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Vertical separation versus vertical integration in an endogenously growing economy

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ABSTRACT

This paper sets up an endogenous growth model with a learning-by-doing externality in capital accumulation under both vertical separation and vertical integration structures. Some major findings emerge from our analysis. First, an increase in monopoly power has a detrimental effect on the balanced growth rate. Second, a vertical integration structure leads to a more balanced economic growth rate than a vertical separation structure. Third, the first-best subsidy rates on labor income and capital income under a vertical separation regime are higher than those under a vertical integration regime. Finally, with the additional externality from productive government spending, the government may levy positive taxes on both labor income and capital income if the extent of the productive public spending externality is sufficiently high.

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1. Introduction

A vast number of recent studies have focused on macroeconomic policies in the presence of an imperfectly competitive final good market; e.g., Blanchard & Kiyotaki (1987); Dixon (1987); Startz (1989); Heijdra & van der Ploeg (1996); Devereux, Head, & Lapham (2000), and Chen, Shieh, Lai, & Chang (2005). The main purpose of these studies is to explore how macroeconomic policies affect the relevant macro variables in the presence of market imperfections. However, these studies are implemented in the context of a single-period analysis, and hence cannot deal with the issue of sustainable economic growth. More recently, Shaw, Chang, & Lai (2006); Wang & Wen (2011), and Jensen (in press) have set up an endogenous growth model with imperfect competition. In these studies, the production side of the economy includes two sectors: a perfectly competitive final good sector and a monopolistically competitive intermediate goods sector. They find that monopoly power in the imperfectly competitive intermediate goods market plays an important role in economic growth.[1] Moreover, these studies unanimously assume that the downstream (final good) firms purchase their production inputs from

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[1] The literature on R&D-based economic growth, such as Romer (1990) and Jones (1995a), stresses that the engine of economic growth is R&D investment. This strand of research emphasizes that the R&D sector produces blueprints, and each of these blueprints can be used to produce a differentiated good (i.e., an imperfectly competitive good). As a result, the literature on the R&D-based economic growth is also able to deal with the linkage between monopoly power in the imperfectly competitive goods market and economic growth. In departing from the literature on R&D-based economic growth, these studies stress that economic growth is driven by production externalities.

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the upstream (intermediate good) firms. This implies that the downstream firms (final good firms) are vertically separated from their upstream firms (intermediate good firms).

Even though some studies have been devoted to examining the linkage between the market power and economic growth, it is surprising that the relationship between the *industrial structure* and economic growth has not been further developed. It is a common belief in the field of industrial economics that vertical separation and vertical integration are two important industrial structures, and a large number of studies (for example, Bonanno & Vickers (1988); Salinger (1988); Gal-Or (1991), and Abiru, Nahata, Raychaudhuri, & Waterson (1998)) have been devoted to each of them. In general, the price of goods in a vertically separated industry is higher than in a vertically integrated industry. The reason for this is that vertical integration can avoid the double price distortion that occurs under the regime of vertical separation when both upstream and downstream firms add their own price–cost margin at each stage of production.[2]

A common feature of existing studies on vertical integration is that they only focus on the partial equilibrium framework, and hence neglect the mutual interaction between the product market and the other markets. To avoid this deficiency, Lai, Chin, & Chang (2010) develop a monopolistic competition macroeconomic model, and use it to compare the relative performance of macro variables between vertical separation and vertical integration regimes. However, as with almost all existing studies concerned with vertical separation and vertical integration, the Lai, Chin, & Chang (2010) analysis is conducted in a static single-period framework, and hence the accumulation of capital is totally ignored. Accordingly, their analysis is unable to deal with issues such as whether the industrial structure can govern economic growth.[3]

This paper attempts to bridge this gap and to provide a systematic analysis to formally address the issue of whether economic growth is related to the industrial structure. In departing from existing studies on vertical integration, this paper is a first attempt to develop a *dynamic* general equilibrium model that features an optimizing microfoundation, in which not only is the mutual interdependence between the goods market and other markets explicitly taken into consideration, but also both the vertical integration and vertical separation structures can be described. Moreover, a common feature of almost all existing studies concerning vertical separation and vertical integration, such as Bonanno & Vickers (1988); Salinger (1988), and Gal-Or (1991), is that some of their behavioral functions, in particular the demand function for goods, are based on ad hoc specifications. Compared with these existing studies, this paper has the advantage of being able to present an optimizing dynamic macro model based on a solid microfoundation for the behavioral functions.

More specifically, this paper builds a simple endogenous growth model with the learning-by-doing externality in capital accumulation under either vertical separation or vertical integration, and uses it to examine whether the industrial structure will govern macroeconomic performance including economic growth, employment, and social welfare. The analysis of this study is roughly divided into four parts. Firstly, we set up a benchmark model, in which industry is vertically separated and both the upstream and downstream markets are imperfectly competitive. To be more specific, we deal with a vertically separated industry in which there are a certain number of upstream firms, each of which has an exclusive relationship with a downstream firm. Then, we examine the existence and uniqueness of the balanced growth equilibrium under the regime of vertical separation. Secondly, we develop an endogenous growth model in which industry is integrated and the integrated goods market is imperfectly competitive, before analyzing the balanced growth equilibrium under the regime of vertical integration. Vertical integration we deal with is that, to attain the profit and efficiency gains of cooperation, an upstream and a downstream firm are motivated to merge into a vertically integrated firm. Moreover, we compare the relative performances of relevant macroeconomic variables (including the balanced growth rate and employment) between the vertical separation regime and the vertical integration regime. Thirdly, and more importantly, in addition to positive analysis concerning the relationship between the industrial structure and economic growth, this paper also deals with normative analysis from the point of view of the social optimum. To be more precise, we discuss how the social planner sets the package of tax rates on labor and capital income to achieve the social optimum under the vertical separation regime and the integrated regime, respectively. Finally, we deal with two extensions of the benchmark model. The first extension is that monopoly power stems from the supply side rather than the demand side, and the second extension is that the productive public spending externality is present. Then, we make a brief discussion on whether our analytical results regarding optimal package of tax rates on labor and capital income are tenable with each extension.

The remainder of this paper proceeds as follows. In Section 2 we build a simple endogenous growth model under the vertical separation regime, and solve the balanced growth equilibrium. Section 3 modifies the theoretical model in Section 2 from the vertical separation regime to the vertical integration regime, and compares the relative performance of the balanced growth rate and the level of employment between the two regimes. Section 4, in order to achieve the social optimum, focuses on whether the social planner can set a package of tax rates on labor and capital income to remedy the distortions stemming from market imperfections under both regimes. Section 5 discusses two extensions of the benchmark model, and then provides a brief discussion on whether our analytical results in Section 4 are tenable with each extension. Finally, Section 6 summarizes the main findings of the analysis.

[2] However, the upstream firm can, for example, impose a two-part tariff by choosing a franchise fee in such a way that all the profit is extracted from the downstream firm. By setting the wholesale price equal to the marginal cost, the downstream firm will produce a quantity of goods that is optimal for the upstream monopoly. Based on this observation, Hart & Tirole (1990) argue that double marginalization will provide no motive for integration when a two-part tariff is allowed.

[3] To be more specific, this paper differs from Lai, Chin, & Chang (2010) in three significant respects. First, this paper is based on a dynamic intertemporal optimizing model, while the Lai, Chin, & Chang (2010) analysis is based on a static single-period framework. Second, in addition to the monopolistic distortion in the product market, this paper introduces a new distortion, namely, a capital externality in the form of learning-by-doing. Third, this paper focuses on whether the social planner can establish a package of tax rates on labor and capital income to remedy the distortions stemming from market imperfections. However, the Lai, Chin, & Chang (2010) analysis ignores the government sector, and hence is unable to discuss how the fiscal authority can choose the optimal tax rule to maximize welfare.

2. Vertical separation

This section sets up the benchmark model. The economy is composed of three types of agents: households, firms, and a government. The production side consists of two types of firms: upstream firms and downstream firms: The production side is characterized as follows: (a) the intermediate goods are produced by m upstream firms, and each of the upstream firms produces substitutable intermediate goods; (b) each of the intermediate goods is sold to an independent retailer, which then transforms the good into a final good to sell to households. To be more specific, we will deal with an industry in which there are m upstream firms (manufacturers), each of which has an exclusive relationship with a downstream firm (retailer). In what follows, we will in turn describe the behavior of each of three types of agents.

2.1. Households

The economy is populated by a unit measure of identical, infinitely-lived households. The representative household derives utility from the consumption of (composite) final goods C and incurs disutility from working N. In line with Benhabib & Farmer (1994), the lifetime utility of the representative household U can be expressed as:

$$U = \int_0 \left(\ln C - \frac{N^{1+\sigma} - 1}{1+\sigma} \right) e^{-\rho t} dt; \tag{1}$$

where σ (0) denotes the inverse of the intertemporal labor supply substitution elasticity, ρ (N0) represents the constant rate of time preference, and t is the time index.

The representative household faces the following budget constraint:

$$\dot{K} = wN + rK + \Pi - \tau_n wN - \tau_k (rK + \Pi) - C + R; \tag{2}$$

where w is the real wage, r is the real rental rate of capital, Π is the real profit, all in terms of the price index of (composite) final goods P^d, K is the capital stock, τ_n is the tax rate applied to labor income, τ_k is the tax rate applied to capital income, and R is a lump-sum transfer received from the government. For simplicity and without loss of generality, in Eq. (2) the depreciation rate of physical capital is set to zero.

