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Resource-based Regions, the Dutch Disease and City Development*

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Abstract

This paper examines the relationship between resource development and industrialization. When transport costs are high, regions with more valuable natural resources offer higher welfare than other regions. However, when transport costs decrease, firms begin to move out of the region, resulting in the Dutch disease, initially in terms of industry shares, but eventually in terms of welfare too when transportation is sufficiently free. If resource goods are also used as manufacturing inputs as well as final goods, they can substitute for labor when wages rise, which tends to alleviate the Dutch disease by keeping production costs down. The model thus provides helpful insight for cities trying to develop efficiently their limited resources.

Keywords: Resource-based regions, Dutch disease, Resource goods, Industrialization, Transport costs
JEL classification: F1, Q2, R1

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1 Introduction

Natural resources could be both a blessing and a curse. Many cities were born and prospered after the discovery of rich natural resources nearby, yet, many of them declined and some even disappeared after the depletion of the resources. For instance, China had about 666 cities in 1996, among which 126 were classified as resource-type cities (Department of Homeland and Resources, China). It was estimated that about 10%–20% of these resource-type cities were further classified as "hopeless" due to resource depletion, and many others were facing serious danger of depletion and heavy pollution, and trapped with slow or even negative growth and high unemployment.[1] Yubari was known as a city of coal in Japan. After the first mine opened in 1890, Yubari reached its highest population of 116,908 in 1960. Nevertheless, it lost 90 per cent of its residents after the mines closed in the 1990s. However, some resource-based cities are more successful. In china, Baotou, Daqing, Tangshan and Jiaozuo are considered model cities that grew on natural resources and still maintain more than 2 million current population each (Tangshan has 7 million). One cannot help but ask, what is the difference between the two types of resource based cities, especially with regards to sustainable city development? It turned out that the successful cities effectively utilized their resources in building vertically and horizontally related industries, such as oil refining, mineral processing, metal fabrication, transportation, storage, forest and soil conservation, environmental protection, water purification, etc. As such, even when natural resources come to be depleted, an industry base has been built and especially technology and management skills are leant and developed. These are essential elements in attracting workers, markets and eventually firms. It is well-known that Southern France is able to use its combination of climate and soil to not only grow grapes, but also produce the highest quality of wines and brandy, in addition to attracting millions of tourists every year. Also, the strategies proposed for the resource-based cities in China were to create sequel industries like paper pulp industry in Yunnan, which is abundant in forest resource.

In the present paper, we intend to model the above phenomena. The issues are closely related to the so-called Dutch disease, known for the relationship between resource development and economic decline, originating from Netherlands' natural gas discovery in 1959 and the fact that it hurt the competitiveness of Dutch manufacturing. Corden and Neary (1982) and Corden (1984) are theoretical studies on the Dutch disease. They clearly

[1]See "The transitional pain of resource cities" (in Chinese): http://finance.sina.com.cn/chanjing/sdbd/20090611/08486334226.shtml

demonstrate that an increase in natural resources will raise the labor demands in both the extraction industry and the nontraded good sector, driving workers away from manufacturing. As a consequence, the relative price of the nontraded good rises. However, their setting is a small open economy, in which the price of the manufacturing good is fixed.

In our view, the development of cities crucially depends on how resources are used. Thus in the present paper, we reexamine the Dutch disease from the viewpoint of industrial agglomeration, in a setting of increasing returns in manufacturing, the so-called "New Economic Geography" (NEG) (e.g., Fujita, *et al.*, 1999; Baldwin, *et al.*, 2003; Tabuchi and Thisse, 2011; Takahashi, 2011). In particular, we remove several restrictions usually imposed in the literature and introduce a few features of trade.

First of all, in our setup, natural resources are extracted and transformed to resource goods, which are used as intermediate goods in the manufacturing sector and/or as final goods for consumption. In the real world, some resource goods are used both as intermediate as well as final goods, while some other resource goods are used in consumption only.[2] We especially focus on region-specific resources, such as glaciers in the Alps that can produce spring water as well as attract tourists and skiers, the combination of sunshine and dry and rich soil in Southern Europe that produces high-quality wine, adjacency to the sea by which beautiful beaches are decorated and seashores are used as fishing bases, a hot and wet climate that produces juicy tropical fruits, etc. The BP oil spill in the Gulf of Mexico in 2010 caused extensive damage to the Gulf's fishing and tourism industries as well as marine and wildlife habitats. These examples show that industries are often linked through the use of natural resources.

The other new features introduced in our model include: endogenously determining the price of the manufacturing good; allowing manufacturing firms to migrate across regions; modeling regional integration as a gradual process, from freer transportation to eventual firm migration; and finally, in contrast to the homogeneous agricultural good usually assumed in standard NEG models, we introduce heterogeneity in the resource goods to reflect the fact that regions are endowed with different natural resources (e.g., Canadian forests and Caribbean beaches).[3]

[2] As examples of the former resource goods, sea water is purified to be used both in production and for consumption; corn and beets are directly consumed and used as petroleum substitutes for fuel sources; Additional examples include forests, glaciers and other minerals. For the latter type of resources, examples include tropical fruits, beaches, ski mountains, and even some scarce minerals.

[3] Fujita *et al.* (1999, Chapter 7) and Picard and Zeng (2005) consider heterogeneous agricultural goods, but they are not inputs in manufacturing production either.

Equipped with the above, we find that the relationship between manufacturing and resource endowment depends crucially on *how resources are used* and *how freely transported* manufacturing goods are. Specifically, if natural resources are consumed directly and *not* used in manufacturing, then for sufficiently high transport costs of the manufacturing goods, firms are evenly distributed across regions with identical population even though the region with a more valuable resource (say, region N) provides a higher wage.[4] As transport costs decrease, manufacturing firms in region N will move out to the other region (say, region S) to save on labor cost, until when wages are equalized across regions, at which region N has a smaller number of firms. This can be called a *Dutch disease in terms of industry shares.* The importance of this result is self evident, because industry share is a key determinant of the relative size of modern cities.

In contrast, when resources are also used as manufacturing inputs, then firms can substitute natural resources for labor if wages become high, and the Dutch disease does not arise if transport is costly to some extent. Note that these resource inputs can be utilized to make additional varieties of goods that are not identical but related to the final consumption good. In other words, resources are used to create vertically and horizontally related industries. Even more interestingly, a resource boom (i.e., an increase in one region's resource expenditure share) may strengthen the tendency for this region to have a more-than-proportionate share of firms when resources are used as intermediate inputs, but will weaken this tendency when resources are used only as final goods. This contrast is especially significant when the resource goods are costly transported. These novel results point to the importance of developing industries that can effectively utilize resources in production rather than in consumption only, as documented in the beginning of this paper.

Finally, we find the *Dutch disease in terms of welfare* when transport is sufficiently free for all goods, regardless if resources are used in manufacturing or not. In other words, the welfare is lower in the region with a more valuable resource than the other region for sufficiently low transport costs, which arises because the endogenous relative wage in the former region becomes too high. This result implies that a decrease in transportation cost may create a conflict of interests among regions, because the welfare loss stemming from de-industrialization as firms move out can be larger than the welfare gain from trade opening, leading to net "losses from trade." These results contrast with those in Venables (1987) and Baldwin *et al.* (2003), who assume factor price equalization in models with a

[4] As will be defined precisely later, "more valuable" means it occupies a higher expenditure share than the other resource good.

homogeneous and freely transported good.

Some other economists have also investigated the Dutch disease. Krugman (1987) and Matsuyama (1992) focus on learning-by-doing in the manufacturing sector via knowledge accumulation. Matsuyama (1992) interestingly finds that the link between agriculture productivity and manufacturing is positive in a closed economy but negative in a small open economy, which suggests the important role that trade plays in economic development. However, in his model natural resources are not involved in production in either sector.

In contrast, in our setup, natural resources can be used as intermediate goods in the manufacturing sector and as final consumption goods. Furthermore, our model generates an endogenous regional wage differential, which enables us to examine how natural resources affect industrialization and welfare differently across regions.

The main mechanisms driving our results are the different usages of natural resources (including heterogeneous resource goods) and trade freeness. This is different from the home-market effect of Krugman (1980), in which firms are attracted by a larger market resulting in a higher wage and a higher firm share there (Takatsuka and Zeng, 2012). If natural resources are not used in manufacturing, then the Dutch disease occurs straightforwardly as soon as goods are allowed to move across regions, because firms will relocate to the lower-wage region to save on labor cost. When natural resources are used in manufacturing, this process is alleviated to a large extent since firms can substitute resources for expensive local labor before relocating to the other region. In addition, our two-region general equilibrium model provides insight on welfare for cities trying to efficiently utilize their limited resources.

While free transportation of resource goods and immobility of labor are assumed in the basic model to simplify the analysis, in an extensive setup we lift these restrictions, and we find that the Dutch disease in terms of both industry share and welfare are softened when resource goods are more costly to be transported. An interesting implication is that, when globalization deepens, the Dutch diseases are more serious.

The rest of paper is structured as follows. Section 2 presents the basic model; Section 3 derives and discusses the equilibrium location and wages, and examines the effects of resource booms. The welfare analysis is conducted in Section 4. Section 5 generalizes the model, by considering the cases of positive transport costs of resource goods and migration of labor. Finally Section 6 concludes.

2 The Model

We investigate the relationship between natural-resource endowment and industrialization in a model of two regions named North (N) and South (S). In order to focus on the resource effects, we assume that both regions have the same population L, thus eliminating the market-size effect on industrial location (e.g., Helpman and Krugman, 1985). Each consumer or worker owns one unit of labor, and consumer tastes are identical across regions. Preferences can be described with a Cobb-Douglas utility function for three types of goods, with a CES subutility on the varieties of manufactured goods. Specifically, the three goods are manufacturing M, non-manufacturing A_N and A_S, in the following manner,

$$U = M^{1-\mu-\eta} A_N^{\mu} A_S^{\eta},$$

where

$$M = \left(\int_0^{n^T} m(i)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}},$$

is a composite good of different varieties of manufacturing products. The number of all varieties in the two regions is denoted by n^T, and $\sigma > 1$ is the elasticity of substitution between varieties. Parameters μ and η stand for expenditure shares of A_N and A_S respectively, and

$$\mu, \eta > 0; \;\; \mu + \eta < 1. \tag{1}$$

While M can be produced in both regions, due to resource constraints, such as climate (warm or cold, wet or dry), geography (coast or inland, flat land or mountains), natural endowment (petroleum and mineral rich or poor), etc., A_N can be produced only in region N and A_S only in region S. Thus N must import A_S and S must import A_N, from the other region. For instance within Japan, Hokkaido must buy warm-weather fruits and vegetables from Kyushu and Okinawa while skiers from the latter two islands travel to Hokkaido for skiing; Internationally, Iceland and Norway must import tropical fruits and wine, Luxemburg must import seafood; and in Hong Kong and Singapore, even fresh water must be imported, etc. We call these non-manufacturing goods *resource goods.*

Samuelson's iceberg transport cost applies in the manufacturing sector: $\tau \geq 1$ units of the manufactured good must be shipped for one unit to reach the other region. On the other hand, both A_N and A_S are assumed to be freely transported (this assumption is relaxed in Section 5.1). Standard NEG models (i.e., with a *homogeneous* non-manufacturing good) usually adopt this assumption to improve mathematical tractability since it equalizes wages across regions. In our model, however, wages are not equalized even with this assumption because the resource goods are differentiated across regions. We can thus analyze the inter-regional wage differential brought by the resource goods and the manufacturing transport costs.

We normalize the wage in S as $w_S = 1$ and denote that in N simply by w. Since each worker owns one unit of labor, the total expenditure spent on goods made in N and S are respectively,

$$E_N = Lw \text{ and } E_S = L. \tag{2}$$

In the production of the resource goods A_N and A_S, we assume one unit of labor produces one unit of output. For simplicity, we further assume that there is free entry and thus zero profits in resource production. Then, the prices of A_N and A_S are respectively

$$p_N^A = w, \quad \text{and} \quad p_S^A = 1. \tag{3}$$

Note that these are countrywide prices, since resource goods are freely transported across regions in this basic model.

In contrast, in manufacturing three inputs are required for production: labor and the two resource goods. Each firm has the following cost structure: a fixed cost of f and marginal cost of $(\sigma-1)/\sigma$. Specifically, we assume the following Cobb-Douglas production function:

$$f + \frac{\sigma - 1}{\sigma} x = l^\alpha A_N^\beta A_S^\gamma, \tag{4}$$

where l stands for labor input, and α, β, γ are cost shares of each input satisfying $\alpha + \beta + \gamma = 1$. Thus, (4) specifies the amount of the three inputs required to produce x units of the manufacturing good.

Since the production-cost share of A_N (resp. A_S) is β (resp. γ), residents indirectly spend $\beta(1 - \mu - \eta)$ (resp. $\gamma(1 - \mu - \eta)$) of their incomes on A_N (resp. A_S) via the consumption of good M. Then, $\hat{\mu} = \mu + \beta(1 - \mu - \eta)$ (resp. $\hat{\eta} = \eta + \gamma(1 - \mu - \eta)$) is the sum of the direct and indirect expenditure shares of A_N (resp. A_S) for each consumer.

