effective technology transfer. Ji and Seater (2011) extend this model to disucss trade and growth. In that paper, we find that *trade affects growth* and that *growth affects trade* in ways never previously explored, and the model can explain in a single framework several observed phenomena usually analyzed separately. We also derive a full transition dynamics and a full welfare analysis.

4 Conclusion

I have studied the underlying reasons for TFP growth and research intensity differences across industries in the context of an endogenous growth model with asymmetric industries and an endogenous market structure. The model is constructed to be consistent with several important facts about the nature of technical progress and the industrial organizational structure of the economy. The endogenous market structure plays a crucial role in the analysis. The asymmetric industries and endogenous market structure provide a substantially different explanation of cross-industry TFP growth differences from the explanations offered in the existing literature.

Two sets of results are produced. First, the balanced growth rate of the aggregate economy positively depends on R&D productivity and *individual* market size. Higher R&D productivity and higher individual market sizes induce a higher return in R&D, thus a higher incentive to perform R&D in both industries, and a higher aggregate TFP growth rate. It's the individual firm market size, not the industry-level market size, which drives the incentives of R&D of individual firms. Market structure is endogenous, so the individual market size endogenously depends on the market and technology conditions. A higher fixed operating cost causes higher market concentration and a smaller amount of firms in the industry. Therefore, a fixed cost parameter is positively related with individual market size, and shows up in the balanced growth rate. The balanced growth rate is positively related with R&D productivity and fixed operating cost parameters of both industries. Other elements such as production unit costs and population size do not affect the balanced growth rate due to endogenous firm entry. On the balanced growth path, both industries grow at the same rate, but the TFP levels across industries are different. Surprisingly, the steady state TFP level ratio between industry 1 and 2 depends negatively on R&D productivity and fixed cost parameters of industry 1; while it depends positively on those parameters of industry 2 due to the endogenous market structure.

Second, during transitional dynamics, the TFP growth rates across industries are different. The differences of TFP growth depend on the differences in quality-adjusted gross profits and R&D productivities, which, in general equilibrium, are essentially depend on R&D productivity and fixed operating costs in general equilibrium. Surprisingly, the industry with a higher R&D productivity and fixed cost parameter has a lower TFP growth compared to the other industry. The key to understanding this is the endogeneity of the market structure. Given no arbitrage condition which is guaranteed by endogenous firm entry, a higher fixed operating cost and R&D productivity of one industry relative to the other industry leads a relatively lower amount of resources of R&D in that industry. So, the industry with higher fixed cost parameters and R&D productivity suffers a lower TFP growth given the same variables across industries. Although a fixed operating cost has not been identified as a potentially important source of cross-industry differences in the related literature, it turns out to play an important role when taking into account the endogenous market structure

Contrasting with other literature, industry market sizes and unit costs do not affect cross-industry TFP growth and research intensity differences. This model emphasizes the role of individual firm market size on R&D decisions of individual firms. The differences in industry sizes and unit costs are absorbed by endogenous firm entry.

The asymmetric growth model with the endogenous market structure offers explanations for both directed technical change and structural change. First, the direction of technology change depends on R&D productivity and fixed operating cost parameters. It does not depend on industry-level market size or unit costs. This model can be extended to discuss based technological change across different factors, and provides a different prediction from Acemoglu (1998, 2002b) due to the endogenous market structure. See Ji (2011). Second, this model predicts that structural change depends on both exponent of technology spillover and the TFP growth differences across industries. Section (2.8) and (3.2) provide explanations. The model could be extended to discuss the reallocation of workers across industries. Finally, this model also provides a basis for examining the interaction between trade and growth in Ji & Seater (2011).

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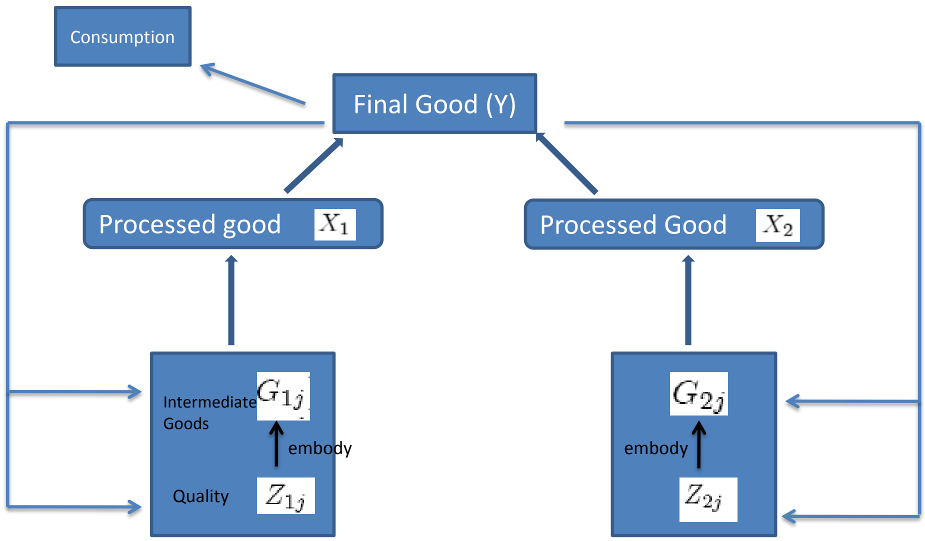

Figure 1: Structure of the Model

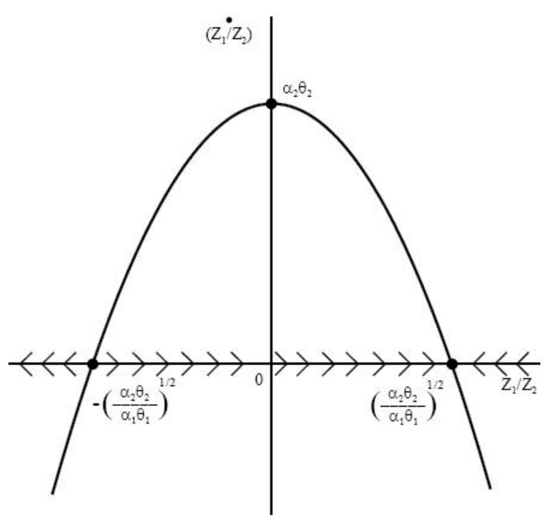

Figure 2: Transitional Dynamics