In line with the insight proposed by Dixit & Stiglitz (1977), the household's composite consumption is defined as a CES-aggregate type for all consumption varieties:

$$C = m\left[\frac{1}{m}\sum_{i=1}^{m} c_i^{1-\theta}\right]^{\frac{1}{1-\theta}}; 1 \text{ N } \theta \quad 0; \tag{3}$$

where m is the number of consumption goods, c_i is the consumption of the ith good ($i = 1, 2, \ldots, m$), and the parameter θ is the reciprocal of the elasticity of substitution between any two goods. We will show later that θ measures the degree of monopoly power of the consumption good firms.

As indicated in Eq. (2), the sources of income of a representative individual consist of real labor income wN, real capital income rK, the real profit Π transferred from firms, and real transfers from the government R. As the owners of all firms, the households receive the real profit $\Pi = \Pi^u + \Pi^d$ in the form of dividends, where Π^u is the aggregate real profit of intermediate firms $i(i = 1, 2, \ldots, m)$, and Π^d is the aggregate real profit of downstream producers $i(i = 1, 2, \ldots, m)$.

The household's optimization problem can be solved by applying a two-stage budgeting decision.[4] In the first stage, the household maximizes the discounted sum of future instantaneous utilities reported in Eq. (1) subject to the budget constraint reported in Eq. (2) and the initial capital stock k_0. In the second stage, the household chooses varieties $c_i(i = 1, 2, \ldots, m)$ to maximize the composite consumption bundle C subject to $\sum_{i=1}^{m} p_i^d c_i = P^d C$ The model is solved backwards by starting from the second stage. The household's second-stage optimization problem can be expressed as follows:

$$\underset{c_i}{Max}\, C = m\left[\frac{1}{m}\sum_{i=1}^{m} c_i^{1-\theta}\right]^{\frac{1}{1-\theta}}; \text{ subject to} \sum_{i=1}^{m} p_i^d c_i = P^d C: \tag{4a}$$

The first-order conditions for this are the following:

$$\left(\frac{c_k}{c_i}\right)^{\theta} = \frac{p_i}{p_k}; \text{for } i; k = 1; 2; \ldots; m \text{ and } i \;\; k: \tag{4b}$$

[4] For a detailed discussion concerning the two-stage budgeting decision, see Heijdra (2009, pp. 359–361).

By repeatedly substituting the first-order condition into the definition of C reported in Eq. (3), we can derive the following expression for c_i:

$$c_i = \frac{\left(p_i^d\right)^{-1=\theta} C}{m[\frac{1}{m}\sum_{i=1}^{m}\left(p_i^d\right)^{\frac{\theta-1}{\theta}}]^{\frac{1}{1-\theta}}}: \tag{4c}$$

By inserting Eq. (4c) into the second-stage constraint $\sum_{i=1}^{m} p_i^d c_i = P^d C$ stated in Eq. (4a), we have the expression for the price index P^d:

$$\sum_{i=1}^{m} p_i^d c_i = \frac{\sum_{i=1}^{m}\left(p_i^d\right)^{\frac{\theta-1}{\theta}} C}{m\left[\frac{1}{m}\sum_{i=1}^{m}\left(p_i^d\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{1}{1-\theta}}} = P^d C; \text{ where } P^d = \left[\frac{1}{m}\sum_{i=1}^{m}\left(p_i^d\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}: \tag{4d}$$

Then, by substituting the price index P^dreported in Eqs. (4d) into (4c), the demand for variety i of the consumption good can be described in a more compact form:

$$c_i = \left(\frac{p_i^d}{P^d}\right)^{-\frac{1}{\theta}} \frac{C}{m}: \tag{4e}$$

Eq. (4e) reveals that (the absolute value of) the price elasticity of demand for the ith consumption good is $1/\theta$.

In this paper, the bundle of composite final goods is treated as the *numeraire*, and hence in what follows the price index of composite consumption P^d is normalized to unity, i.e., $P^d = 1$. As a result, the household's demand for variety i of the consumption good can further be expressed as:

$$c_i = \left(p_i^d\right)^{-\frac{1}{\theta}} \frac{C}{m}: \tag{4f}$$

We then turn to deal with the household's optimizing decision in the first stage. As described above, in the first stage, the household's objective is to maximize the discounted sum of future instantaneous utilities reported in Eq. (1) subject to its budget constraint reported in Eq. (2) and the initial capital stock k_0. Then, we can formulate the current-value Hamiltonian as follows:

$$H = \left(\ln C - \frac{N^{1+\sigma}-1}{1+\sigma}\right) + \lambda[wN + rK + \Pi - \tau_n wN - \tau_k(rK + \Pi) - C + R]; \tag{5}$$

where λ is the shadow value of the physical capital stock K.

The optimum conditions for the representative household with respect to the indicated variables are:

$$C : \frac{1}{C} = \lambda; \tag{6a}$$

$$N : N^{\sigma} = \lambda(1-\tau_n)w; \tag{6b}$$

$$K : \lambda = [\rho - (1-\tau_k)r]\lambda; \tag{6c}$$

$$\lambda : K = wN + rK + \Pi - \tau_n wN - \tau_k(rK + \Pi) - C + R: \tag{6d}$$

Moreover, we have to impose the following transversality condition:

$$\lim_{t\to} K_t \lambda_t e^{-\rho t} = 0: \tag{6e}$$

By combining Eq. (6a) with Eq. (6b), we obtain:

$$CN^{\sigma} = (1-\tau_n)w: \tag{7}$$

Eq. (7) indicates that the marginal rate of substitution between consumption and labor supply is equal to the after-tax real wage rate in terms of the price of final goods.

Let $V(=K)$ denote the household's investment. As in the case of the household's consumption, the household's investment is also composed of m-types of different goods. The household's investment in the ith good v_i $(i=1,2,\ldots,m)$ can be expressed as:

$$v_i = \left(\frac{p_i^d}{P^d}\right)^{-\frac{1}{\theta}} \frac{V}{m} = \left(p_i^d\right)^{-\frac{1}{\theta}} \frac{V}{m}: \tag{8}$$

Based on Eqs. (4f) and (8), we can define the total demand for each good $y_i^d(=c_i+v_i)$ as follows[5]:

$$y_i^d = \left(\frac{p_i^d}{P^d}\right)^{-\frac{1}{\theta}} \left(\frac{C+K}{m}\right) = \left(p_i^d\right)^{-\frac{1}{\theta}} \left(\frac{C+K}{m}\right): \tag{9}$$

2.2. Firms

We are now in a position to deal with the production side of the economy. The production side consists of two (intermediate goods and final goods) sectors and is characterized as follows: (a) the intermediate goods are produced by $m$upstream firms, and each of the upstream firms produces imperfectly substitutable intermediate goods; (b) each intermediate good is sold to an independent retailer, who then transforms it into a final good to sell to households. For simplicity, assume that each of the downstream firms (retailers) transforms one unit of the intermediate good purchased from the upstream firm into one unit of the final good. As a consequence, the number of downstream firms (retailers) and final goods is also equal to m. More specifically, we will deal with an economy in which there are m upstream firms (manufacturers), each of which has an exclusive relationship with a downstream firm (retailer).

We first deal with the optimal behavior of the downstream firms (retailers). As stated previously, each downstream firm transforms the intermediate product (produced by the upstream firm) into the final good on a one-for-one basis. The final goods are thus produced by using the following constant returns to scale technology:

$$y_i^d = y_i^u; i = 1; 2; \ldots; m: \tag{10}$$

In Eq. (10) y_i^u denotes the level of the intermediate goods produced by the upstream firm i.

Let p_i^u denote the price of the intermediate goods and, by recalling that p_i^d is the price of the final goods, it follows from Eqs. (9) and (10) that the maximization problem of the i th final-goods (downstream) firm can be expressed as follows:

$$\underset{p_i^d}{Max}\, \pi_i^d = p_i^d y_i^d - p_i^u y_i^u = \left(p_i^d - p_i^u\right) y_i^d; \tag{11}$$

$$s{:}t{:}\ y_i^d = \left(\frac{p_i^d}{P^d}\right)^{-\frac{1}{\theta}} \left(\frac{C+K}{m}\right) = \left(p_i^d\right)^{-\frac{1}{\theta}} \left(\frac{C+K}{m}\right): \tag{11a}$$

The first-order condition for profit maximization leads to the following demand function for the ith intermediate good and the final good:

$$\frac{p_i^d - p_i^u}{p_i^d} = -\frac{p_i^d}{y_i^d}\frac{y_i^d}{p_i^d} = \theta: \tag{12}$$

Eq. (12) indicates that the price of the final goods is positively related to the price of the intermediate goods and the market power. That is:

$$p_i^d = \frac{p_i^u}{1-\theta}: \tag{13}$$

Eq. (13) reflects the fact that the parameter θ can be treated as the degree of monopoly power of the downstream firm. When $\theta=0$, the final goods are perfect substitutes and hence the price of the final goods is equal to that of the intermediate goods.

[5] Coto-Martínez (2006) and Heijdra (2009, Ch.12) make a similar assumption, and hence derive a similar function for the total demand for each good.