In addition, we assume that

$$\alpha \in \left[\frac{1}{2\sigma}, 1\right], \ \beta, \gamma \in [0, 1), \tag{5}$$

$$\hat{\eta} < \hat{\mu} < \frac{1}{2}. \tag{6}$$

The inequality $\alpha \geq 1/(2\sigma)$ in (5) requires that either α or σ be not too small, which is always satisfied if $\beta + \gamma \leq 1/2$. The first inequality in (6) implies that the expenditure on A_N is larger than that on A_S. Since A_N is more valuable than A_S, region N has a "resource advantage" over region S. Both $\hat{\mu}$ and $\hat{\eta}$ are assumed to be less than 1/2 in (6), which seems to be realistic in our modern society.[5]

For expositional clarity, we further introduce the following notations:

$$\Phi \equiv w - \hat{\mu}(1 + w), \quad \Psi \equiv 1 - \hat{\eta}(1 + w) \tag{7}$$

$$\bar{w} \equiv \frac{\hat{\mu}}{\hat{\eta}} \ \ (> 1). \tag{8}$$

Note that $\hat{\mu}(L + Lw)$ is the two-region total expenditure for A_N, which requires $L\hat{\mu}(1 + w)/w$ workers to produce in region N. Then, $L\Phi = Lw - L\hat{\mu}(1 + w)$ is the total labor cost for the manufacturing sector in region N. Similarly, $L\Psi$ is the total labor cost for the manufacturing sector in region S. Because both Φ and Ψ depend on w, they are sometimes written as $\Phi(w)$ and $\Psi(w)$ below. Meanwhile, $\bar{w}$ is the relative *resource advantage* of A_N over A_S, and inequality $\bar{w} > 1$ holds from (6). As will be clarified in Appendix A, the equilibrium wage $w \in [1, \bar{w}]$ holds for any transport costs. This fact and (6) suggest that $\Phi \geq 0$ and $\Psi \geq 0$ always hold.

Observe that the model contains a special case when resource goods are not used as an input in manufacturing (as in most existing NEG models). This can be captured by setting $\alpha = 1$ and $\beta = \gamma = 0$, satisfying (5) and (6). As will be demonstrated shortly, whether resources are used as manufacturing inputs ($\alpha < 1$) or not ($\alpha = 1$) plays a key role in determining whether the Dutch disease arises or not.

By cost minimization,

$$\begin{aligned} &\alpha\Gamma w_k^{\alpha-1} \left(p_N^A\right)^{\beta} \left(p_S^A\right)^{\gamma} \text{ units of labor,} \\ &\beta\Gamma w_k^{\alpha} \left(p_N^A\right)^{\beta-1} \left(p_S^A\right)^{\gamma} \text{ units of } A_N, \end{aligned} \tag{9}$$

[5]Without the second inequality in (6), firms may agglomerate completely in region S for some ϕ. The analysis of such a corner solution is complicated but does not add much essential insight. We assume this inequality to exclude the corner solution, which is explained in detail in Appendix B.

$$\gamma \Gamma w_k^{\alpha} \left(p_N^A\right)^{\beta} \left(p_S^A\right)^{\gamma-1} \text{ units of } A_S$$

are required in region $k \in \{N, S\}$ to produce one unit of the composite input, where $\Gamma \equiv \alpha^{-\alpha}\beta^{-\beta}\gamma^{-\gamma}$.

To produce x units of a manufactured variety, $f + (\sigma - 1)\, x/\sigma$ units of the composite input are needed. Using (3) and (9), the total cost of producing x units can be rewritten as

$$c_N(x) = \Gamma \left(f + \frac{\sigma - 1}{\sigma} x\right) w^{\alpha+\beta},$$
$$c_S(x) = \Gamma \left(f + \frac{\sigma - 1}{\sigma} x\right) w^{\beta}.$$

In this sector, the Dixit-Stiglitz setup of monopolistic competition (Dixit and Stiglitz, 1977) implies

$$p_{NN} = \Gamma w^{\alpha+\beta}, \quad p_{SS} = \Gamma w^{\beta}, \tag{10}$$
$$p_{SN} = p_{SS}\tau, \quad p_{NS} = p_{NN}\tau,$$

where p_{kj} is the price of a variety produced in region k and sold in region j ($k, j \in \{N, S\}$). Since the varieties are symmetric, we can omit the variety name here.

Then the manufacturing price indices can be obtained as

$$\begin{aligned} P_N =& [\theta n^T (p_{NN})^{1-\sigma} + (1-\theta) n^T \phi (p_{SS})^{1-\sigma}]^{\frac{1}{1-\sigma}} \\ =& [\theta w^{\alpha(1-\sigma)} + (1-\theta)\phi]^{\frac{1}{1-\sigma}} p_{SS} (n^T)^{\frac{1}{1-\sigma}}, \end{aligned} \tag{11}$$

$$\begin{aligned} P_S =& [\theta n^T \phi (p_{NN})^{1-\sigma} + (1-\theta) n^T (p_{SS})^{1-\sigma}]^{\frac{1}{1-\sigma}} \\ =& [\theta \phi w^{\alpha(1-\sigma)} + 1 - \theta]^{\frac{1}{1-\sigma}} p_{SS} (n^T)^{\frac{1}{1-\sigma}}, \end{aligned} \tag{12}$$

where θ is the share of manufacturing firms in N, and $\phi = \tau^{1-\sigma} \in [0, 1]$ is called the trade freeness of good M, which decreases in the transport cost τ.

3 Equilibrium

The demands for the manufacturing goods can be derived as

$$d_{NN} = \frac{(p_{NN})^{-\sigma}}{P_N^{1-\sigma}} (1 - \mu - \eta) E_N = \frac{1}{p_{NN}} \frac{w^{\alpha(1-\sigma)}(1 - \mu - \eta) E_N}{[\theta w^{\alpha(1-\sigma)} + (1-\theta)\phi] n^T},$$

$$d_{NS} = \frac{(\tau p_{NN})^{-\sigma}}{P_S^{1-\sigma}}(1-\mu-\eta)E_S = \frac{1}{\tau p_{NN}} \frac{\phi w^{\alpha(1-\sigma)}(1-\mu-\eta)E_S}{(\theta\phi w^{\alpha(1-\sigma)}+1-\theta)n^T},$$
$$d_{SS} = \frac{(p_{SS})^{-\sigma}}{P_S^{1-\sigma}}(1-\mu-\eta)E_S = \frac{1}{p_{SS}} \frac{(1-\mu-\eta)E_S}{(\theta\phi w^{\alpha(1-\sigma)}+1-\theta)\, n^T},$$
$$d_{SN} = \frac{(\tau p_{SS})^{-\sigma}}{P_N^{1-\sigma}}(1-\mu-\eta)E_N = \frac{1}{\tau p_{SS}} \frac{\phi(1-\mu-\eta)E_N}{[\theta w^{\alpha(1-\sigma)}+(1-\theta)\phi]n^T},$$

where d_{kj} stands for the demand for a variety made in region k by residents in region j $(k, j \in \{N, S\})$.

Using these demand functions and the zero profit condition, profit maximization gives the total outputs of a typical firm in N and S as $x_n = x_s = \sigma f$. Thus, the market-clearing conditions for good M in N and S are respectively

$$\frac{w^{\alpha(1-\sigma)}(1-\mu-\eta)}{p_{NN}n^T}\left[\frac{E_N}{\theta w^{\alpha(1-\sigma)}+(1-\theta)\phi} + \frac{\phi E_S}{\theta\phi w^{\alpha(1-\sigma)}+1-\theta}\right] = \sigma f, \tag{13}$$
$$\frac{1-\mu-\eta}{p_{SS}n^T}\left[\frac{E_S}{\theta\phi w^{\alpha(1-\sigma)}+1-\theta} + \frac{\phi E_N}{\theta w^{\alpha(1-\sigma)}+(1-\theta)\phi}\right] = \sigma f. \tag{14}$$

By use of (10), the above equalities give

$$(1-\phi^2)\frac{E_N}{\theta w^{\alpha(1-\sigma)}+(1-\theta)\phi} = \frac{\sigma f n^T}{1-\mu-\eta}\Gamma w^\beta(w^{\alpha\sigma}-\phi), \tag{15}$$
$$(1-\phi^2)\frac{E_S}{\theta\phi w^{\alpha(1-\sigma)}+1-\theta} = \frac{\sigma f n^T}{1-\mu-\eta}\Gamma w^\beta(1-w^{\alpha\sigma}\phi). \tag{16}$$

Since the above left-hand sides are nonnegative, we obtain two bounds of the equilibrium wage

$$\phi \le w^{\alpha\sigma} \le \frac{1}{\phi}. \tag{17}$$

On the other hand, invoking (3) and (9), the market-clearing conditions for the resource goods are

$$\mu\Big(\frac{E_N+E_S}{w}\Big) + \theta n^T f\sigma\Gamma\beta w^{-\gamma} + (1-\theta)n^T f\sigma\Gamma\beta w^{\beta-1} = L - \theta n^T f\sigma\Gamma\alpha w^{-\gamma}, \tag{18}$$
$$\eta(E_N+E_S) + \theta n^T f\sigma\Gamma\gamma w^{1-\gamma} + (1-\theta)n^T f\sigma\Gamma\gamma w^\beta = L - (1-\theta)n^T f\sigma\Gamma\alpha w^\beta. \tag{19}$$

Substituting (2) into (18) and (19), we obtain

$$\theta = \frac{\Phi}{\Phi + w^\alpha\Psi}, \tag{20}$$

$$n^T = \frac{Lw^{-\alpha-\beta}}{\sigma f \alpha \Gamma}(\Phi + w^\alpha \Psi), \tag{21}$$

where Φ and Ψ are defined in (7). Alternatively, each manufacturing firm produces σf units of output. From (3) and (9), the labor cost each firm needs is $\sigma f \alpha \Gamma w_k^\alpha w^\beta$ in region $k \in \{N, S\}$, and, thus, the number of firms in N and S are

$$\frac{L\Phi}{\sigma f \alpha \Gamma w^{\alpha+\beta}} = \frac{L\Phi}{\sigma f \alpha \Gamma} w^{-\alpha-\beta} \quad \text{and} \quad \frac{L\Psi}{\sigma f \alpha \Gamma w^\beta} = \frac{L\Psi}{\sigma f \alpha \Gamma} w^{-\beta}, \tag{22}$$

respectively, which are consistent with (20) and (21).

Note that (20) is true only if the equilibrium is interior (i.e., the RHS is in $[0, 1]$), which is the case in our setup as shown in Appendix B. On the other hand, both sides of (13) are positive, and so is n^T at the equilibrium. In contrast to most existing NEG models treating the size of manufacturing varieties n^T as exogenously given, (21) shows that n^T depends on w.

Substituting (20) and (21) into (13), we obtain an equation implicitly identifying the relationship of w and ϕ in equilibrium:

$$\mathcal{F}(w, \phi) \equiv \mathcal{A}(w) + \mathcal{B}(w)\phi + \mathcal{C}(w)\phi^2 = 0, \tag{23}$$

where

$$\mathcal{A}(w) \equiv -\Psi + \alpha(1 - \mu - \eta), \tag{24}$$

$$\mathcal{B}(w) \equiv w^{\alpha\sigma}\Psi - w^{-\alpha\sigma}\Phi, \tag{25}$$

$$\mathcal{C}(w) \equiv \Phi - \alpha(1 - \mu - \eta). \tag{26}$$

3.1 Wages and Industry Share

Equation (23) implicitly defines w as a function of ϕ at an interior equilibrium. Appendix C shows that this function has nice properties such as uniqueness, continuity and monotonicity. Our rigorous analysis in Appendix C gives the following proposition:

Proposition 1 *For any $\phi \in [0, 1]$, a unique equilibrium exists. Furthermore,*
(i) the equilibrium wage w in N monotonically decreases in $\phi \in [0, 1)$, and $w \in [1, \bar{w}]$;
(ii) the number of firms decreases in N and increases in S with respect to ϕ.

Proposition 1 (i) suggests that the region with a more valuable resource (region N) always provides a higher wage than the other region (region S) for $\phi < 1$. The reason is as follows. Starting at a point when wages are equalized and the markets of all manufacturing varieties are completely segmented so that $w = 1$ and $\phi = 0$. Then the prices of all varieties are identical across regions. Given identical market size, manufacturing activities will be evenly distributed across regions and this sector in each region requires the same amount of labor input. However, by assumption, A_N is more valuable than A_S, so the demand for A_N is higher. As a result, region N uses more labor in the extraction of resources (A_N) relative to region S. It follows that the total labor demand is higher in N than in S, which puts upward pressure on w and eventually results in $w > 1$ for $\phi = 0$.

On the other hand, the total number n^T of firms is determined endogenously. Although the relationship between n^T and ϕ is non-monotone, (ii) of Proposition 1 implies that the manufacturing sector shrinks in N and expands in S. Let

$$\overline{\theta} \equiv \frac{1}{1 + \bar{w}^{\alpha - 1}} \in [1/2, 1), \tag{27}$$

$$\underline{\theta} \equiv \frac{1 - 2\hat{\mu}}{2\alpha(1 - \mu - \eta)} \in (0, \frac{1}{2}). \tag{28}$$

Then we have:

Corollary 1 *The firm share θ in N monotonically decreases in ϕ and $\theta \in [\underline{\theta}, \overline{\theta}]$.*

In other words, when the manufacturing markets in the two regions become more integrated, some firms in N will move to S to save wage payment. This process continues which decreases w, until finally wages are equalized across regions when transportation in manufacturing is completely free at $\phi = 1$.