If 1 N θ N 0, the downstream firm faces a downward-sloping demand curve that can be exploited to manipulate prices, and hence it will set the price of the final goods higher than that of the intermediate goods.[6]

Substituting Eq. (13) into (11), we can derive the profit of the ith final-goods firm:

$$\pi_i^d = \theta p_i^d y_i^d: \tag{14}$$

Eq. (14) indicates that the profit of the ith downstream firm is positively related to the degree of monopoly power.

By inserting Eq. (13) into (9), the level of the ith final good sold to households is given by:

$$y_i^d = \left[\frac{p_i^u}{(1-\theta)}\right]^{-\frac{1}{\theta}} \left(\frac{C+K}{m}\right): \tag{15}$$

We then deal with the optimal behavior of the upstream firms. Assume that each intermediate good (upstream) firm hires physical capital k_i and labor n_i to produce a single good y_i^u. In line with Romer (1986), the production function of the ith upstream firm is subject to the following technology:

$$y_i^u = (An_i)^\beta k_i^{\ \alpha}; A = K; 0 \text{ b } \beta \text{ b } 1; 0 \text{ b } \alpha \quad 1; \alpha + \beta = 1; i = 1; 2; \ldots; m; \tag{16}$$

where A is the labor-augmenting technology, k_i and n_i denote the capital and labor inputs of individual firm i, and $K(=\sum_{i=1}^{m} k_i)$ is the aggregate capital stock employed in the intermediate goods sector. It should be noted that An_i denotes efficient labor.

In Eq. (16), in line with Arrow (1962) and Romer (1986), we assume that learning by doing works through each firm's investment, indicating that an increase in a firm's capital stock leads to a parallel increase in its stock of knowledge$A$, i.e., $A = K$. Moreover, each firm's knowledge is a public good that any other firm can access at zero cost. This assumption implies that the change in each firm's technology corresponds to the economy's overall learning and is therefore proportional to the level of the aggregate capital stock.

The production function of the ith upstream firm can be alternatively expressed as:

$$y_i^u = K^\beta n_i^\beta k_i^\alpha: \tag{16a}$$

It should be noted that the parameter β measures the degree of the capital externality. More specifically, $\beta = 0$ indicates that the capital externality in the form of learning-by-doing is absent, while 0 b β b 1 indicates that the capital externality in the form of learning-by-doing is present.[7]

The optimization problem of an intermediate-goods producer is:

$$\underset{p_i^u; k_i; n_i}{Max}\ \pi_i^u = p_i^u y_i^u - rk_i - wn_i; \tag{17}$$

$$s{:}t{:}\ y_i^u = K^\beta n_i^\beta k_i^\alpha \text{ and } y_i^u = y_i^d = \left[\frac{p_i^u}{1-\theta}\right]^{-\frac{1}{\theta}} \left(\frac{C+K}{m}\right); \tag{17a}$$

where π_i^u is the profit of the ith intermediate-goods producer ($i = 1, 2, \ldots, m$). The first-order conditions for this problem yield:

$$p_i^u = \frac{wn_i}{(1-\theta)\beta y_i^u} = \frac{rk_i}{(1-\theta)\alpha y_i^u}: \tag{18}$$

Then, it follows from Eqs. (10), (13), and (18) that the final-goods price is given by:

$$p_i^d = \frac{wn_i}{(1-\theta)^2 \beta y_i^d} = \frac{rk_i}{(1-\theta)^2 \alpha y_i^d}: \tag{19}$$

[6] Following Dixon (1987) and as in the case of the Lerner (1934) index, the degree of monopoly power of the ith final-goods firm Λ is defined as $\Lambda = (p_i^d - MC_i^d)/p_i^d$, where MC_i^d is the marginal cost of the ith final-goods firm. Given that $MC_i^d = p_i^u$ and $p_i^d = p_i^u/(1-\theta)$reported in Eq. (13), we can infer the result $\Lambda = \theta$. It should be noted that our model does not cover "the full monopoly power case". The reason for excluding this case is that, as indicated in Eqs. (11) and (11a), the ith final-goods firm chooses its optimal price by treating the price index P^d as given. This assumption is inconsistent with the profit-maximizing pricing of the monopoly firm.

[7] Barro (1990) introduces a distortion arising from productive public spending. To simplify the analysis, the benchmark model in this section emphasizes the externality of learning-by-doing. In the later analysis (Section 5), we will deal with the productive public spending externality.

Substituting Eqs. (13) and (18) into (17) and being reminded of the expression $y_i^d = y_i^u$, we can derive the profit of the ith intermediate-goods firm:

$$\pi_i^u = \theta(1-\theta)p_i^d y_i^d: \tag{20}$$

We confine the analysis to a symmetric equilibrium under which $k = k_i$, $n = n_i$, $y^u = y_i^u$, $y^d = y_i^d$, $\pi^d = \pi_i{}^d$, $\pi^u = \pi_i^u$, $c = c_i$, $v = v_i$, $p^d = p_i^d$ and $p^u = p_i^u$ for $i = 1, 2, \ldots, m$.[8] Let K denote the aggregate capital demand, N denote the aggregate labor demand, Y^u denote the aggregate intermediate-good output, and Y^d denote the aggregate final-good output. Then, we have $N = mn$, $K = mk$, $Y^u = my^u$, and $Y^d = my^d$.

Given $p^d = p_i^d$ and $c = c_i$, $P^d = 1$, and the price index defined in Eq. (4d), the composite consumption defined in Eq. (3) can be rewritten as:

$$P^d = \left[\frac{1}{m}\sum_{i=1}^{m}\left(p_i^d\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}} = p^d = 1; \tag{21a}$$

$$C = mc: \tag{21b}$$

Moreover, given the production function of the final goods reported in Eq. (10) (i.e., $y_i^d = y_i^u$), the production function of the intermediate goods reported in Eq. (16) (i.e., $y_i^u = K^\beta n_i^\beta k_i^\alpha$), and the symmetric feature, we can further infer the following result:

$$Y^d = Y^u = KN^\beta: \tag{21c}$$

Based on the above symmetric results, from Eq. (19) we can derive the expressions for the real wage rate w and the real rental rate of capital r:

$$w = (1-\theta)^2\beta\frac{y^d}{n} = (1-\theta)^2\beta\frac{Y^d}{N}; \tag{22a}$$

$$r = (1-\theta)^2\alpha\frac{y^d}{k} = (1-\theta)^2\alpha\frac{Y^d}{K}: \tag{22b}$$

Moreover, based on the symmetric feature, from Eqs. (14) and (20) we can derive the expressions for the aggregate real profit of downstream firms Π^d and the aggregate real profit of upstream firms Π^u:

$$\Pi^d = m\,\pi^d = m\,\theta\,y^d = \theta Y^d; \tag{22c}$$

$$\Pi^u = m\,\pi^u = m\,\theta(1-\theta)y^d = \theta(1-\theta)Y^d: \tag{22d}$$

Accordingly, the total real profit of all downstream and upstream firms is:

$$\Pi = \Pi^d + \Pi^u = \theta(2-\theta)Y^d: \tag{22e}$$

2.3. The government and the resource constraint

The government collects taxes, including labor income taxes $\tau_n wN$ and capital income taxes $\tau_k(rK + \Pi)$, to finance the government's real transfer. Thus, the government budget constraint can be expressed as:

$$\tau_n wN + \tau_k(rK + \Pi) = R: \tag{23}$$

[8] We consider a symmetric equilibrium, which embodies three features. First, all upstream and downstream firms produce the same level of output, $y^u = y_i^u$ and $y^d = y_i^d$, with the same quantity of inputs, $k = k_i$ and $n = n_i$, set the same optimal price, $p^d = p_i^d$ and $p^u = p_i^u$, and have the same gross profit, $\pi^d = \pi_i^d$ and $\pi^u = \pi_i^u$ $(i = 1, 2, \ldots, m)$. Second, all households choose symmetric consumption and investment over the final goods, i.e., $c = c_i$ and $v = v_i$ for $i = 1, 2, \ldots, m$. Third, all households have the same shareholdings for each of the upstream and downstream firms, and hence they receive the same profit from each of the firms. Accordingly, no distributive issue arises, in the sense that the optimization problem of the household reported in Eqs. (1) and (2) is greatly simplified. The third feature is pointed out by an anonymous referee, to whom we are grateful.

Combining the household's budget constraint (2) and the government's budget constraint (23) yields the following aggregate resource constraint of the economy:

$$K = Y^d - C: \tag{24}$$

2.4. Macroeconomic equilibrium

The main equations of the symmetric equilibrium of the economy can then be described in summary fashion as follows:

$$\frac{1}{C} = \lambda; \tag{25a}$$

$$N^{\sigma} = \lambda(1-\tau_n)(1-\theta)^2\beta\frac{Y^d}{N}; \tag{25b}$$

$$\dot{\lambda} = \left[\rho - (1-\tau_k)(1-\theta)^2\alpha\frac{Y^d}{K}\right]\lambda; \tag{25c}$$

$$K = Y^d - C; \tag{25d}$$

$$Y^d = Y^u = KN^{\beta}; \tag{25e}$$

$$\Pi = \Pi^d + \Pi^u = \theta(2-\theta)Y^d; \tag{25f}$$

$$\tau_n wN + \tau_k(rK + \Pi) = R: \tag{25g}$$

In the next subsection, we will study the dynamic property of the balanced growth equilibrium.

2.5. Stability properties

Based on Eqs. (25a), (25c), and (25e), the dynamic system in terms of C (the Keynes–Ramsey rule) can be described by:

$$\frac{\dot{C}}{C} = \alpha(1-\tau_k)(1-\theta)^2N^{\beta} - \rho: \tag{26}$$

To obtain an endogenous growth equilibrium, we follow Barro & Sala-i-Martin (2004) in defining the consumption–capital ratio as $x = C/K$. Given the symmetric equilibrium conditions (25d) and (26), the dynamic system in terms of the transformed variable x can be expressed as follows:

$$\frac{\dot{x}}{x} = \frac{\dot{C}}{C} - \frac{\dot{K}}{K} = N^{\beta}\left[\alpha(1-\tau_k)(1-\theta)^2 - 1\right] - \rho + x: \tag{27}$$

Let $\mathbf{x}$ and $\mathbf{N}$ denote the stationary values of x and N, respectively, under the regime of vertical separation. At the balanced growth equilibrium, the economy is characterized by $\dot{x} = 0$, $x = \mathbf{x}$, and $N = \mathbf{N}$ in Eq. (27). As a consequence, we have:

$$\mathbf{x} = \rho + \left[1 - \alpha(1-\tau_k)(1-\theta)^2\right]\mathbf{N}^{\beta}: \tag{28}$$

In the balanced-growth-path equilibrium, consumption and capital grow at a common growth rate γ and the level of employment converges to its stationary value $\mathbf{N}$. By combining Eq. (25a) with Eq. (25b), we obtain the following balanced growth relationship:

$$\mathbf{N}^{1-\beta+\sigma} = (1-\tau_n)(1-\theta)^2\beta\frac{1}{\mathbf{x}}: \tag{29}$$

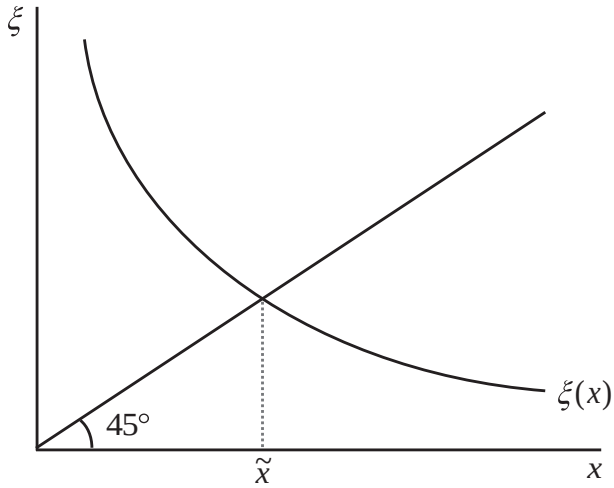

Fig. 1. The existence and uniqueness of the stationary value of x.

To prove the existence and uniqueness of the balanced-growth-path equilibrium, we apply the Brouwer fixed-point theorem. Substituting Eqs. (28) into (29), we can derive the function ξ defined as follows:

$$x = \xi(x) = \beta(1-\theta)^2(1-\tau_n)\left[\frac{1-\alpha(1-\tau_k)(1-\theta)^2}{x-\rho}\right]^{\frac{1-\beta+\sigma}{\beta}}: \tag{30}$$

As depicted in Fig. 1, the fixed-point theorem immediately leads to a stationary x that exists and is unique.[9] Therefore, from Eqs. (28) and (29) we have the following stationary relationships[10]:

$$N = N(\tau_n;\tau_k;\theta);\ N_{\tau_n}\ \mathrm{b}\ 0;\ N_{\tau_k}\ \mathrm{b}\ 0;\ N_\theta\ \mathrm{b}\ 0; \tag{31a}$$

$$x = x(\tau_n;\tau_k;\theta);\ x_{\tau_n}\ \mathrm{b}\ 0;\ x_{\tau_k}\ \mathrm{N}\ 0;\ x_\theta\ \frac{\mathrm{N}}{\mathrm{b}}\ 0: \tag{31b}$$

Eqs. (31a) and (31b) reveal useful findings. First, a rise in the labor income tax rate leads to a fall in both the level of employment and the consumption–capital ratio. Second, a rise in the capital income tax rate reduces the level of employment and boosts the consumption–capital ratio. Third, an increase in the degree of monopoly power reduces the level of employment, while having an ambiguous effect on the consumption–capital ratio.

A graphical presentation will be helpful to our understanding of the comparative results reported in Eqs. (31a) and (31b). In Fig. 2, the loci $\dot{x} = 0|_{VS}$ and $AA|_{VS}$ trace all combinations of x and N that satisfy Eqs. (28) and (29), respectively, where the subscript "VS" indicates the vertical separation regime.[11] It is quite easy to infer from Eqs. (28) and (29) that the $\dot{x} = 0|_{VS}$ locus is upward sloping and the $AA|_{VS}$ locus is downward sloping. In Fig. 2, in response to a rise in the labor income tax rate, the $AA|_{VS}$ schedule shifts leftward and the balanced growth equilibrium changes from Q_0 to Q_1. At the new stationary equilibrium, both x and N fall from x_0 to x_1 and N_0 to N_1, respectively. With a similar graphical analysis, a rise in the capital income tax rate shifts $\dot{x} = 0|_{VS}$ to the left, and hence leads to a rise in x and a fall in N. Moreover, an increase in the degree of monopoly power θ shifts both loci $\dot{x} = 0|_{VS}$ and $AA|_{VS}$ to the left, causing a fall in N and leading to an ambiguous change in x depending upon the relative leftward movements of $\dot{x} = 0|_{VS}$ and $AA|_{VS}$.

At the balanced growth equilibrium, the economy is characterized by $\dot{x} = 0$. Eq. (27) implies that consumption and the capital stock grow at a common rate γ along the balanced growth path. Based on the production function of final goods $Y^d = Y^u = KN^\beta$ reported in Eq. (21c), we can then infer that $\dot{Y}^d = \dot{Y}^d = \dot{K} = \dot{K} + \beta(\dot{N} = \dot{N})$. At the balanced growth equilibrium, N converges to its stationary value N, implying that $\dot{N} = 0$. As a consequence, we can further infer that output and the capital stock also grow at a common rate γ along the balanced growth path.

It follows from Eq. (26) that, at the balanced-growth equilibrium, the common balanced-growth rate γ is given by:

$$\gamma = \alpha(1-\tau_k)(1-\theta)^2 N^\beta - \rho: \tag{32}$$

[9] The first and second derivatives of function ξ are $\xi' = \frac{(1-\beta+\sigma)\xi}{-\beta(x-\rho)}\ \mathrm{b}\ 0$ and $\xi'' = \frac{(1-\beta+\sigma)[\xi'-\xi=(x-\rho)]}{-\beta(x-\rho)}\ \mathrm{N}\ 0$, respectively.
[10] The exact comparative results for x and N are provided in Appendix A.
[11] Appendix A provides a detailed description.

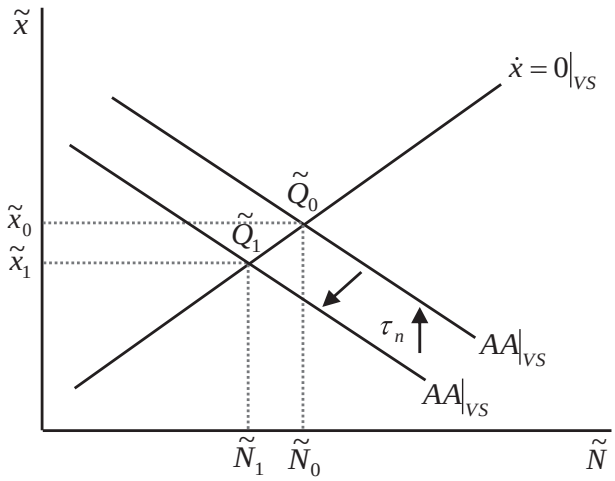

Fig. 2. A rise in the labor income tax rate under the vertical separation regime.

Differentiating Eq. (32) with respect to θ gives rise to:

$$\frac{\bar{\gamma}}{\theta} = \alpha(1-\tau_k)(1-\theta)\bar{N}^{\beta}\left[-2+(1-\theta)\beta\frac{\bar{N}_{\theta}}{\bar{N}}\right] \text{b } 0: \tag{32a}$$

Eq. (32a) tells us that an increase in the degree of monopoly power has a negative effect on the balanced long-run growth rate. This result can be explained intuitively by referring to the Keynes–Ramsey rule stated in Eq. (32). On the one hand, a higher degree of monopoly power directly lowers the marginal product of capital. On the other hand, a higher degree of monopoly power leads the firm to hire fewer employees, indirectly causing a fall in the marginal product of capital. Given that both direct and indirect effects have an adverse impact on the marginal product of capital, a higher degree of monopoly power is thus definitely associated with a lower value of the net-of-tax marginal product of capital. With a decline in the after-tax rate of return on holding physical capital, the household is inclined to substitute away from savings to consumption, thereby leading to a negative effect on the economic growth rate.[12]

Accordingly, we have the following proposition:

Proposition 1. Under the regime of vertical separation, there exists a unique balanced growth equilibrium in which real consumption C, physical capital K and the output of final goods Y^d grow at the same rate.