Note that region N's firm share depends on the parameter α. If $\alpha = 1$, resource goods are not used in manufacturing, and we find that N's maximum share is $\overline{\theta} = 1/2$. In this case, region N has fewer firms than region S for any $\phi > 0$ according to Corollary 1. This is a typical *Dutch disease in terms of industry shares.*

To see the logic, we again imagine the initial state of $w = 1$ and $\phi = 0$. As aforementioned, the manufacturing sector is initially evenly distributed and the labor demand is higher in N than in S, which tends to increase w. A higher wage increases the demand in the region because of the income effect, while it decreases the demand by raising the manufacturing price. If $\alpha = 1$, the two opposing effects completely cancel out since the manufacturing price ratio (p_{NN}/p_{SS}) is just equal to the income ratio (w) from (10). Therefore if $\alpha = 1$, we have $\theta = 1/2$ for $\phi = 0$, and $\theta < 1/2$ for any $\phi > 0$, resulting in the Dutch disease in terms of industry shares.

In contrast, when $\alpha < 1$, the resource goods are also used in manufacturing production, in addition to direct consumption. Then we have $\overline{\theta} > 1/2$, and the Dutch disease may not occur in terms of industry shares. This arises because firms facing a higher wage will substitute natural resource goods for labor to save on costs, and this can prevent some firms from immediately moving out to region S after opening to interregional trade. Thus, the aforementioned two opposing effects (i.e., the income and price effects) do not cancel out even when $\phi = 0$. Specifically, the income ratio (w) is higher than the manufacturing price ratio $p_{NN}/p_{SS} = w^{\alpha}$ from (10). That is, the positive effect of a higher income on θ dominates the negative effect of a higher manufacturing price. As a result, more firms are located in N, as long as ϕ is not too large.

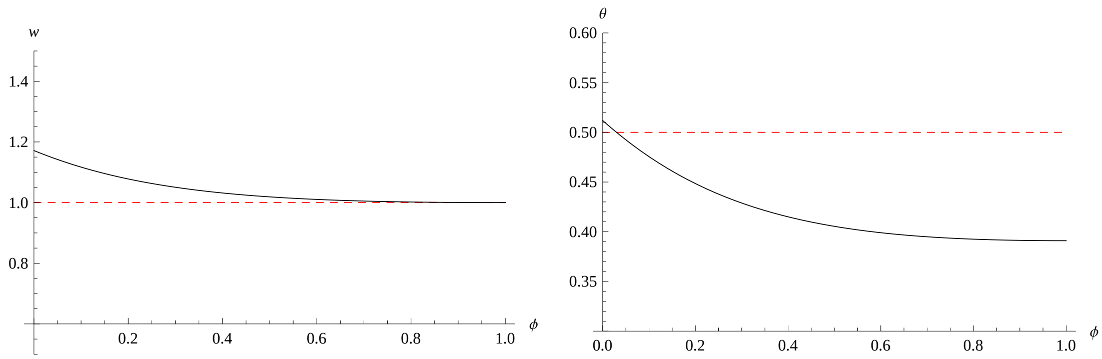
But notice that if ϕ becomes very large (e.g., approaching 1), then regardless of the value of α, both the wage w and firm share θ approach their minimum values, 1 and $\underline{\theta} \in (0, 1/2)$. In this case, we still obtain the *Dutch disease* in terms of industry shares.

In summary, industrial location is determined based on the balance of two effects: the *production-cost effect* and the *market-access effect*. When ϕ is large (transport cost being small), advantageous resources *drive out* manufacturing firms since the former effect (i.e, higher labor costs) dominates the latter one. On the other hand, when ϕ is small, advantageous resources can *attract* firms due to the reverse dominance.[6]

The above conclusions can be viewed from the solid lines of Figures 1, which illustrates a simulation example of $\sigma = 4$, $\mu = 0.32$, $\eta = 0.3$, $\alpha = 0.7$, $\beta = 0.2$, $\gamma = 0.1$, $L/f = 50$. Our assumptions (1), (5) and (6) hold in this setting. Panels (a) and (b) show how the nominal wage w and the firm share in region N depend on the trade freeness ϕ, respectively. They confirm Proposition 1 and Corollary 1: When trade freeness increases, both the wage w and the firm share θ decrease. While the wage curve converges to $w = 1$, the firm share curve cuts through the line of $\theta = 1/2$ in an early stage of ϕ, straightforwardly leading to the Dutch disease in terms of industry shares.

Some regional governments have recognized the importance of inputting resource goods in manufacturing production. For example, Yunnan of China is known for its forest resource. The local government succeeded in attracting Sinar Mas Group to develop the local paper pulp industry since 2002. Such a policy can lessen the Dutch disease and revitalize the regional economy according to our theoretical result.

[6]Here, the market-access effect refers to the effect arising from the transport cost of manufacturing goods, since both resource goods A_N and A_S are freely transported.



(a) Wage w (b) Firm share θ

Figure 1: Wage and firm share in region N

3.2 Resource Booms

In this subsection we consider the effects of resource booms, i.e, a certain resource suddenly becoming more important or fashionable so that it occupies a higher expenditure share. Specifically, the following four types are examined:

(i) A boom in N's resource good as a final good,
(ii) A boom in S's resource good as a final good,
(iii) A boom in N's resource good as an intermediate good,
(iv) A boom in S's resource good as an intermediate good.

We model the above types by increasing μ, η, β, and γ, respectively. Note that those cases cannot be divided absolutely. For example, in Case (i), an increase of μ mainly implies a larger consumption of A_N as a final good. However, it also leads to a smaller consumption of manufacturing goods, decreasing the input of A_N as an intermediate good. For the same reason, because of $\alpha + \beta + \gamma = 1$, a change in β (resp. γ) may alter both γ (resp. β) and α. For simplicity, we fix γ when β changes and fix β when γ changes, while α adjusts to satisfy $\alpha + \beta + \gamma = 1$. In other words, the resource good that experiences a boom substitutes for labor in production if it is used as intermediate goods. Since the resource good is produced by local labor only, a boom of type (iii) (resp. (iv)) does not change the labor input of N (resp. S) in the manufacturing production but results in less labor of S (resp. N) working in the manufacturing sector.

We first examine how a boom impacts on the local wage rate. Since the labor in S is chosen as the numéraire, we cannot explicitly observe any effect on the wage in S. We therefore focus on the wage rate w in N, taking a decrease of wage w in N as a (relative) increase of wage in S. As mentioned before, a resource-good boom as a final good is accompanied by its decrease as an input in the manufacturing production, and a boom of resource good as an intermediate good implies a less labor input. Nevertheless, Proposition 2 concludes that a boom of Cases (i) and (iii) increases w while a boom of Case (ii) decreases w.

Secondly, we examine the impact of resource boom on firm share. To gain analytical tractability, we employ three representative values: θ at $\phi = 0$ (i.e., $\overline{\theta}$), θ at $\phi = 1$ (i.e., $\underline{\theta}$), and $\hat{\phi}$ satisfying $\theta(\hat{\phi}) = 1/2$. Proposition 2 summarizes the comparative static results.

Proposition 2 *(Resource Booms). For $\phi \in (0, 1]$, equilibrium wage w increases in Cases (i), (iii), and decreases in Case (ii). Furthermore, we have*

$$\text{Case (i):} \quad \frac{\partial \overline{\theta}}{\partial \mu} > 0, \ \frac{\partial \underline{\theta}}{\partial \mu} < 0, \ \frac{\partial \hat{\phi}}{\partial \mu} < 0,$$

$$\text{Case (ii):} \quad \frac{\partial \overline{\theta}}{\partial \eta} < 0, \ \frac{\partial \underline{\theta}}{\partial \eta} > 0, \ \frac{\partial \hat{\phi}}{\partial \eta} > 0,$$

$$\text{Case (iii):} \quad \frac{\partial \overline{\theta}}{\partial \beta} > 0, \ \frac{\partial \underline{\theta}}{\partial \beta} < 0,$$

$$\text{Case (iv):} \quad \frac{\partial \underline{\theta}}{\partial \gamma} > 0, \ \frac{\partial \hat{\phi}}{\partial \gamma} > 0.$$

Meanwhile, $\partial\hat{\phi}/\partial\beta < 0$ and $\partial\bar{\theta}/\partial\gamma < 0$ if the relative resource advantage in N is small, $\partial\hat{\phi}/\partial\beta > 0$ and $\partial\bar{\theta}/\partial\gamma > 0$ if the relative resource advantage in N is large.

The proof is relegated to Appendix D. We now interprete this proposition in detail. Cases (i) and (ii) give the impacts of the *resource booms in final goods*, and show that the link between the resource sector and manufacturing sector for a closed region is different from the case of an open region. In Case (i), the resource boom in N increases the relative wage there. If ϕ is very small (as in a closed region), it attracts more firms since the market-size effect is dominant. On the other hand, if ϕ is large enough(as in a free-trade region), some firms will be driven out since the production-cost effect becomes dominant.[7] In addition, the results on $\hat{\phi}$ say that a boom in region N (resp. S) makes it more difficult (easier) to keep a larger firm share there. In other words, a boom in a resource that is consumed weakens the tendency for the region to have a more-than-proportionate share of manufacturing firms.

[7]Matsuyama (1992) also finds that the link between agriculture productivity and manufacturing is positive in a closed economy but negative in a small open economy. However, his mechanism is capital accumulation and natural resources are not involved in production in either sector.

Cases (iii) and (iv) examine the *resource booms in intermediate goods*. In Case (iii), the impacts on $\overline{\theta}$ and $\underline{\theta}$ are the same as in Case (i), where a rise in β raises the wage in N on one hand, but on the other hand it also leads both regions to use less labor in manufacturing, which tends to weaken the production-cost effect on firm location. If the relative resource advantage of N is small, then the wage differential becomes very small, and thus the production-cost effect of a rise in β can be ignored. In this situation, the impact of a larger β on $\hat{\phi}$ is similar to that of a larger μ. In contrast, if the relative resource advantage is large, the production-cost effect of a rise in β becomes significant. Then the resource boom in intermediate inputs strengthens the tendency for the region to have a more-than-proportionate share of manufacturing firms. Similarly, in Case (iv), the impacts on $\underline{\theta}$ and $\hat{\phi}$ are the same as in Case (ii). However, the effect of γ on $\overline{\theta}$ is ambiguous.

Differently from the clear results of wage impact in Cases (i)-(iii), the result for case (iv) is ambiguous. As mentioned before, a higher γ decreases the input of labor in the manufacturing sector in both N and S. The labor cost of N is w, which is larger than the labor cost of S and the price of N_S (both of them are 1). Attracted by the larger market and lower production costs, more firms move to region N. As a result, a larger γ may increase w. Figure 2 plots a simulation result of w with parameters $\beta = 0.2, \sigma = 1.2, \mu = 0.3, \eta = 0.1, \sigma = 2$. When γ increases from 0.1 to 0.26, the equilibrium wage changes from the solid line to the dashed line. We can visually observe that the solid line is higher for a small ϕ but lower for a large ϕ.

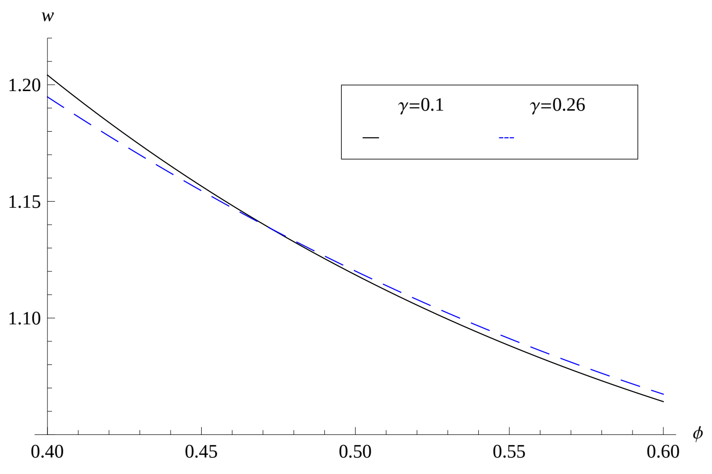


Figure 2: The impact on wage of γ

In summary, the effects of resource booms on industrial location depend on how resources are used as well as the trade freeness of the manufacturing sector. In particular, a resource boom in intermediate goods may strengthen the tendency for the region to have a more-than-proportionate share of manufacturing firms, while a resource boom in final goods must weaken this tendency but increases the local wage ratio. The results suggest the importance of developing industries that can effectively utilize resource goods in production rather than in consumption only.

4 Welfare

In the previous section, it has been shown that the nominal wage is higher in N while the share of firms is lower in N if ϕ is large. Let us now turn to the welfare analysis, i.e., the real wages, which can be expressed as follows:

$$\omega_N = \omega_N(\phi) \equiv w \cdot P_N^{-(1-\mu-\eta)} \left(p_N^A\right)^{-\mu} \left(p_S^A\right)^{-\eta}, \tag{29}$$

$$\omega_S = \omega_S(\phi) \equiv 1 \cdot P_S^{-(1-\mu-\eta)} \left(p_N^A\right)^{-\mu} \left(p_S^A\right)^{-\eta}. \tag{30}$$

Proposition 1 shows firms move from N to S when transport cost decreases, so the firm number decreases in N but increases in S. In this process, the nominal income in N also decreases. Do these imply a decrease in N's welfare and an increase in S's welfare? The answer is not necessarily, because a lower transport cost benefits both regions when they trade with each other. Precise calculations derive the following result:

Proposition 3 *(i) Region S's welfare ω_S increases in ϕ if $\sigma > 1 + \mu - \eta$.*
(ii) For region N, $\omega_N'(1) > 0$ always holds while $\omega_N'(0) < 0$ when σ is large enough.

The proof is given in Lemmas 2 and 3 of Appendix E. This proposition says that when σ is large enough, lowering transport costs unambiguously increases the welfare in S but decreases that in N for a small ϕ.[8] Intuitively, when ϕ is small, more firms are located in region N. As transport cost falls (raising ϕ), firms move out to S which decreases the price of A_N (equal to w). This causes a welfare loss in N and a welfare gain in S. On the other hand, lower transport costs enable cheaper imports, resulting in a welfare gain for region N. But this gain is small when ϕ is small because more than half of the firms are located in N (who do not trade with each other). In particular, when the substitute elasticity σ is large, the merit of cheaper imported goods is negligible. Thus, when ϕ is small, an increase in it reduces N's welfare.

[8] We can show that $\omega_S'(1) > 0$ and $\omega_S'(0) > 0$ for any σ.

However, region N's gain described above increases in ϕ since firms move to regions S and more varieties are imported from region S to region N. In fact, the welfare gain dominates the welfare loss when $\phi = 1$: $\omega_N'(1) > 0$. Indeed, we can show that $\partial w/\partial\phi = 0$ at $\phi = 1$ (see Lemma 1 of Appendix E). As a result, region N benefits from the free trade policy when the trade costs are already small.

The above proposition also shows that the welfare in region S monotonically increases in ϕ if $\sigma > 1.5$, since $1 + \mu - \eta < 1.5$ holds by (6). Many empirical studies (e.g., Hanson, 2005; Crozet, 2004; Brakman *et al.*, 2006) estimating the value of σ support the assumption of $\sigma > 1.5$, and it is thus reasonable to believe that ω_S monotonically increases in ϕ.[9] On the other hand, this monotone property does not hold for the welfare in N for a general σ. As we show later in a numerical simulation, $\omega_N'(0) < 0$ for $\sigma = 4$.

Meanwhile the welfare ratio in the two regions can be calculated as

$$q(\phi) \equiv \frac{\omega_S(\phi)}{\omega_N(\phi)} = \frac{1}{w}\left(\frac{P_N}{P_S}\right)^{1-\mu-\eta} = \frac{1}{w}\left[\frac{\theta\phi w^{\alpha(1-\sigma)} + 1 - \theta}{\theta w^{\alpha(1-\sigma)} + (1-\theta)\phi}\right]^{\frac{1-\mu-\eta}{\sigma-1}}, \tag{31}$$

where $w = w(\phi)$ is the equilibrium nominal wage and $\theta = \theta(\phi)$ is the equilibrium firm share, both depending on ϕ.

When the manufacturing transport costs are infinitely large, the welfare in region N must be higher than in S, since N has a higher income and a higher share of firms. In fact, from (27), (31), $w(0) = \bar{w} > 1$ and $\theta(0) = \overline{\theta}$, we have

$$q(0) = \bar{w}^{-1+(\alpha\sigma-1)\frac{1-\mu-\eta}{\sigma-1}} < 1, \tag{32}$$

where the inequality holds from $\alpha < 1$. Fixing $\bar{w}$, the relative resource advantage in N, (32) increases in α. When more resource goods as used as intermediate inputs, α decreases, increasing the relative welfare in N that has the relative resource advantage if ϕ is small.

On the other hand, there is no difference in the welfare levels in the two regions when manufacturing goods are transported freely. Precisely, $q(1) = 1$ since $w(1) = 1$ and $P_N = P_S$ hold at $\phi = 1$. Therefore, although the real wage in region S with a resource disadvantage must be lower than in region N when ϕ is sufficiently low, the difference disappears if $\phi = 1$. Furthermore, we can show that ω_S becomes higher than ω_N for a

[9] In the case of $\sigma < 1+\mu-\eta$, the monotone property is not true and there is another type of conflict of interest via economic integration. According to our numerical simulation, if $\sigma = 1.1$, $\mu = 0.375$, $\eta = 0.02$, $\alpha = 0.7$, $\beta = 0.2$, $\gamma = 0.1$, ω_S decreases while ω_N increases for a $\phi \in (0.79, 0.96)$.

large $\phi \neq 1$. These results are summarized in the following proposition:

Proposition 4 *The following results hold:*
(i) $\omega_S/\omega_N < 1$ *at* $\phi = 0$*;*
(ii) $\omega_S/\omega_N > 1$ *for a sufficiently large* $\phi \neq 1$*;*
(iii) $\omega_S/\omega_N = 1$ *at* $\phi = 1$*.*

Proof: (i) has already been proved in the previous context and (iii) is evident.
(ii). From (13) and (14), we have

$$\frac{(1-\phi^2)L}{\theta\phi w^{\alpha(1-\sigma)} + 1 - \theta} = \frac{\sigma f n^T}{1-\mu-\eta}\Big[p_{SS} - \frac{p_{NN}\phi}{w^{\alpha(1-\sigma)}}\Big],$$
$$\frac{(1-\phi^2)L}{\theta w^{\alpha(1-\sigma)} + (1-\theta)\phi} = \frac{\sigma f n^T}{(1-\mu-\eta)w}\Big[\frac{p_{NN}}{w^{\alpha(1-\sigma)}} - \phi p_{SS}\Big].$$

Then, (31) can be rewritten as

$$q(\phi) = \frac{1}{w}\left(\frac{w^{\alpha\sigma} - \phi}{w - w^{1+\alpha\sigma}\phi}\right)^{\frac{1-\mu-\eta}{\sigma-1}},$$

where w is the equilibrium wage determined by (23). Lemma 5 in Appendix E shows that $q'(1) < 0$. Therefore there exists a $\phi^\sharp \in (0,1)$ such that $q(\phi) > q(1) = 1$ for all $\phi \in (\phi^\sharp, 1)$.
■

Proposition 4 (i) suggests that although the price index can be higher in N when ϕ is small,[10] a higher income makes the residents there better off than those in S. In contrast, Proposition 4 (ii) shows that the opposite is true for a large ϕ ($\neq 1$ though), because more firms choose to locate in S, which makes the price index there lower than in N, and thus the income differential $w - 1$ becomes sufficiently small as shown by Proposition 1. This is a typical *Dutch disease in terms of welfare.*

We plot Figure 3 by a numerical example to confirm Propositions 3 and 4. The parameters are the same as in Figure 1. We see that the welfare in region S increases in ϕ while that in region N decreases first and then increases. The welfare level is higher in N than in S for a low ϕ but then turns to be lower for a high ϕ. This contrast can explain an interesting phenomenon in Young (2000), who reports that in the 1980s and early 1990s many local governments in rural China even imposed barriers against interregional trade within China, hoping to increase local welfare and reduce the income gap with

[10]In fact, if $\phi = 0$, we have $P_N/P_S = \bar{w}^{\frac{\alpha\sigma-1}{\sigma-1}}$, which is larger than one when $\alpha > 1/\sigma$.

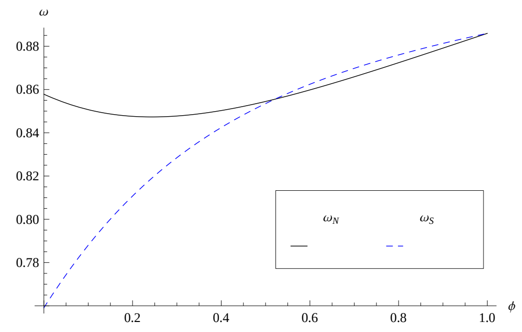


Figure 3: Welfare in two regions

more advanced regions. However, such protective local policies were almost completely abolished voluntarily entering this century, in favor of free trade and even free migration of labor. This aim of such policies is to attract more manufacturing industries.

5 Generalizations of the Model

So far our results are based on the assumptions of costless transportation of the resource goods and immobility of labor. Although these assumptions simplify our analysis and help to derive clear cut results, transportation of resource goods is not free in the real world and workers are often mobile across regions. This section generalizes the model by lifting these two restrictions.

5.1 Costly Transportation of Resource Goods

Denote the iceberg transport cost of the resource goods by τ_A. Incorporating it into the basic model of Section 2, the market-clearing conditions for M in N and S become respectively

$$\frac{(w^{\alpha}\tau_a^{\gamma-\beta})^{1-\sigma}(1-\mu-\eta)}{p_{NN}n^T}\left[\frac{E_N}{\theta(w^{\alpha}\tau_a^{\gamma-\beta})^{1-\sigma}+(1-\theta)\phi}+\frac{\phi E_S}{\theta\phi(w^{\alpha}\tau_a^{\gamma-\beta})^{1-\sigma}+1-\theta}\right]=\sigma f,$$
$$\frac{1-\mu-\eta}{p_{SS}n^T}\left[\frac{E_S}{\theta\phi(w^{\alpha}\tau_a^{\gamma-\beta})^{1-\sigma}+1-\theta}+\frac{\phi E_N}{\theta(w^{\alpha}\tau_a^{\gamma-\beta})^{1-\sigma}+(1-\theta)\phi}\right]=\sigma f,$$

and the market-clearing conditions for the resource goods are

$$\mu\Big(\frac{E_N+E_S}{w}\Big)+\theta n^T f\sigma\Gamma\beta w^{-\gamma}\tau_a^{\gamma}+(1-\theta)n^T f\sigma\Gamma\beta w^{\beta-1}\tau_a^{\beta}=L-\theta n^T f\sigma\Gamma\alpha w^{-\gamma}\tau_a^{\gamma},$$

$$\eta(E_N + E_S) + \theta n^T f\sigma\Gamma\gamma w^{1-\gamma}\tau_a^{\gamma} + (1-\theta)n^T f\sigma\Gamma\gamma w^{\beta}\tau_a^{\beta} = L - (1-\theta)n^T f\sigma\Gamma\alpha w^{\beta}\tau_a^{\beta}.$$

Using the above, further derivations give the firm share and the total number of firms:

$$\begin{aligned}
\theta &= \frac{\Phi}{\Phi + w^{\alpha}\Psi\tau_a^{\gamma-\beta}}, \\
n^T &= \frac{Lw^{-\alpha-\beta}\tau_a^{-\gamma}}{\sigma f\alpha\Gamma}(\Phi + w^{\alpha}\Psi\tau_a^{\gamma-\beta}).
\end{aligned}$$

The price indices in two regions become

$$\begin{aligned}
P_N =& \left\{ \frac{L}{\sigma f\alpha\Gamma^{\sigma}} \left[w^{-(\alpha+\beta)\sigma}\tau_a^{-\gamma\sigma}\Phi + w^{-\beta\sigma}\tau_a^{-\beta\sigma}\Psi\phi \right] \right\}^{\frac{1}{1-\sigma}}, \\
P_S =& \left\{ \frac{L}{\sigma f\alpha\Gamma^{\sigma}} \left[w^{-(\alpha+\beta)\sigma}\tau_a^{-\gamma\sigma}\Phi\phi + w^{-\beta\sigma}\tau_a^{-\beta\sigma}\Psi \right] \right\}^{\frac{1}{1-\sigma}}.
\end{aligned}$$

The wage $w(\phi)$ is again implicitly determined by a wage equation $\mathcal{F}_a(w,\phi) = \mathcal{A}(w) + \mathcal{B}_a(w)\phi + \mathcal{C}(w)\phi^2 = 0$, similar to (23), where

$$\mathcal{B}_a(w) = w^{\alpha\sigma}\Psi\tau_a^{(\gamma-\beta)\sigma} - w^{-\alpha\sigma}\Phi\tau_a^{(\beta-\gamma)\sigma}.$$

Finally, the welfare in the two regions can be rewritten as

$$\begin{aligned}
\omega_N =& \left\{ \frac{L}{\sigma f\alpha\Gamma^{\sigma}} \left[\frac{\Phi}{w^{1-\frac{\hat{\eta}\sigma-\eta}{1-\mu-\eta}}\tau_a^{\gamma\sigma+\frac{\eta(\sigma-1)}{1-\mu-\eta}}} + \frac{\Psi\phi}{w^{1-\frac{(1-\hat{\mu})\sigma-\eta}{1-\mu-\eta}}\tau_a^{\beta\sigma+\frac{\eta(\sigma-1)}{1-\mu-\eta}}} \right] \right\}^{\frac{1-\mu-\eta}{\sigma-1}}, \\
\omega_S =& \left\{ \frac{L}{\sigma f\alpha\Gamma^{\sigma}} \left[\frac{\Phi\phi}{w^{(\alpha+\beta)\sigma+\frac{\mu(\sigma-1)}{1-\mu-\eta}}\tau_a^{\gamma\sigma+\frac{\mu(\sigma-1)}{1-\mu-\eta}}} + \frac{\Psi}{w^{\beta\sigma+\frac{\mu(\sigma-1)}{1-\mu-\eta}}\tau_a^{\beta\sigma+\frac{\mu(\sigma-1)}{1-\mu-\eta}}} \right] \right\}^{\frac{1-\mu-\eta}{\sigma-1}}.
\end{aligned}$$

Although $\mathcal{F}_a(w,\phi) = 0$ is generally not solvable, it is easy to derive

$$\begin{aligned}
& w(0) = \bar{w} > 1, \quad w(1) = \tau_a^{\frac{\beta-\gamma}{\alpha}}, \\
& \theta(0) = \frac{1}{1 + \bar{w}^{\alpha-1}\tau_a^{\gamma-\beta}}, \\
& \theta(1) = \max\{\min\{\theta^0(1), 1\}, 0\},
\end{aligned} \tag{33}$$

where

$$\theta^0(1) = \left. \frac{\Phi}{\Phi + \Psi} \right|_{w=w(1)} = \frac{1 - \hat{\mu}(1 + \tau_a^{\frac{\gamma-\beta}{\alpha}})}{(1 - \hat{\mu} - \hat{\eta})(1 + \tau_a^{\frac{\gamma-\beta}{\alpha}})}. \tag{34}$$

A corner equilibrium may arise in this case. Indeed, we have

$$\lim_{\tau_a \to \infty} \theta^0(1) = \begin{cases} \frac{1-\hat{\mu}}{1-\hat{\mu}-\hat{\eta}} > 1, & \text{if } \beta > \gamma \\ -\frac{\hat{\mu}}{1-\hat{\mu}-\hat{\eta}} < 0, & \text{if } \beta < \gamma, \end{cases}$$

so firms agglomerate in either N or S if $\beta \neq \gamma$ and τ_a is sufficiently large.