3. Vertical integration

One possible way for an upstream and a downstream firm to attain the profit and efficiency gains of cooperation is to merge vertically. Such vertical integration leads both firms to operate under a single decision-making entity, thereby causing the externality to be internalized. This leads to a rise in the joint profit of the merging upstream and downstream firms after they merge. Accordingly, the upstream and downstream firms are motivated to merge vertically. An obvious example is that of an integrated hardware and software firm which maximizes its joint profit by reducing the prices of both complementary goods. This section thus turns to deal with the vertical integration regime.[13]

The objective of vertical integration is to avoid the double price distortion that occurs when each firm adds its own price–cost margin at each stage of production. A vertically integrated industry generates higher profits than a vertically separated industry, and also results in lower consumer prices. In this section we will analyze the equilibrium prices, employment, and balanced economic growth rate arising after vertical integration occurs in a monopolistic industrial structure. To be more specific, we

[12] In line with the capital accumulation-driven growth literature, such as Shaw, Chang, & Lai (2006) and Wang & Wen (2011), our analysis reveals that more market competition tends to boost the economic growth rate. However, the R&D-driven growth literature, such as Romer (1990) and Jones (1995a), stresses that monopoly power leads the innovative firm to have positive profits, which is a crucial factor in stimulating investment in R&D activity and the economic growth rate. As a result, the R&D-driven growth literature does not support the positive relationship between market competition and economic growth with a consensus. Some empirical studies, e.g., Geroski (1994) and Nickell (1996), find a positive relationship between product market competition and innovation (economic growth). To fit this empirical finding, Aghion, Harris, Howitt, & Vickers (2001) extend the Schumpeterian model by taking step-by-step innovations into consideration, and find an inverted-U relationship between market competition and innovation. For a comprehensive survey on the theoretical and empirical relationships between market competition and economic growth in the R&D-driven (Schumpeterian) growth literature, see Aghion & Griffith (2005) and Aghion and Howitt (2009, Ch. 12).

[13] As documented in Ravenscraft & Scherer (1987), there are four prominent waves of merger activities in American history.

will illustrate the case in which the ith upstream firm integrates with the ith downstream firm ($i=1,2,\ldots,m$)in Section 2. In what follows, we will refer to this integrated firm as "the ith integrated firm."

Let π_i^I stand for the profit of the ith integrated firm. The optimal behavior of the ith integrated firm can be expressed as follows:

$$\underset{p_i^d;k_i;n_i}{Max}\ \pi_i^I = p_i^d y_i^d - rk_i - wn_i; \tag{33}$$

$$s{:}t{:}\ y_i^d = K^\beta n_i^\beta k_i^\alpha \text{ and } y_i^d = \left(p_i^d\right)^{-\frac{1}{\theta}}\left(\frac{C+K}{m}\right): \tag{33a}$$

The first-order conditions for this problem yield:

$$p_i^d = \frac{rk_i}{(1-\theta)\alpha y_i^d} = \frac{wn_i}{(1-\theta)\beta y_i^d} \tag{34}$$

We restrict our attention to a symmetric equilibrium in which $k=k_i$, $n=n_i$, $y^d=y_i^d$, $\pi^I=\pi_i{}^I$, $c=c_i$, $v=v_i$ and $p^d=p_i^d$ for $i=1,2,\ldots,m$. Then, in a way that is similar to the inference under the vertical separation regime, we can infer the following results:

$$P^d = \left[\frac{1}{m}\sum_{i=1}^{m}\left(p_i^d\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}} = p^d = 1; \tag{35a}$$

$$C = mc; \tag{35b}$$

$$Y^d = KN^\beta; \tag{35c}$$

$$w = (1-\theta)\beta\frac{Y^d}{N}; \tag{35d}$$

$$r = (1-\theta)\alpha\frac{Y^d}{K}: \tag{35e}$$

Let Π^I stand for the aggregate real profit of all integrated firms. We can infer the following result:

$$\Pi^I = m\pi^I = \theta Y^d: \tag{35f}$$

As can be seen, the aggregate real profit of the integrated firms is closely related to the index of monopoly power.

As the owners of all integrated firms, the households receive real profit (in terms of final goods) in the form of dividends. We then have:

$$\Pi = \Pi^I = \theta Y^d: \tag{35g}$$

3.1. Macroeconomic equilibrium

The household's optimization problem, the government and the resource constraint are the same as in the regime characterized by vertical separation. Thus, the symmetric equilibrium of the economy can be summarized as follows:

$$\frac{1}{C} = \lambda; \tag{36a}$$

$$N^\sigma = \lambda(1-\tau_n)(1-\theta)\beta\frac{Y^d}{N}; \tag{36b}$$

$$\dot{\lambda} = \left[\rho - (1-\tau_k)(1-\theta)\alpha\frac{Y^d}{K}\right]\lambda; \tag{36c}$$

$$\dot{K} = Y^d - C; \tag{36d}$$

$$Y^d = KN^{\beta}; \tag{36e}$$

$$\Pi = \theta Y^d; \tag{36f}$$

$$\tau_n wN + \tau_k(rK + \Pi) = R: \tag{36g}$$

In the next subsection, we will examine the dynamic property of the balanced growth equilibrium under the regime of vertical integration.

3.2. Stability properties

It follows from Eqs. (36a), (36c) and (36e) that the transitional dynamics in terms of C can be expressed by:

$$\frac{\dot{C}}{C} = \alpha(1-\tau_k)(1-\theta)N^{\beta} - \rho: \tag{37}$$

Similarly, let us define a transformed variable by $x = C/K$. Given the symmetric equilibrium conditions (36d), (36e) and (37), the dynamic system in terms of the transformed variable x can be expressed as follows:

$$\frac{\dot{x}}{x} = \frac{\dot{C}}{C} - \frac{\dot{K}}{K} = N^{\beta}[\alpha(1-\tau_k)(1-\theta) - 1] - \rho + x: \tag{38}$$

Let $\hat{x}$ and $\hat{N}$ stand for the stationary values of x and N under the regime of vertical integration, respectively. At the balanced growth equilibrium, the economy is characterized by $\dot{x} = 0$, $x = \hat{x}$ and $N = \hat{N}$ in Eq. (38). Then, from Eq. (38) we have:

$$\hat{x} = \rho + [1 - \alpha(1-\tau_k)(1-\theta)]\hat{N}^{\beta}: \tag{39}$$

By using Eqs. (36a) and (36b), we can obtain the following balanced growth relationship:

$$\hat{N}^{1-\beta+\sigma} = (1-\tau_n)(1-\theta)\beta\frac{1}{\hat{x}}: \tag{40}$$

Then, from Eqs. (39) and (40) we have the following stationary relationships under the regime of vertical separation[14]:

$$\hat{N} = \hat{N}(\tau_n; \tau_k; \theta); \hat{N}_{\tau_n} \text{ b } 0; \hat{N}_{\tau_k} \text{ b } 0; \hat{N}_{\theta} \text{ b } 0; \tag{41a}$$

$$\hat{x} = \hat{x}(\tau_n; \tau_k; \theta); \hat{x}_{\tau_n} \text{ b } 0; \hat{x}_{\tau_k} \text{ N } 0; \hat{x}_{\theta} \frac{\text{N}}{\text{b}} 0: \tag{41b}$$

Eqs. (41a) and (41b) report some results that are similar to those under the regime of vertical integration. First, a rise in the labor income tax rate lowers both the level of employment and the consumption–capital ratio. Second, a rise in the capital income tax rate lowers the level of employment and raises the consumption–capital ratio. Third, an increase in the degree of monopoly power lowers the level of employment, while having an ambiguous effect on the consumption–capital ratio.

The results reported in Eqs. (41a) and (41b) can be explained graphically. In Fig. 3, the $\dot{x} = 0|_{VI}$ locus and the $AA|_{VI}$ locus trace all combinations of $\hat{x}$ and $\hat{N}$ that satisfy Eqs. (39) and (40), respectively, where the subscript "VI" refers to the vertical integration regime.[15] It is quite easy to infer from Eqs. (39) and (40) that the $\dot{x} = 0|_{VI}$locus is upward sloping and the $AA|_{VI}$ locus is downward sloping. In Fig. 3, in response to a rise in the labor income tax rate, the $AA|_{VI}$ schedule shifts leftward, causing $\hat{x}$ and $\hat{N}$ to fall from $\hat{x}_0$ to $\hat{x}_1$ and from $\hat{N}_0$ to $\hat{N}_1$, respectively. Similarly, a rise in the capital income tax rate shifts $\dot{x} = 0|_{VI}$ to the left, thereby leading to a rise in $\hat{x}$ and a fall in $\hat{N}$. Moreover, a rise in monopoly power shifts both loci $\dot{x} = 0|_{VI}$ and $AA|_{VI}$ to the left, causing a fall in $\hat{N}$ and an ambiguous change in $\hat{x}$ depending upon the relative leftward movement of $\dot{x} = 0|_{VI}$ and $AA|_{VI}$.

[14] The exact comparative results for $\hat{x}$ and $\hat{N}$ are provided in Appendix B.
[15] Appendix A provides a detailed description.