Denote the trade freeness of resource goods by $\phi_a = \tau_a^{1-\sigma}$. From (33) and (34), we obtain counterpart results of Proposition 1 and Corollary 1:

Proposition 5 *Assume that $\phi = 1$. Then, if $\beta > \gamma$ (resp. $\beta < \gamma$),*
(i) the equilibrium wage w in N monotonically decreases (resp. increases) in $\phi_a \in (0, 1]$, and $w \in [1, \infty)$ (resp. $w \in (0, 1]$);
(ii) the firm share θ in N monotonically decreases (resp. increases) in ϕ_a and $\theta \in [\underline{\theta}, 1)$ (resp. $\theta \in (0, \underline{\theta}]$) at the interior equilibrium.

This implies that, when manufactured goods are freely transported but resource goods are costly transported, the wage is higher (resp. lower) in N than in S if $\beta > \gamma$ (resp. $\beta < \gamma$). Intuitively, firms find it more profitable to locate in the region producing the resource good used more in manufacturing. It follows that making more or better use of one's resource good in manufacturing can attract more firms to locate in the region. Furthermore, a larger τ_a (i.e., a smaller ϕ_a) strengthens this tendency.

In the special case with $\phi = 1$, we also have a simple result on the relative welfare. From (29), (30), and (33), we have

$$\frac{\omega_S}{\omega_N} = \tau_a^{-\mu+\eta+\frac{\gamma-\beta}{\alpha}},$$

because $P_N = P_S$ holds. Thus, we obtain counterpart results of Proposition 4:

Proposition 6 *Assume that $\phi = 1$. Then,*

$$\textit{(i)} \quad \frac{\omega_S}{\omega_N} \leq 1 \textit{ and } \frac{\partial}{\partial \phi_a} \frac{\omega_S}{\omega_N} > 0 \textit{ if } \mu - \eta > \frac{\gamma - \beta}{\alpha};$$

$$\textit{(ii)} \quad \frac{\omega_S}{\omega_N} \geq 1 \textit{ and } \frac{\partial}{\partial \phi_a} \frac{\omega_S}{\omega_N} < 0 \textit{ if } \mu - \eta < \frac{\gamma - \beta}{\alpha}.$$

Note that the case of (i) holds when $\beta \geq \gamma$. This is because

$$\begin{aligned} \mu - \eta + \frac{\beta - \gamma}{\alpha} &> -(\beta - \gamma)(1 - \mu - \eta) + \frac{\beta - \gamma}{\alpha} \\ &= (\beta - \gamma)\left[\frac{1}{\alpha} - (1 - \mu - \eta)\right] \geq 0, \end{aligned}$$

where the first inequality is from our assumption (6).

We can use numerical examples to illustrate the case with general values of ϕ and ϕ_a. In Panel (a) of Figure 4, the parameters are the same as in Figure 1 except for ϕ_a. One sees that the Dutch disease in terms of industry shares arises in a wide range of trade freeness and it disappears when either ϕ or ϕ_a is small. This is because the rich-resource country has a larger market which is important if ϕ is small, while it produces a better supply access when $\beta > \gamma$ which is important if ϕ_a is small. In contrast, the Dutch disease in terms of welfare occurs in a limited range of trade freeness in which both ϕ and ϕ_a are large. Specifically, when ϕ_a is less than 0.9 (i.e., τ_a is larger than 1.04) or ϕ is less than 0.5 (i.e., τ is larger than 1.26), the Dutch disease in terms of welfare disappears.

It is noteworthy that $\beta > \gamma$ holds in Panel (a) of Figure 4. As stated in Propositions 5 and 6, the results are quite different if $\beta < \gamma$. Panel (b) draws another example with $\beta = 0.08$ and other parameters are the same as in Panel (a). In this case, it holds that $\beta < \gamma$ and $\mu - \eta < (\gamma - \beta)/\alpha$. Panel (b) confirms Propositions 5 and 6 and shows that both types of the Dutch disease arises in a very wide range of trade freeness. Panels (a) and (b) suggest that a boom in N's resource good as an intermediate good dramatically changes the firm share and the relative welfare. More specifically, such a resource boom tends to eliminate both types of the Dutch disease, especially in terms of welfare.

Finally, in Panel (c) of Figure 4, $\mu = 0.45$ and other parameters are the same as in Panel (b). In this case, it holds that $\beta < \gamma$ and $\mu - \eta > (\gamma - \beta)/\alpha$. By a comparison of Panels (b) and (c), we can see the effect of a boom in N's resource good as a final good. Such a resource boom significantly shrinks the area of the Dutch disease in terms of welfare, as in the change from Panel (b) to Panel (a). However, the Dutch disease in terms of industry shares occurs in almost all the area of trade freeness as in Panel (b). This shows that it is difficult to avoid the Dutch disease in terms of industry shares if the resource good is not used as an intermediate good for manufacturing.

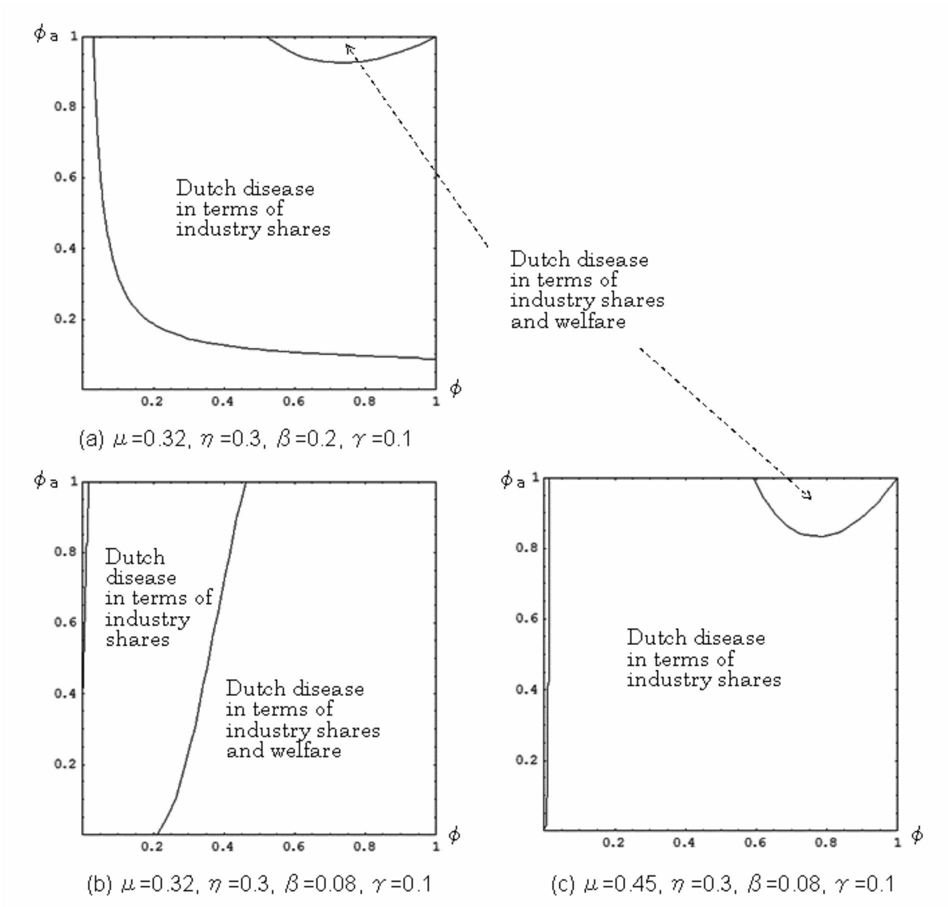


Figure 4: Simulations for general trade costs

5.2 Labor Migration

Next we allow labor to move across regions, applying the footloose entrepreneur (FE) model à la Forslid and Ottaviano (2003) and adding heterogeneous resource goods. We find that the qualitative results obtained so far remain valid. Specifically, we introduce immobile unskilled labor and mobile skilled labor. Both regions have the same amount of unskilled labor L while there are K units of skilled labor in the whole country. Each firm has the following cost structure: a fixed cost of one unit of skilled labor and a marginal cost of $(\sigma - 1)/\sigma$ units of a composite good, which is produced by the Cobb-Douglas technology defined by the RHS of (4). In this case, $n^T = K$, and the total output of a firm in N and S is respectively,

$$x_N = \frac{\sigma R_N}{\Gamma w^{\alpha+\beta}}, \quad x_S = \frac{\sigma R_S}{\Gamma w^{\beta}}, \tag{35}$$

where R_k is the wage of skilled labor in region k.

Then the market-clearing conditions for M in N and S are respectively

$$\frac{w^{\alpha(1-\sigma)}(1-\mu-\eta)}{p_{NN}K}\left[\frac{E_N}{\theta w^{\alpha(1-\sigma)}+(1-\theta)\phi}+\frac{\phi E_S}{\theta\phi w^{\alpha(1-\sigma)}+1-\theta}\right]=\frac{\sigma R_N}{\Gamma w^{\alpha+\beta}}, \tag{36}$$

$$\frac{1-\mu-\eta}{p_{SS}K}\left[\frac{E_S}{\theta\phi w^{\alpha(1-\sigma)}+1-\theta}+\frac{\phi E_N}{\theta w^{\alpha(1-\sigma)}+(1-\theta)\phi}\right]=\frac{\sigma R_S}{\Gamma w^{\beta}}, \tag{37}$$

where

$$E_N=\theta K R_N+Lw, \quad E_S=(1-\theta)KR_S+L. \tag{38}$$

Note that only (36) (resp. (37)) is true if all firms locate in N (resp. S). Meanwhile, the market-clearing conditions for the resource goods are

$$\begin{aligned}
&\mu\Big(\frac{E_N+E_S}{w}\Big)+\theta K x_N\Gamma\beta w^{-\gamma}\frac{\sigma-1}{\sigma}+(1-\theta)Kx_S\Gamma\beta w^{\beta-1}\frac{\sigma-1}{\sigma}\\
&\qquad=L-\theta K x_N\Gamma\alpha w^{-\gamma}\frac{\sigma-1}{\sigma},\\
&\eta(E_N+E_S)+\theta K x_N\Gamma\gamma w^{1-\gamma}\frac{\sigma-1}{\sigma}+(1-\theta)Kx_S\Gamma\gamma w^{\beta}\frac{\sigma-1}{\sigma}\\
&\qquad=L-(1-\theta)Kx_S\Gamma\alpha w^{\beta}\frac{\sigma-1}{\sigma}.
\end{aligned}$$

From these two equations, (35), and (38), we obtain

$$\begin{aligned}
R_N&=\frac{L}{K}\frac{(\sigma-1)[(1-\hat{\mu})w-\hat{\mu}]-\mu+\eta w}{\theta\alpha(\sigma-1)(\sigma-1+\mu+\eta)},\\
R_S&=\frac{L}{K}\frac{(\sigma-1)[(1-\hat{\eta})-\hat{\eta}w]+\mu-\eta w}{(1-\theta)\alpha(\sigma-1)(\sigma-1+\mu+\eta)}.
\end{aligned}$$

Substituting the above two equations into (36) or (37), we have an equation implicitly identifying the equilibrium between w and θ for a given ϕ.

Finally, the real wages of skilled and unskilled labor in region k can be expressed as follows:

$$\begin{aligned}
\omega_k^{\text{skill}}&=R_k\cdot P_k^{-(1-\mu-\eta)}\left(p_N^A\right)^{-\mu}\left(p_S^A\right)^{-\eta},\\
\omega_k^{\text{unskill}}&=w_k\cdot P_k^{-(1-\mu-\eta)}\left(p_N^A\right)^{-\mu}\left(p_S^A\right)^{-\eta}.
\end{aligned}$$

We assume the following standard replicator dynamics for skilled labor migration:

$$\frac{d\theta}{dt} = (\omega_N^{\text{skill}} - \omega_S^{\text{skill}})\theta(1-\theta).$$

It is well-known that the FE model exhibits a bifurcation of equilibrium. Panel (a) in Figure 5 illustrates a simulation example of the equilibrium firm share in N when the two regions are symmetric. Parameters are $\sigma = 2$, $\mu = \eta = 0.25$, $\beta = \gamma = 0.15$, $L = K = 1000$. The solid (resp. dotted) lines correspond to stable (resp. unstable) equilibria. However, different from Forslid and Ottaviano (2003), we obtain re-dispersion of firms when ϕ is sufficiently large since the unskilled-labor wage in the core region is higher, which forms a strong dispersion force when ϕ is large.

Panel (b) shows an asymmetric case with parameters $\sigma = 2$, $\mu = 0.3$, $\eta = 0.2$, $\alpha = 0.7$, $\beta = 0.2$, $\gamma = 0.1$, $L = K = 1000$. More than one half of firms locate in N when ϕ is sufficiently small. And as in the basic model, lifting trade barriers drives firms to relocate to the region with resource disadvantage. However, different from the immobile-labor case, here multiple equilibria are possible and full agglomeration in N is another stable equilibrium for $\phi \in (0.24, 0.40)$. Nevertheless, agglomeration is more unlikely to occur in N than in S.