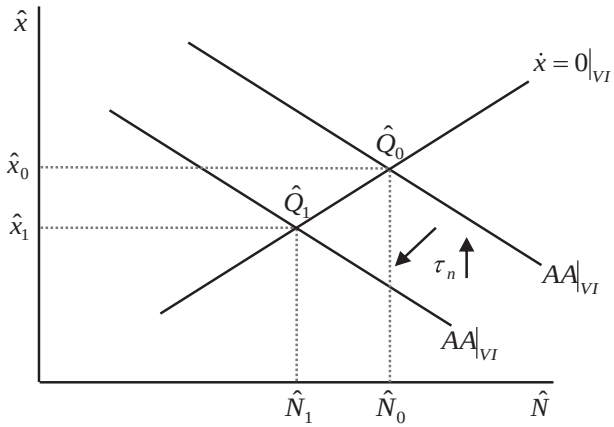

Fig. 3. A rise in the labor income tax rate under the vertical integration regime.

At the balanced growth equilibrium, the economy is characterized by $\dot{x} = 0$. Eq. (38) implies that consumption and the capital stock grow at a common rate $\hat{\gamma}$ along the balanced growth path. Based on the production function of final goods $Y^d = KN^{\beta}$ stated in Eq. (36e), we can infer that $\dot{Y}^d = \dot{Y}^d = \dot{K} = \dot{K} + \beta(\dot{N} = \dot{N})$. At the balanced growth equilibrium, N converges to its stationary value $\hat{N}$, implying that $\dot{N} = 0$. As a consequence, we can further infer that output and the capital stock also grow at a common rate $\hat{\gamma}$ along the balanced growth path.

From Eq. (37) we can further solve the common balanced growth rate $\hat{\gamma}$ under the regime of vertical separation:[16]

$$\hat{\gamma} = \alpha(1-\tau_k)(1-\theta)\hat{N}^{\beta} - \rho: \tag{42}$$

Differentiating Eq. (42) with respect to θ, we can infer the following expression:

$$\frac{\hat{\gamma}}{\theta} = \alpha(1-\tau_k)\hat{N}^{\beta}\left[-1 + (1-\theta)\beta\frac{\hat{N}_{\theta}}{\hat{N}}\right] \text{ b } 0: \tag{42a}$$

Similar to the regime of vertical separation, Eq. (42a) indicates that the balanced economic growth rate is negatively related to the degree of monopoly power. Since the intuition behind this result is the same as that under the regime of vertical separation, to save space we do not explain it again here.

Based on Eq. (42a), we can establish the following proposition:

Proposition 2. An increase in monopoly power has a detrimental effect on the balanced growth rate regardless of whether the vertical separation regime or the vertical integration regime is in place.

3.3. Vertical separation versus vertical integration

This subsection analyzes the relative performance of relevant macroeconomic variables under both the vertical separation and vertical integration regimes. We first compare the employment level between both regimes. For ease of comparison, both Figs. 2 and 3 are included together in Fig. 4. It is easy to infer from Eqs. (28) and (39) that, in association with given values of τ_k and θ, the $\dot{x} = 0|_{VS}$ locus is located above the $\dot{x} = 0|_{VI}$ locus. Moreover, we can infer from Eqs. (29) and (40) that, in association with given values of τ_n and θ, the $AA|_{VS}$ locus lies below the $AA|_{VI}$ locus. The $\dot{x} = 0|_{VS}$ locus intersects the $AA|_{VS}$ locus at point $\hat{Q}_0$, which determines the level of employment $\hat{N}_0$ under the regime of vertical separation. The $\dot{x} = 0|_{VI}$ schedule intersects the $AA|_{VI}$ locus at point $\hat{Q}_0$, which determines the level of employment $\hat{N}_0$ under the regime of vertical integration. As is clearly exhibited in Fig. 4, the level of stationary employment under the regime of vertical integration is greater than that under the regime of vertical separation (i.e., $\hat{N}_0 \text{N} \hat{N}_0$).

[16] Eqs. (32) and (42) reveal that the balanced growth rate is related to the level of employment under both the vertical separation and vertical integration regimes. This implies that the growth model in the paper features the scale effect, i.e., it predicts that a rise in the size of employment (or population) will lead to a higher growth rate. Many growth models have been criticized for this, as it is arguably at odds with the empirical studies based on US and OECD data, for instance, Backus, Kehoe, & Kehoe (1992) and Jones (1995b). To remove the undesirable scale effect, two strands of the literature have been developed and proposed. The first strand, including Jones (1995a); Segerstrom (1998) and Eicher & Turnovsky (2000), introduces the population growth rate, and shows that the balanced per capita growth rate is crucially determined by the rate of population growth (rather than the level of population). The second strand, such as Peretto (1996, 1998) and Howitt (1999), specifies that a rise in the scale of the aggregate economy is perfectly fragmented by the proliferation of endogenous product varieties.

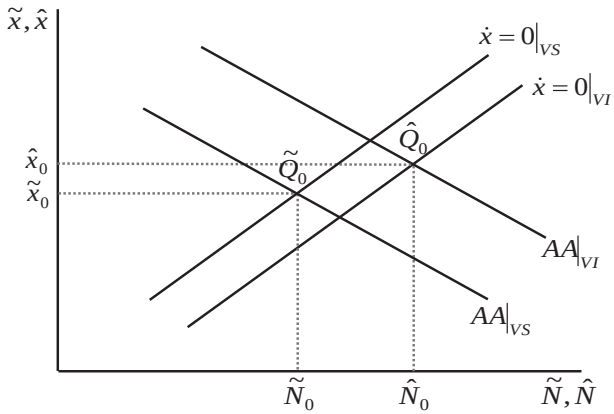

Fig. 4. The relative employment level between two regimes.

We then turn to compare the balanced growth rate between both regimes. From Eqs. (32) and (42) with $\hat{N} > \tilde{N}$ we can further infer the following result:

$$\hat{\gamma} = \alpha(1-\tau_k)(1-\theta)\hat{N}^{\beta} - \rho > \alpha(1-\tau_k)(1-\theta)^2\tilde{N}^{\beta} - \rho = \tilde{\gamma}: \tag{43}$$

Eq. (43) indicates that the regime of vertical integration displays a higher balanced growth rate than the regime of vertical separation. The economic reasoning for this result can be explained by virtue of the Keynes–Ramsey rule.

Vertical integration between the upstream and downstream firms leads to a higher value of the after-tax rate of return on holding physical capital. With a higher rate of return on holding physical capital, the household is inclined to substitute away from consumption to investment. As a consequence, vertical integration between the upstream and downstream firms is favorable to the balanced economic growth rate. The policy implication for the above results is that, to promote employment and economic growth, the government should encourage manufacturers to engage in vertical integration, and discourage manufacturers from engaging in vertical separation.[17]

The above discussion leads us to establish the following proposition:

Proposition 3. A vertical integration structure leads to a higher level of stationary employment and a higher balanced economic growth rate than a vertical separation structure.

4. The optimal tax rate

Owing to the fact that imperfectly competitive behavior emerges in either separated or integrated industries, the market equilibrium is inefficient. When faced with the distortion stemming from imperfect competition, the social planner has an incentive to correct the distortion by setting the optimal tax policies in order to achieve the Pareto optimum. This section deals with how the social planner sets the package of tax rates on labor and capital income under both a regime characterized by separation and one that is integrated.

4.1. First-best taxes under a vertical separation regime

In the centralized economy, the social planner, subject to the aggregate resource constraint (24) and the aggregate production function (25e), maximizes Eq. (1) by choosing C, N and K. By letting μ stand for the co-state variable associated with the capital stock, the optimal conditions for the social planner's optimization problem are given by:

$$\frac{1}{C} = \mu; \tag{44a}$$

$$N^{\sigma} = \mu\,\beta\frac{Y^d}{N}; \tag{44b}$$

[17] It should be noted that vertical integration can also have other effects on the market competition, which are both pro- and anti-competitive. Two additional effects are commonly discussed in the literature. First, by eliminating the monopsony distortion when a downstream firm exerts market power on the upstream market, vertical integration can further raise efficiency. Second, the ability of integrating parties to raise rivals' costs has been recognized as an important factor in driving market-exit, which tends to raise market-power and lower efficiency. Riordan (2008) and Church (2008) provide a more detailed discussion on these effects of vertical integration. Even so, the consensus in the literature appears to support our analytical result, i.e., vertical integration generally does reduce the mark-ups that consumers pay. We are grateful to an anonymous referee for bringing this point to our attention.

$$\mu = \mu\left(\rho - \frac{Y^d}{K}\right); \tag{44c}$$

$$Y^d = KN^{\beta}; \tag{44d}$$

$$K = Y^d - C: \tag{44e}$$

In contrast to an individual household, the planner takes into account the social marginal products of the labor and capital inputs. By comparing Eq. (25a) with Eq. (44a), we obtain $\lambda = \mu$. Substitution $\lambda = \mu$ and Eq. (25e) into (25b) gives rise to $N^{\sigma} = \mu(1-\tau_n)(1-\theta)^2\beta KN^{\beta-1}$. Moreover, substituting Eq. (44d) into (44b) yields $N^{\sigma} = \mu\beta KN^{\beta-1}$. Let superscript "*" denote the first-best tax rate associated with the relevant variables. From the above two expressions we can infer the first-best policy for the labor income tax rate in a vertical separation regime $\tau_n{}^*$:

$$\tau_n{}^* = \frac{\theta(\theta-2)}{(1-\theta)^2} \text{ b } 0: \tag{45a}$$

By analogy, equipped with the relation $\alpha + \beta = 1$ in Eq. (16), we can also obtain the first-best policy for the capital income tax rate in a vertical separation regime $\tau_k{}^*$:

$$\tau_k{}^* = 1 - \frac{1}{(1-\beta)(1-\theta)^2} \text{ b } 0: \tag{45b}$$

The first-best optimal policies reported in Eqs. (45a) and (45b) provide some important results, which we now describe.