Excluding the corner solution of full agglomeration in N, panels (c) and (d) depict the equilibrium wage in N and the welfare in both regions, respectively. Panel (c) shows that w becomes lower (resp. higher) when firms relocate to S (resp. N). Panel (d) shows a similar relationship for welfare and ϕ as in Figure 3 of the immobile-labor case. In other words, $\omega_N^{\text{unskill}} > \omega_S^{\text{unskill}}$ holds when ϕ is smaller than a threshold; otherwise, the reverse holds. In summary, we still obtain the Dutch disease in terms of both industry shares and welfare when transportation costs fall in the mobile-labor case.

6 Conclusion

This paper has examined how resource development affects industrialization in cities. We find two key factors in determining whether a resource is a blessing or it may cause a Dutch disease. One is the transport cost of manufacturing goods as in standard NEG models, and the other is whether resource goods are used as intermediate inputs in manufacturing production or simply consumed. The latter finding is novel in the literature.

Specifically, we find that if the resource goods are only consumed as final goods, then the region with a resource advantage has fewer industries than the other region,

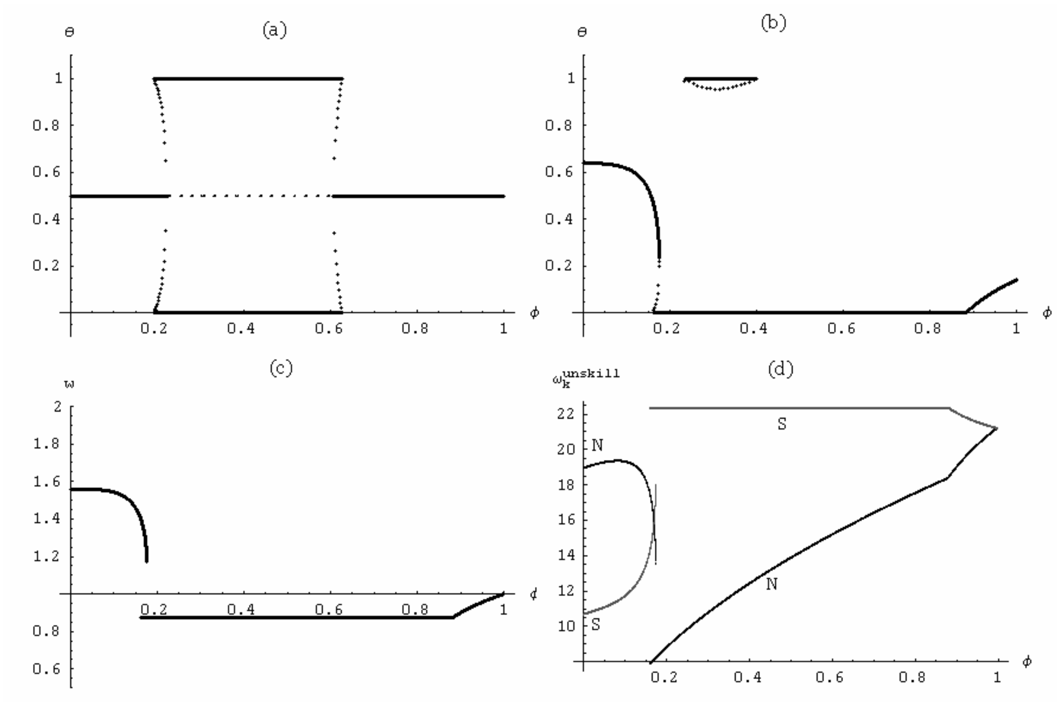


Figure 5: A simulation example of mobile-labor case

leading to a Dutch disease in industry shares. In contrast, if the resource goods are also used as inputs in manufacturing, then the Dutch disease is mitigated because firms can substitute resources for labor when wages are high, resulting in more firms being located in the region with a resource advantage when transport costs are not too low. In practice, resources can be used as inputs to build vertically and horizontally related industries and develop new technology, which are essential in attracting workers, markets and eventually sustain city development. For the same reason, a resource boom in intermediate goods can strengthen the tendency for this region to have a more-than-proportionate share of firms, while a resource boom in final goods will weaken the tendency. This is especially significant when the resource goods are costly transported. These predictions seem to match the experiences of many resource-based cities in China.

In addition, our welfare analysis reveals that the region with a resource advantage offers a higher welfare than the other region when transport costs are high but the opposite occurs when transport costs are sufficiently low. In other words, the Dutch disease in terms of welfare may arise. Furthermore, since firms will move to the region with a lower production cost, welfare in the region with resource advantages may decrease absolutely while that in the region with resource disadvantages increases. These results remain qualitatively valid even when we allow labor to move across regions and assume positive transport costs for the resource goods.

Our model discloses a conflict of interests when transport costs fall, and also explain why many regions and areas with resource disadvantages have adopted various pro-trade or even free trade policies for decades, such as Hong Kong, Singapore, etc.

Appendix A. The Implicit Wage Function

This appendix shows that the wage function

$$w(\phi): \ [0,1] \to [1, \bar{w}], \tag{1}$$

implicitly defined by $\mathcal{F}(w, \phi) = 0$ (see (23)), is well defined and continuous, where $\bar{w}$ is given by (8).

Recall that $\mathcal{F}(w, \phi)$ and its partial derivative with respect to w are written as

$$\begin{aligned}
&\mathcal{F}(w, \phi) = \mathcal{A}(w) + \mathcal{B}(w)\phi + \mathcal{C}(w)\phi^2, \\
&\frac{\partial \mathcal{F}(w, \phi)}{\partial w} = \mathcal{A}'(w) + \mathcal{B}'(w)\phi + \mathcal{C}'(w)\phi^2,
\end{aligned}$$

where $\mathcal{A}(w)$, $\mathcal{B}(w)$, and $\mathcal{C}(w)$ are defined in (24), (25) and (26), respectively.

Lemma 1 *Equations*

$$\mathcal{F}(w, \phi) = 0, \qquad \frac{\partial \mathcal{F}(w, \phi)}{\partial w} = 0$$

do not have a solution in $(w, \phi) \in [1, \bar{w}] \times [0, 1]$.

Proof: On the contrary, assuming that (w_0, ϕ_0) is such a solution, then

$$\begin{aligned}
\phi_0 =& \frac{\mathcal{A}'(w_0)\mathcal{C}(w_0) - \mathcal{A}(w_0)\mathcal{C}'(w_0)}{\mathcal{B}(w_0)\mathcal{C}'(w_0) - \mathcal{B}'(w_0)\mathcal{C}(w_0)}, \\
0 =& \mathcal{A}'(w_0)\mathcal{F}(w_0, \phi_0) - \mathcal{A}(w_0)\frac{\partial \mathcal{F}(w_0, \phi_0)}{\partial w} \\
=& \frac{\mathcal{A}(w_0)\mathcal{C}'(w_0) - \mathcal{A}'(w_0)\mathcal{C}(w_0)}{(\mathcal{B}(w_0)\mathcal{C}'(w_0) - \mathcal{B}'(w_0)\mathcal{C}(w_0))^2}\Big\{[\mathcal{A}(w_0)\mathcal{C}'(w_0) - \mathcal{A}'(w_0)\mathcal{C}(w_0)]^2 \\
&+ [\mathcal{A}'(w_0)\mathcal{B}(w_0) - \mathcal{A}(w_0)\mathcal{B}'(w_0)][\mathcal{B}(w_0)\mathcal{C}'(w_0) - \mathcal{B}'(w_0)\mathcal{C}(w_0)]\Big\}.
\end{aligned} \tag{2}$$

Since $w_0 \in [1, \bar{w}]$ holds, we have

$$\mathcal{A}'(w_0)\mathcal{C}(w_0) - \mathcal{A}(w_0)\mathcal{C}'(w_0) = \alpha(1-\mu-\eta)(\hat{\mu}-\hat{\eta}) > 0,$$

and

$$\begin{aligned}
&\mathcal{A}'(w_0)\mathcal{B}(w_0) - \mathcal{B}'(w_0)\mathcal{A}(w_0)\\
&\qquad=\alpha\sigma w_0^{-1-\alpha\sigma}(\hat{\mu}-w_0\hat{\eta})^2(w_0^{2\alpha\sigma}-1)\\
&\qquad\quad+\alpha(1-\mu-\eta)w_0^{-\alpha\sigma}\{(2\alpha\sigma-1)(\hat{\mu}-w_0\hat{\eta})\\
&\qquad\quad+[(1-\alpha\sigma)\hat{\eta}w_0+\alpha\sigma\hat{\mu}](w_0^{2\alpha\sigma-1}-1)\}\\
&\qquad\geq 0,
\end{aligned} \tag{3}$$

where the last inequality is from (5) and $w_0 \geq 1$.

For ϕ_0 to be in $[0, 1]$, it is necessary that $\mathcal{B}(w_0)\mathcal{C}'(w_0)-\mathcal{B}'(w_0)\mathcal{C}(w_0) > 0$, which ensures

$$\begin{aligned}
&[\mathcal{A}(w_0)\mathcal{C}'(w_0) - \mathcal{A}'(w_0)\mathcal{C}(w_0)]^2\\
&+[\mathcal{A}'(w_0)\mathcal{B}(w_0) - \mathcal{A}(w_0)\mathcal{B}'(w_0)][\mathcal{B}(w_0)\mathcal{C}'(w_0) - \mathcal{B}'(w_0)\mathcal{C}(w_0)] > 0
\end{aligned}$$

according to (3). Then we find that (2) cannot be equal to zero. Therefore, solution (w_0, ϕ_0) does not exist. ■

Lemma 2 *(i) Equation $\mathcal{F}(\bar{w}, \phi) = 0$ has only one solution $\phi = 0$;*
(ii) Equation $\mathcal{F}(1, \phi) = 0$ has only one solution $\phi = 1$.

Proof: (i) Since $\mathcal{A}(\bar{w}) = 0$, we have $\mathcal{F}(\bar{w}, \phi) = \phi[\mathcal{C}(\bar{w})\phi + \mathcal{B}(\bar{w})]$. Furthermore, $\bar{w} > 1$ holds so that

$$\begin{aligned}
&\mathcal{C}(\bar{w}) = \alpha(1-\eta-\mu)(\bar{w}-1) > 0,\\
&\mathcal{B}(\bar{w}) = \alpha(1-\mu-\eta)\bar{w}^{1-\alpha\sigma}(\bar{w}^{2\alpha\sigma-1}-1) \geq 0,
\end{aligned}$$

where the second inequality holds from (5). Therefore, $\phi = 0$ is the only solution of $\mathcal{F}(\bar{w}, \phi) = 0$.

(ii) Similarly, we have

$$\mathcal{F}(1, \phi) = (\hat{\eta} - \hat{\mu})(1-\phi)^2.$$

Using assumption (6), $\phi = 1$ is the only solution of $\mathcal{F}(1, \phi) = 0$. ■

Lemma 3 *Function $w(\phi)$ of (1) is well defined and continuous in* $[0,1]$.

Proof: Since $\mathcal{F}(w,\phi)$ is continuously differentiable, the implicit function theorem and Lemma 1 ensures that function $w(\phi)$ is well defined and continuous in $[0,1]$ if the range is $[1,\bar{w}]$. On the other hand, Lemma 2 says that curve $w(\phi)$ crosses the box $[0,1]\times[1,\bar{w}]$ only at $(0,\bar{w})$ and $(1,1)$, so the range of $w(\phi)$ is indeed $[1,\bar{w}]$. ■

Appendix B: Nonexistence of Corner Equilibria

Lemma 1 *There is no corner equilibrium of either $\theta = 1$ or $\theta = 0$.*

Proof: If there exists a corner equilibrium of $\theta = 1$, then (18) and (19) imply

$$w = \frac{1-\hat{\eta}}{\hat{\eta}} > \bar{w} > 1, \tag{1}$$

where the first inequality is from (6). Meanwhile, (13) and (14) are replaced by

$$\frac{1-\mu-\eta}{p_{NN}n^T}(E_S+E_N) = \sigma f, \quad \frac{1-\mu-\eta}{w^{\alpha(1-\sigma)}p_{SS}n^T}\left(\frac{E_N}{\phi}+\phi E_S\right) \leq \sigma f,$$

where the inequality arises because no firm is located in S. From these and (2), (10), we have

$$\frac{1}{\phi}+\phi w \leq w^{-\alpha\sigma}(1+w) \leq w^{-\frac{1}{2}}(1+w), \tag{2}$$

where the last inequality is from (5) and (1). However, (2) contradicts with the following fact:

$$\frac{1}{\phi}+\phi w - \frac{1+w}{\sqrt{w}} \geq 2\sqrt{w} - \frac{1+w}{\sqrt{w}} > 0,$$

where the inequality is from (1) again. Thus, there is no corner equilibrium of $\theta = 1$.