First, we deal with the situation where both the intermediate goods and final goods markets are perfectly competitive ($\theta = 0$) and the production externality in the intermediate sector is present ($0 \text{ b } \beta \text{ b } 1$). It is clear from Eqs. (45a) and (45b) with $\theta = 0$ and $0 \text{ b } \beta \text{ b } 1$ that the first-best tax policies in relation to labor and capital income are given by $\tau_n{}^* = 0$ and $\tau_k^* = 1 - 1 = (1-\beta)\text{b}0$, respectively. The economic intuition underlying this result is quite straightforward. Given that the capital externality takes the form of learning-by-doing, the private rate of return on capital investment will be lower than the social rate, but the private rate of return on the labor input will be equal to its social rate. This leads the firm to employ too little capital compared to the first-best optimum. In order to correct for the undue level of capital, a subsidy on capital income should be utilized to remove the distortion.

Secondly, we consider the situation where both the intermediate goods and final goods markets are imperfectly competitive ($0 \text{ b } \theta \text{ b } 1$) and the production externality in the intermediate goods sector is present ($0 \text{ b } \beta \text{ b } 1$). Under such a situation, the first-best tax policies on labor and capital income are reported in Eqs. (45a) and (45b). The intuition behind this result can be explained as follows. Given that both the intermediate goods and final goods markets are imperfectly competitive, the private rates of return on capital investment and the labor input will be lower than their social rates. This leads the firm to employ too little capital and labor relative to the social optimum. To restore the optimal levels of capital and labor, subsidy policies for both labor income and capital income are required to correct the imperfectly competitive double inefficiency in the upstream and downstream industries. Moreover, given that the capital externality is in the form of learning-by-doing, the private rate of return on capital investment will be lower than its social rate. This leads the firm to employ too little capital compared to the first-best optimum. In order to correct for the inappropriate level of capital, a subsidy on capital income should be utilized to remove the distortion arising from the capital externality in the form of learning-by-doing. With this understanding, we can conclude that the tax rate on subsidizing capital income is greater than that on subsidizing labor income, since the former is used to remedy a single distortion (i.e., imperfect competition) and the latter is used to remedy a double distortion (i.e., imperfect competition and the capital externality).[18]

Thirdly, when the capital externality in the form of learning-by-doing is absent ($\beta = 0$), Eqs. (45a) and (45b) indicate that the first-best tax policy requires a uniform subsidy on labor and capital incomes at the rate $\theta(\theta-2)/(1-\theta)^2(\text{b } 0)$. The reason is that under the regime of vertical separation both the intermediate goods and final goods markets are imperfectly competitive, implying that a double inefficiency emerges in the economy. As a consequence, the first-best tax policy is used to remedy the distortions stemming from this double inefficiency in both goods markets.

Summing up the discussion, we can establish the following proposition:

Proposition 4. In a vertical separation regime where both the upstream and downstream markets are characterized by imperfect competition and the capital externality in the form of learning-by-doing is present, the first-best tax policies on labor and capital income are given by $\tau_n^* = \frac{\theta(\theta-2)}{(1-\theta)^2}$ b 0 and $\tau_k^* = 1 - \frac{1}{(1-\beta)\,(1-\theta)^2}$ b 0, respectively. As a result, the tax rate on subsidizing capital income is greater than that on subsidizing labor income.

[18] From Eqs. (45a) and (45b), we can infer the following expression:
$|\tau_k^*| = \frac{1}{(1-\beta)\,(1-\theta)^2} - 1 \text{ N } \frac{1}{(1-\theta)^2} - 1 = \frac{1-(1-\theta)^2}{(1-\theta)^2} = \frac{\theta(2-\theta)}{(1-\theta)^2} = |\tau_n^*|$.

4.2. First-best taxes in an integrated regime

In this case, the social planner's optimization problem is the same as in the vertical separation regime. By comparing Eq. (36b) with Eq. (44b) and recalling the result of $\lambda = \mu = 1/C$ in Eqs. (36a) and (44a), the first-best policy for the labor income tax rate in an integrated regime $\hat{\tau}_n^*$ is as follows:

$$\hat{\tau}_n^* = \frac{-\theta}{(1-\theta)} \text{ b } 0: \tag{46a}$$

Moreover, by comparing Eq. (36c) with Eq. (44c) and recalling the results of $\lambda = \mu = 1/C$ in Eqs. (36a) and (44a) and $\alpha + \beta = 1$ in Eq. (16), we can infer the first-best policy for the capital income tax rate in an integrated regime $\hat{\tau}_k^*$:

$$\hat{\tau}_k^* = 1 - \frac{1}{(1-\beta)(1-\theta)} \text{ b } 0: \tag{46b}$$

Similar to the vertical separation regime, with imperfect competition in the integrated goods market, the private rates of return on capital investment and the labor input will be lower than their social rates. This leads the firm to hire too little capital and labor compared to the social optimum. In order to remedy the inappropriate levels of capital and labor, a package comprising a capital income subsidy and a labor income subsidy should be utilized to remove the distortions. In addition, in the presence of the capital externality in the form of learning-by-doing, the private rate of return on capital investment will be lower than the social rate. In order to remedy the inappropriate level of capital, a subsidy on capital income should be utilized to remove the distortion arising from the capital externality. Accordingly, the rate on subsidizing capital income should be greater than that on subsidizing labor income.[19]

Eqs. (46a) and (46b) with $\beta = 0$ reveal the result $\hat{\tau}_n^* = \hat{\tau}_k^* = -\theta/(1-\theta)$ b 0, implying that the first-best policy consists of a uniform subsidy in relation to labor and capital income. Summing up the above discussion, the following proposition can be established:

Proposition 5. In a vertical integration regime where imperfectly competitive upstream and downstream markets are integrated and a capital externality in the form of learning-by-doing is present, the first-best tax policies on labor and capital income are given by $\hat{\tau}_n^* = \frac{-\theta}{(1-\theta)}$ b 0 and $\hat{\tau}_k^* = 1 - \frac{1}{(1-\beta)(1-\theta)}$ b 0, respectively.

Comparing Eq. (45a) with Eq. (46a) and Eq. (45b) with Eq. (46b) with 1 N θ N 0 yields:

$$\left|\tilde{\tau}_n^*\right| = \frac{\theta(2-\theta)}{(1-\theta)^2} = \frac{\theta}{(1-\theta)} \times \frac{2-\theta}{(1-\theta)} \text{ N } \frac{\theta}{1-\theta} = \left|\hat{\tau}_n^*\right|; \tag{47a}$$

$$\left|\tilde{\tau}_k^*\right| = \frac{1}{(1-\beta)(1-\theta)^2} - 1 \quad \text{N} \quad \frac{1}{(1-\beta)(1-\theta)} - 1 = \left|\hat{\tau}_k^*\right|: \tag{47b}$$

Eqs. (47a) and (47b) indicate that, in comparison with a vertical integration regime, the first-best subsidy rates on labor income and capital income are higher under a vertical separation regime. The intuition behind this result can be explained as follows. Given that a vertical separation regime leads to a double distortion in the upstream and downstream markets and that a vertical integration regime gives rise to a single distortion in the integrated goods market, the private rates of return on capital investment and the labor input under the vertical separation regime are lower than those under the vertical integration regime. This leads the firm under the vertical separation regime to employ more capital and labor relative to the optimum than the firm under the vertical integration regime. In order to correct for the undue level of capital and labor inputs, there should be a higher subsidy rate on labor income and capital income under a vertical separation regime than under a vertical integration regime.

To sum up the above discussion, we present the following proposition:

Proposition 6. In comparison with an integrated regime, the first-best subsidy rates of return on labor income and capital income are higher under a vertical separation regime.

5. Extensions and discussions

This section discusses two extensions of the benchmark model developed in Section 2. The first extension is that monopoly power stems from the supply side rather than the demand side, and the second extension is that the productive public spending externality is present. In what follows, we will respectively provide a brief discussion on whether the analytical results in Section 4 are tenable with each extension.

[19] From Eqs. (46a) and (46b), we have the following result:
$|\hat{\tau}_k^*| = \frac{1}{(1-\beta)(1-\theta)} - 1 \text{ N } \frac{1}{(1-\theta)} - 1 = \frac{1-(1-\theta)}{(1-\theta)} = \frac{\theta}{(1-\theta)} = |\hat{\tau}_n^*|$.

5.1. Monopoly power arising from the supply side

The benchmark model in Section 2 specifies that the household treats all consumption varieties c_i as imperfectly substitutable goods. This implies that the degree of monopoly is something entirely arising from the demand side. It would be worthwhile discussing whether our findings in Section 4 are valid if monopoly power emerges from the supply side rather than the demand side.