If there exists a corner equilibrium of $\theta = 0$, then (18) and (19) imply

$$w = w^{\dagger} \equiv \frac{\hat{\mu}}{1-\hat{\mu}} < 1, \tag{3}$$

where the inequality is from (6). Meanwhile, (13) and (14) are replaced by

$$\frac{w^{(\sigma-1)\alpha}(1-\mu-\eta)}{p_{NN}n^T}\left(\frac{E_N}{\phi}+\phi E_S\right) \leq \sigma f, \quad \frac{1-\mu-\eta}{p_{SS}n^T}(E_S+E_N) = \sigma f,$$

where the inequality arises because no firm is located in N. From these and (2), (10), we have

$$(w^\dagger)^{-\alpha\sigma}\Big(\frac{w^\dagger}{\phi}+\phi\Big)\leq 1+w^\dagger.$$

The above inequality contradicts the following facts:

$$(w^\dagger)^{-\alpha\sigma}\Big(\frac{w^\dagger}{\phi}+\phi\Big)\geq (w^\dagger)^{-\frac{1}{2}}\Big(\frac{w^\dagger}{\phi}+\phi\Big)\geq 2(w^\dagger)^{-\frac{1}{2}}(w^\dagger)^{\frac{1}{2}}=2>1+w\dagger.$$

Therefore, there is no corner equilibrium of $\theta=0$. ■

Appendix C: Proof of Proposition 1

Lemma 1 *For $\phi\in[0,1)$, we have*

$$\frac{\partial\mathcal{F}(w,\phi)}{\partial\phi}>0. \tag{1}$$

Proof: According to Lemmas 2 (ii) and 3, $w(\phi)\in(1,\bar{w}]$ for $\phi\in[0,1)$. We have

$$\begin{aligned}&w\Psi-\Phi=(1+w)(\hat{\mu}-\hat{\eta}w)>0,\\&\mathcal{B}(w)=w^{\alpha\sigma-1}(w\Psi-\Phi)+w^{-\alpha\sigma}(w^{2\alpha\sigma-1}-1)\Phi>0,\end{aligned}$$

where the second inequality is from (5). If $w\in[\frac{1-\hat{\eta}}{1-\hat{\mu}},\frac{\hat{\mu}}{\hat{\eta}}]$, then $\mathcal{C}$ is nonnegative so that (1) is true. If $w\in(1,\frac{1-\hat{\eta}}{1-\hat{\mu}})$, then

$$\begin{aligned}\frac{\partial\mathcal{F}(w,\phi)}{\partial\phi}=&\mathcal{B}(w)+2\mathcal{C}(w)\phi\geq\mathcal{B}(w)+2\mathcal{C}(w)\\=&w^{\alpha\sigma}(\Psi-w^{1-2\alpha\sigma}\frac{\Phi}{w})+2[\Phi-(1-\hat{\mu}-\hat{\eta})]\\\geq&w^{\alpha\sigma}(\Psi-\frac{\Phi}{w})+2[w(1-\hat{\mu})-(1-\hat{\eta})]\\=&w^{\alpha\sigma}(1+w)(\frac{\hat{\mu}}{w}-\hat{\eta})+2[w(1-\hat{\mu})-(1-\hat{\eta})]\\\geq&2[\frac{\hat{\mu}}{w}+w(1-\hat{\mu})-1]\\=&\frac{2}{w}[(1-\hat{\mu})(w-1)^2+(1-2\hat{\mu})(w-1)]>0,\end{aligned}$$

where the first inequality is due to a negative $\mathcal{C}(w)$, the second inequality stems from (5), and the last inequality is from (6). ■

Lemma 2 *Function* $w(\phi)$ *decreases in* $[0, 1)$.

Proof: According to Lemma 1, $\partial\mathcal{F}(w(\phi), \phi)/\partial w \neq 0$ for all $\phi \in [0, 1)$. The implicit function theorem gives

$$w'(\phi) = -\frac{\dfrac{\partial\mathcal{F}(w(\phi), \phi)}{\partial\phi}}{\dfrac{\partial\mathcal{F}(w(\phi), \phi)}{\partial w}}. \tag{2}$$

According to Lemma 1, (2) does not change sign in $[0, 1)$. On the other hand,

$$\frac{\partial\mathcal{F}(\bar{w}, 0)}{\partial w} = \hat{\eta} > 0,$$

so (2) is negative at $\phi = 0$ according to Lemma 1. Therefore, (2) is negative for all $\phi \in [0, 1)$. ■

The monotonicity obtained in Lemma 2 implies that $w \in [1, \bar{w}]$ holds for any ϕ. Rewrite (20) as

$$\theta(w) \equiv \frac{\Phi(w)}{\Phi(w) + w^{\alpha}\Psi(w)}. \tag{3}$$

Since $\Psi(w) > 0$ and $\Phi(w) > 0$ hold for all $w \in [1, \bar{w}]$, we immediately know $\theta(w) \in (0, 1)$, which implies that an interior equilibrium with $w = w(\phi)$ exists for any $\phi \in [0, 1]$.

Lemma 3 *The number of firms decreases in* N *and increases in* S *with respect to* $\phi \in [0, 1]$.

Proof: The numbers of firms in the two regions are determined by (22). Then the Lemma follows from:

$$\begin{aligned}\frac{d}{dw}\frac{\Psi}{w^{\beta}} &= -\frac{\beta(1-\hat{\eta}) + (1-\beta)\hat{\eta}w}{w^{1+\beta}} < 0, \\ \frac{d}{dw}\frac{\Phi}{w^{\alpha+\beta}} &= \frac{w\gamma(1-\hat{\mu}) + (1-\gamma)\hat{\mu}}{w^{2-\gamma}} > 0.\end{aligned}$$

■

From (3), we know that $\theta = \overline{\theta}$ (resp. $\theta = \underline{\theta}$) at $\phi = 0$ (resp. $\phi = 1$), where $\overline{\theta}$ and $\underline{\theta}$ are defined by (27) and (28). Thus, Proposition 1 is obtained from Lemmas 3, 2 and 3.

Appendix D. Proof of Proposition 2

Lemma 1 *At equilibrium, the following inequalities hold:*

$$1-(1+\frac{1}{w})w^{\alpha\sigma}\phi+\frac{1}{w}\phi^2>0, \tag{1}$$

$$1-(1+w)w^{-\alpha\sigma}\phi+w\phi^2>0. \tag{2}$$

Proof: If $\phi=0$, then the left-hand sides of (1) and (2) are 1 so both inequalities hold trivially. If $\phi\neq 0$, then the LHS of (1) is

$$\begin{aligned}
&1-w^{\alpha\sigma}\phi+\frac{1}{w}\phi(\phi-w^{\alpha\sigma})\\
&\quad=(1-\phi^2)\frac{1-\mu-\eta}{\sigma f n^T\Gamma w^\beta}\left[\frac{E_S}{\theta\phi w^{\alpha(1-\sigma)}+1-\theta}-\frac{\phi}{w}\frac{E_N}{\theta w^{\alpha(1-\sigma)}+(1-\theta)\phi}\right]\\
&\quad=L(1-\phi^2)\frac{1-\mu-\eta}{\sigma f n^T\Gamma w^\beta}\left[\frac{1}{\theta\phi w^{\alpha(1-\sigma)}+1-\theta}-\frac{1}{\frac{\theta}{\phi}w^{\alpha(1-\sigma)}+1-\theta}\right]\\
&\quad>0,
\end{aligned}$$

where the first equality is from (15) and (16), while the second equality is from (2). Similarly, the LHS of (2) is

$$\begin{aligned}
&w^{-\alpha\sigma}[(w^{\alpha\sigma}-\phi)-w\phi(1-w^{\alpha\sigma}\phi)]\\
&\quad=Lw^{1-\alpha\sigma}(1-\phi^2)\frac{1-\mu-\eta}{\sigma f n^T\Gamma w^\beta}\left[\frac{1}{\theta w^{\alpha(1-\sigma)}+(1-\theta)\phi}-\frac{1}{\theta w^{\alpha(1-\sigma)}+\frac{1-\theta}{\phi}}\right]\\
&\quad>0,
\end{aligned}$$

■

We now prove Proposition 2. First, we show the results on w. Since ϕ is fixed while μ, η and β are variable, we rewrite the wage equation (23) as $\mathcal{F}(w,\mu,\eta,\beta)\equiv\mathcal{A}(w,\mu,\eta,\beta)+\mathcal{B}(w,\mu,\eta,\beta)\phi+\mathcal{C}(w,\mu,\eta,\beta)\phi^2=0$. Their partial derivatives are given by

$$\begin{aligned}
\frac{\partial\mathcal{A}}{\partial\mu}&=-(1+w)\gamma-\alpha,\\
\frac{\partial\mathcal{A}}{\partial\eta}&=(1+w)(1-\gamma)-\alpha,\\
\frac{\partial\mathcal{B}}{\partial\mu}&=w^{\alpha\sigma}(1+w)\gamma+w^{-\alpha\sigma}(1+w)(1-\beta),
\end{aligned}$$

$$
\begin{aligned}
\frac{\partial \mathcal{B}}{\partial \eta} &= -w^{\alpha\sigma}(1+w)(1-\gamma) - w^{-\alpha\sigma}(1+w)\beta, \\
\frac{\partial \mathcal{C}}{\partial \mu} &= -(1+w)(1-\beta) + \alpha, \\
\frac{\partial \mathcal{C}}{\partial \eta} &= \alpha + \beta + w\beta, \\
\frac{\partial \mathcal{A}}{\partial \beta} &= -(1-\mu-\eta), \\
\frac{\partial \mathcal{B}}{\partial \beta} &= -\sigma w^{\alpha\sigma}\Psi \ln w - \sigma w^{-\alpha\sigma}\Phi \ln w + w^{-\alpha\sigma}(1+w)(1-\mu-\eta), \\
\frac{\partial \mathcal{C}}{\partial \beta} &= -(1-\mu-\eta)w.
\end{aligned}
$$

Therefore, we obtain

$$
\begin{aligned}
\frac{\partial \mathcal{F}}{\partial \mu} =& - w\gamma[1-(1+\frac{1}{w})w^{\alpha\sigma}\phi + \frac{1}{w}\phi^2] - (1-\beta)[1-(1+w)w^{-\alpha\sigma}\phi + w\phi^2] \leq 0, \\
\frac{\partial \mathcal{F}}{\partial \eta} =& w(1-\gamma)[1-(1+\frac{1}{w})w^{\alpha\sigma}\phi + \frac{1}{w}\phi^2] + \beta[1-(1+w)w^{-\alpha\sigma}\phi + w\phi^2] \geq 0, \\
\frac{\partial \mathcal{F}}{\partial \beta} =& - (1-\mu-\eta)[1-(1+w)w^{-\alpha\sigma}\phi + w\phi^2] - [\sigma w^{\alpha\sigma}\Psi \ln w + \sigma w^{-\alpha\sigma}\Phi \ln w]\phi \\
\leq& - (1-\mu-\eta)[1-(1+w)w^{-\alpha\sigma}\phi + w\phi^2] \leq 0,
\end{aligned}
$$

where the first, the second and the last inequalities are from (1) and (2), while the third inequality is from the fact of $w \geq 1$. Meanwhile, the proof of Proposition 1 gives inequality $\partial\mathcal{F}/\partial w > 0$ at equilibrium, we have

$$
\frac{\partial w}{\partial \mu} = -\frac{\frac{\partial \mathcal{F}}{\partial \mu}}{\frac{\partial \mathcal{F}}{\partial w}} \geq 0, \quad \frac{\partial w}{\partial \eta} = -\frac{\frac{\partial \mathcal{F}}{\partial \eta}}{\frac{\partial \mathcal{F}}{\partial w}} \leq 0, \quad \frac{\partial w}{\partial \beta} = -\frac{\frac{\partial \mathcal{F}}{\partial \beta}}{\frac{\partial \mathcal{F}}{\partial w}} \geq 0.
$$

Then we turn to the second part of Proposition 2 about the firm share. From (8) and (27), we have

$$
\begin{aligned}
\frac{\partial \bar{\theta}}{\partial \mu} &= \frac{(1-\alpha)\bar{w}^{\alpha-2}}{(1+\bar{w}^{\alpha-1})^2} \, \frac{\gamma + \alpha\eta}{\hat{\eta}^2} > 0, \\
\frac{\partial \bar{\theta}}{\partial \eta} &= -\frac{(1-\alpha)\bar{w}^{\alpha-2}}{(1+\bar{w}^{\alpha-1})^2} \, \frac{\beta + \alpha\mu}{\hat{\eta}^2} < 0, \\
\frac{\partial \bar{\theta}}{\partial \beta} &= \frac{\bar{w}^{\alpha-1}}{(1+\bar{w}^{\alpha-1})^2} \left[\frac{(\beta+\gamma)(1-\mu-\eta)}{\hat{\mu}} + \log \bar{w} \right] > 0,
\end{aligned} \tag{3}
$$

$$\frac{\partial \overline{\theta}}{\partial \gamma} = -\frac{\bar{w}^{\alpha-1}}{(1+\bar{w}^{\alpha-1})^2}\left[\frac{(\beta+\gamma)(1-\mu-\eta)}{\hat{\eta}} - \log \bar{w}\right], \tag{4}$$

where the inequality of (3) is from (8). If the relative resource advantage in N is small, then $\hat{\mu} \approx \hat{\eta}$ and $\bar{w} \approx 1$ so that (4) is negative. To the contrary, if the relative resource advantage in N is large, then $\bar{w}$ is also large so that (4) is positive.

Second, from (28), we have

$$\begin{aligned}
\frac{\partial \underline{\theta}}{\partial \mu} &= -\frac{1-2\eta}{2\alpha(1-\mu-\eta)^2} < 0, \\
\frac{\partial \underline{\theta}}{\partial \eta} &= \frac{1-2\mu}{2\alpha(1-\mu-\eta)^2} > 0, \\
\frac{\partial \underline{\theta}}{\partial \beta} &= -\frac{1-2\hat{\eta}}{2\alpha^2(1-\mu-\eta)} < 0, \\
\frac{\partial \underline{\theta}}{\partial \gamma} &= \frac{1-2\hat{\mu}}{2\alpha^2(1-\mu-\eta)} > 0,
\end{aligned}$$

where the positiveness of each numerator is from (6).