To minimize the change in the industrial structure compared to Section 2, in departing from the benchmark model, we assume that there are three types of firms in the production sector: a single final-goods assembly firm, m downstream firms, and m upstream firms. The mutual interactions among the three types of firms can be described as follows. First, the single firm that assembles the final goods purchases the final goods from the$m$ downstream firms, and then assembles all of them in one composite consumption good to sell to the households. Second, the intermediate goods are produced by m upstream firms, and each of the upstream firms produces imperfectly substitutable intermediate goods. Third, all downstream firms are retailers, and each of the intermediate goods produced by upstream firms is sold to an independent retailer, which then transforms the good into a final good and sells it to the assembly firm. Compared with the production sector in Section 2, the main distinction is to introduce the final-goods assembly firm. We then in turn deal with the optimal decisions of each of the three types of firms.

We first discuss the optimal behavior of the final-goods assembly firm. As stated above, the final-goods assembly firm purchases m kinds of final goods y_i^d $(i=1,2,\ldots,m)$ from downstream firms, and assembles them in one composite good. Let Y^d be the output level produced by the assembly firm. Then, in line with Benhabib & Farmer (1994) and Devereux, Head, & Lapham (1996), the assembly firm's output is produced with the following technology:

$$Y^d = m\left[\frac{1}{m}\sum_{i=1}^{m}\left(y_i^d\right)^{1-\theta}\right]^{\frac{1}{1-\theta}};\ 1 \text{ N } \theta \quad 0: \tag{48a}$$

As indicated in Eq. (48a), to introduce the supply-side monopoly power, we specify that the assembly firm treats all final goods purchased from the m downstream firms as imperfectly substitutable goods.

Let P^d be the price of Y^d, p_i^d be the price of y_i^d, and Π^{Y^d}be the profit of the assembly firm. The profit-maximization problem for the assembly firm is expressed as:

$$\underset{y_i^d}{\text{Max}}\ \Pi^{Y^d} = P^d Y^d - \ {}_{i=1}^{m} p_i^d y_i^d = P^d\left\{m\left[\frac{1}{m};\ {}_{i=1}^{m};\left(y_i^d\right)^{1-\theta}\right]\frac{1}{1-\theta}\right\} - \ {}_{i=1}^{m} p_i^d y_i^d: \tag{48b}$$

The first-order condition for profit maximization leads to the following demand function for the ith final good:

$$y_i^d = \left(\frac{p_i^d}{P^d}\right)^{-\frac{1}{\theta}}\frac{Y^d}{m}: \tag{48c}$$

Eq. (48c) indicates that the price elasticity of demand for the ith final good is $1/\theta$.

We then deal with the optimal behavior of the downstream firms (retailers). Let y_i^u denote the output level of the intermediate goods produced by the upstream firm i, and p_i^u denote the price of y_i^u. As stated previously, each downstream firm transforms the intermediate product (produced by the upstream firm) into the final one on a one-for-one basis, i.e., $y_i^d = y_i^u$. Then, the maximization problem of the ith final-goods (downstream) firm can be expressed as follows:

$$\underset{p_i^d}{\text{Max}}\ \pi_i^d = p_i^d y_i^d - p_i^u y_i^u = \left(p_i^d - p_i^u\right) y_i^d; \tag{49a}$$

$$s{:}t{:}\ y_i^d = \left(\frac{p_i^d}{P^d}\right)^{-\frac{1}{\theta}}\frac{Y^d}{m}: \tag{49b}$$

It is quite easy to show that the optimal price of the ith downstream firm is the same as Eq. (13) in the benchmark model.

We finally discuss the optimal behavior of the upstream firms. As in Eq. (16a) in Section 2, the production function of the ith upstream firm is specified as $y_i^u = K^\beta n_i^\beta k_i^\alpha$. Then, the optimizing problem of the ith upstream producer can be described as:

$$\underset{p_i^u;k_i;n_i}{Max}\ \pi_i^u = p_i^u y_i^u - rk_i - wn_i; \tag{50a}$$

$$s{:}t{:}\ y_i^u = K^\beta n_i^\beta k_i^\alpha \ \text{ and } \ y_i^u = y_i^d = \left(\frac{p_i^d}{P^d}\right)^{-\frac{1}{\theta}}\left(\frac{Y^d}{m}\right): \tag{50b}$$

It is straightforward to show that the first-order conditions for this problem yield the same results as those reported in Eqs. (18) and (19) in the benchmark model.

We now turn our focus to the optimal behavior of the representative household. To shed light on the supply-side monopoly power, it is better for us to take away the demand-side monopoly power. To this end, in line with Benhabib & Farmer (1994), the household's consumption C in Eqs. (1) and (2) is now treated as a single consumption good produced by the assembly firm (rather than the composite consumption composed of m kinds of varieties). With this modification, the household will only engage in a single stage budgeting decision, and its optimal decisions at this single stage are the same as those at the first stage in the benchmark model, as reported in Eqs. (6a)-(6e).

Given that both downstream and upstream firms and the representative household have the same optimal decisions as those in the benchmark model, we can obtain the same macroeconomic models as those in the benchmark, as reported in Eqs. (25a)..(25g) under the vertical separation regime and Eqs. (36a)..(36g) under the vertical integration regime.[20] As a result, our findings in Section 4 remain valid when monopoly power emerges from the supply side.

5.2. Productive public expenditure

To simplify the analysis, the benchmark model emphasizes a single production externality, i.e., the learning-by-doing externality in capital accumulation. However, after the pioneering work by Barro (1990), a growing number of studies on endogenous growth have focused attention on the production externality arising from productive government spending.[21] As such, this subsection turns to discuss the robustness of our results for the benchmark model if productive public spending is brought into the picture.

In a departure from the benchmark model, assume that both learning-by-doing in capital accumulation $K = \sum_{i=1}^{m} k_i$ and the government's infrastructure expenditure G raises the productivity of the labor input. Accordingly, the production function reported in Eq. (16) in the benchmark model is modified as follows:

$$y_i^u = (An_i)^{\alpha}; \quad A = K^{\gamma_1} G^{\gamma_2}; \quad 0 < \alpha < 1; \quad 0 < \gamma_1 < 1; \quad 0 < \gamma_2 < 1; \quad \gamma_1 + \gamma_2 = 1; \quad \alpha + \gamma_1 = 1; \quad i = 1, 2, \ldots, m. \tag{51a}$$

The labor-augmenting technology A stands for production externalities related to the ith upstream firm. As exhibited by $A = K^{\gamma_1} G^{\gamma_2}$, two types of production externalities are present in the production process: aggregate physical capital and the government's infrastructure. The first is the learning-by-doing externality arising from the capital accumulation emphasized in the benchmark model. The second is the productive government spending externality proposed by Barro (1990). This additional externality indicates that the individual upstream firm benefits from the provision of public goods by producing more output without incurring any cost for using the government's infrastructure. It should be noted that γ_1 measures the degree of the learning-by-doing externality, and γ_2 measures the degree of the productive public spending externality. Accordingly, the situation in association with $\gamma_1 = 1$ and $\gamma_2 = 0$ indicates that only the learning-by-doing externality is present, while the situation in association with $\gamma_1 = 0$ and $\gamma_2 = 1$ reveals that only the productive public spending externality is present.

In departing from the benchmark model, in the presence of government spending on infrastructure, we assume that the government adjusts its public expenditure (other than transfers) according to the total tax collected (the sum of labor income taxes and capital income taxes).[22] Accordingly, the government budget constraint and aggregate resource constraint of the economy are modified as follows:

$$\tau_n wN + \tau_k (rK + \delta K) = R + G; \tag{51b}$$

$$\dot{K} = Y^d - \delta K - C - G. \tag{51c}$$

Before discussing the first-best policies, one point should be mentioned here. In the benchmark model, there are two distortions in the economy, namely, imperfect competition and learning-by-doing in capital accumulation. Accordingly, two tax instruments τ_n and τ_k are adopted to remedy these two distortions. However, in the presence of productive government spending, three distortions emerge from the economy in this extended model: imperfect competition, learning-by-doing in capital accumulation, and productive public infrastructure. As such, to restore the first-best equilibrium, in addition to τ_n and τ_k, we should introduce an additional policy instrument. In line with the existing literature on productive public spending, for example, Turnovsky (1996, 1999) and Eicher & Turnovsky (2000), the additional policy we choose is the size of government expenditure $g (= G/Y)$, i.e., the ratio between government spending and output.

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[20] It should be noted that, with the three types of firms in the production sector, the total real profit of all three types of firms is defined as $\pi = \pi^{Y^d} + \pi^d + \pi^u$ in the vertical separation regime. It is quite easy from Eqs. (48b) and (48c) to show the result $\pi^{Y^d} = 0$, and hence the expression $\pi = \pi^d + \pi^u$ reported in Eq. (22e) remains intact in the vertical separation regime. Similarly, in the vertical integration regime, given that $\pi = \pi^{Y^d} + \pi^l$ and $\pi^{Y^d} = 0$, we can infer that the expression $\pi = \pi^l$ in Eq. (35g) also remains intact.

[21] Gramlich (1994) provides an excellent survey of the relevant empirical studies on productive public spending. Irmen & Kuehnel (2009) provide a comprehensive

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