Finally, we examine the effects of resource booms on $\hat{\phi}$. Since w is a decreasing function of ϕ, we need only to check $\hat{w} = w(\hat{\phi})$ at which $\theta = 1/2$.

Using (20) and $\alpha = 1-\beta-\gamma$, we can rewrite $\theta = 1/2$ as

$$0 = \mathcal{D}(w, \beta, \gamma, \mu, \eta) \equiv (1-\hat{\mu})w^{\beta+\gamma} - \hat{\mu}w^{-\alpha} + \hat{\eta}w - (1-\hat{\eta}). \tag{5}$$

In other words, $\hat{w}$ is implicitly given by $\mathcal{D}(w, \beta, \gamma, \mu, \eta) = 0$.

The partial derivatives of $\mathcal{D}$ are calculated as follows.

$$\begin{aligned}
\frac{\partial \mathcal{D}}{\partial w} &= (\beta+\gamma)(1-\hat{\mu})w^{-\alpha} + \alpha\hat{\mu}w^{-1-\alpha} + \hat{\eta} > 0, \\
\frac{\partial \mathcal{D}}{\partial \beta} &= w^{-\alpha}\{[w-(1+w)\hat{\mu}]\log w - (1-\mu-\eta)(1+w)\}, \\
\frac{\partial \mathcal{D}}{\partial \gamma} &= w^{-\alpha}[(1-\hat{\mu})w - \hat{\mu}]\log w + (1-\mu-\eta)(1+w) > 0, \\
\frac{\partial \mathcal{D}}{\partial \mu} &= -[(1-\beta)w^{-\alpha} + \gamma](1+w) < 0, \\
\frac{\partial \mathcal{D}}{\partial \eta} &= (1+w)(1-\gamma+\gamma w^{-\alpha}).
\end{aligned} \tag{6}$$

Then

$$\frac{\partial \hat{w}}{\partial \gamma} = -\frac{\dfrac{\partial \mathcal{D}}{\partial \gamma}}{\dfrac{\partial \mathcal{D}}{\partial w}} < 0, \quad \frac{\partial \hat{w}}{\partial \mu} = -\frac{\dfrac{\partial \mathcal{D}}{\partial \mu}}{\dfrac{\partial \mathcal{D}}{\partial w}} > 0, \quad \frac{\partial \hat{w}}{\partial \eta} = -\frac{\dfrac{\partial \mathcal{D}}{\partial \eta}}{\dfrac{\partial \mathcal{D}}{\partial w}} < 0.$$

Meanwhile, if the relative resource advantage in N is small, then the solution w of (5) is close to 1, so (6) is negative, and $\partial \hat{w}/\partial \beta > 0$. As an example, this occurs when $\mu = 0.2, \beta = 0.125, \eta = 0.19, \gamma = 0.12$. On the other hand, if the relative resource advantage in N is large, then (6) is positive and $\partial \hat{w}/\partial \beta < 0$. As an example, it arises when $\mu = 0.2, \beta = 0.125, \eta = 0.01, \gamma = 0.01$. ■

Appendix E. Proofs for Propositions 3 and 4

Lemma 1 *The first-order and the second-order derivatives of* $w(\phi)$ *at* $\phi = 1$ *are*

$$w'(1) = 0, \tag{1}$$

$$w''(1) = \frac{\hat{\mu} - \hat{\eta}}{\alpha^2(1 - \mu - \eta)\sigma} > 0. \tag{2}$$

Proof: From Lemma 1 and

$$\left.\frac{\partial \mathcal{F}(w(\phi), \phi)}{\partial \phi}\right|_{\phi=1} = \mathcal{B}(1) + 2\mathcal{C}(1) = 0,$$

we obtain

$$w'(1) = 0.$$

The second-order total differential of $\mathcal{F}(w, \phi)$ with respect to ϕ should be zero:

$$\left[w'(\phi)\frac{\partial^2 \mathcal{F}(w, \phi)}{\partial w^2} + 2\frac{\partial^2 \mathcal{F}(w, \phi)}{\partial w \partial \phi}\right]w'(\phi) + \frac{\partial \mathcal{F}(w, \phi)}{\partial w}w''(\phi) + \frac{\partial^2 \mathcal{F}(w, \phi)}{\partial \phi^2} = 0.$$

Using (1), we have

$$w''(1) = -\frac{\dfrac{\partial^2 \mathcal{F}}{\partial \phi^2}}{\dfrac{\partial \mathcal{F}}{\partial w}} = \frac{\hat{\mu} - \hat{\eta}}{\alpha^2(1 - \mu - \eta)\sigma} > 0.$$

■

Lemma 2 *If $\sigma > 1+\mu-\eta$, then ω_S increases in ϕ.*

Proof: From (3), (11), (12) and (30), ω_S can be rewritten as

$$\omega_S = \left[\frac{L}{\sigma f \alpha \Gamma^{\sigma}} \mathcal{G}(w,\phi)\right]^{\frac{1-\mu-\eta}{\sigma-1}},$$

where

$$\mathcal{G}(w,\phi) = \frac{\Phi}{w^{(\alpha+\beta)\sigma+\frac{\mu(\sigma-1)}{1-\mu-\eta}}}\phi + \frac{\Psi}{w^{\beta\sigma+\frac{\mu(\sigma-1)}{1-\mu-\eta}}}.$$

If

$$\begin{aligned}\frac{\partial}{\partial w}\frac{\Phi}{w^{(\alpha+\beta)\sigma+\frac{\mu(\sigma-1)}{1-\mu-\eta}}} =& -\frac{1}{w^{1+(\alpha+\beta)\sigma+\frac{\mu(\sigma-1)}{1-\mu-\eta}}} \\ &\times\left\{-w(1-\hat{\mu}) + \left[(\alpha+\beta)\sigma + \frac{\mu(\sigma-1)}{1-\mu-\eta}\right]\Phi\right\} \\ <&0, \end{aligned} \tag{3}$$

then both terms of $\mathcal{G}(w,\phi)$ are decreasing functions of w, so ω_S increases in ϕ. If inequality (3) fails, then

$$\begin{aligned}\frac{d\mathcal{G}(w,\phi(w))}{dw} =&\phi\frac{d}{dw}\frac{\Phi}{w^{(\alpha+\beta)\sigma+\frac{\mu(\sigma-1)}{1-\mu-\eta}}} + \frac{\Phi\phi'(w)}{w^{(\alpha+\beta)\sigma+\frac{\mu(\sigma-1)}{1-\mu-\eta}}} + \frac{d}{dw}\frac{\Psi}{w^{\beta\sigma+\frac{\mu(\sigma-1)}{1-\mu-\eta}}} \\ \leq& -\frac{-w(1-\hat{\mu}) + [(\alpha+\beta)\sigma + \frac{\mu(\sigma-1)}{1-\mu-\eta}]\Phi}{w^{1+(\alpha+\beta)\sigma+\frac{\mu(\sigma-1)}{1-\mu-\eta}}} - \frac{\hat{\eta}w + [\beta\sigma + \frac{\mu(\sigma-1)}{1-\mu-\eta}]\Psi}{w^{1+\beta\sigma+\frac{\mu(\sigma-1)}{1-\mu-\eta}}} \\ \leq&\frac{w(1-\hat{\mu}) - [(\alpha+\beta)\sigma + \frac{\mu(\sigma-1)}{1-\mu-\eta}]\Phi - \hat{\eta}w - [\beta\sigma + \frac{\mu(\sigma-1)}{1-\mu-\eta}]\Psi}{w^{1+\beta\sigma+\frac{\mu(\sigma-1)}{1-\mu-\eta}}} \\ =& -\frac{\alpha}{w^{1+\beta\sigma+\frac{\mu(\sigma-1)}{1-\mu-\eta}}}[w(\sigma-1+\eta)-\mu] \\ <&0,\end{aligned}$$

where the first inequality is from $\phi'(w) \leq 0$ and the last inequality is from $w \geq 1$. ■

Lemma 3 *For region N, $\omega_n'(1) > 0$ always holds while $\omega_n'(0) < 0$ holds for a sufficiently large σ.*

Proof: From (3), (11), (12) and (29), ω_N can be written as

$$\omega_N = \left[\frac{L}{\sigma f \alpha \Gamma^\sigma}\mathcal{H}(w,\phi)\right]^{\frac{1-\mu-\eta}{\sigma-1}},$$

where

$$\mathcal{H}(w,\phi) = \frac{\Phi}{w^{1-\frac{\hat{\eta}\sigma-\eta}{1-\mu-\eta}}} + \frac{\Psi}{w^{1-\frac{(1-\hat{\mu})\sigma-\eta}{1-\mu-\eta}}}\phi.$$

Then $\omega_N'(1) > 0$ holds because

$$\left.\frac{d\mathcal{H}(w(\phi),\phi)}{d\phi}\right|_{\phi=1} = \left.\left[\frac{\Psi}{w^{1-\frac{(1-\hat{\mu})\sigma-\eta}{1-\mu-\eta}}} + \frac{\partial \mathcal{H}(w,\phi)}{\partial w}w'(1)\right]\right|_{\phi=1,w=1} = 1-2\hat{\eta} > 0,$$

where the last equality is from (1).

On the other hand, let

$$\mathcal{H}(w) \equiv \mathcal{H}(w,\phi(w)) = w^{\frac{\hat{\eta}\sigma-\eta}{1-\mu-\eta}-1}\Phi(w) + w^{\frac{(1-\hat{\mu})\sigma-\eta}{1-\mu-\eta}-1}\Psi(w)\phi(w).$$

Then we have

$$\omega_N' = \omega_N\frac{1-\mu-\eta}{\sigma-1}\frac{\mathcal{H}'(w)}{\mathcal{H}(w)}. \tag{4}$$

Meanwhile, the derivative of $\mathcal{H}(w)$ is given as

$$\begin{aligned}\mathcal{H}'(w) =& w^{\frac{\hat{\eta}\sigma-\eta}{1-\mu-\eta}-2}\left[\left(\frac{\hat{\eta}\sigma-\eta}{1-\mu-\eta}-1\right)\Phi(w) + w(1-\hat{\mu})\right] \\ &+ w^{\frac{(1-\hat{\mu})\sigma-\eta}{1-\mu-\eta}-2}\left\{\left[\frac{(1-\hat{\mu})\sigma-\eta}{1-\mu-\eta}-1\right]\Psi(w)\phi(w) - \hat{\mu}w\phi(w) + \Psi(w)\phi'(w)\right\}.\end{aligned}$$

Noting that

$$\begin{aligned}&\phi(\bar{w}) = 0, \\ &\phi'(\bar{w}) = -\left.\frac{\frac{\partial \mathcal{F}}{\partial w}}{\frac{\partial \mathcal{F}}{\partial \phi}}\right|_{\bar{w}} = -\frac{\mathcal{A}'(\bar{w})}{\mathcal{B}(\bar{w})} = \frac{\hat{\eta}}{\bar{w}^{\alpha\sigma}\Psi(\bar{w}) - \bar{w}^{-\alpha\sigma}\Phi(\bar{w})},\end{aligned}$$

we have

$$\mathcal{H}'(\bar{w}) = \bar{w}^{\frac{\sigma\hat{\eta}-\eta}{1-\mu-\eta}-2}\Big[\frac{\hat{\eta}\sigma-\eta}{1-\mu-\eta}\Phi(w)+\hat{\mu}+\frac{\hat{\eta}\Psi(\bar{w})}{\Psi(\bar{w})-\bar{w}^{-2\alpha\sigma}\Phi(\bar{w})}\Big].$$

$\mathcal{H}'(\bar{w}) > 0$ if the squared bracket is positive, which is true for a sufficiently large σ. Then conclusion (ii) holds from (4). ■

Lemma 4 *For any differentiable function $\mathcal{Z}(w,\phi)$ and $z(\phi) = \mathcal{Z}(w(\phi),\phi)$, we have*

$$z'(1) = \frac{\partial \mathcal{Z}(1,1)}{\partial \phi}, \tag{5}$$

$$z''(1) = \frac{\partial \mathcal{Z}(1,1)}{\partial w}w''(1) + \frac{\partial^2 \mathcal{Z}(1,1)}{\partial^2 \phi} \tag{6}$$

Proof: The first-order and the second-order differentials of $z(\phi)$ are calculated as

$$\begin{aligned} z'(\phi) =& \frac{\partial \mathcal{Z}(w,\phi)}{\partial w}w'(\phi) + \frac{\partial \mathcal{Z}(w,\phi)}{\partial \phi}, \\ z''(\phi) =& \Big[\frac{\partial^2 \mathcal{Z}(w,\phi)}{\partial w^2}w'(\phi) + 2\frac{\partial^2 \mathcal{Z}(w,\phi)}{\partial w \partial \phi}\Big]w'(\phi) \\ &+ \frac{\partial \mathcal{Z}(w,\phi)}{\partial w}w''(\phi) + \frac{\partial^2 \mathcal{Z}(w,\phi)}{\partial^2 \phi}. \end{aligned}$$

Then (5) and (6) are derived from (1). ■

Lemma 5 $q'(1) < 0$.

Proof: Let $\epsilon = (1-\mu-\eta)/(\sigma-1)$ and

$$Q(w,\phi) = \frac{1}{w}\left(\frac{w^{\alpha\sigma}-\phi}{w-w^{1+\alpha\sigma}\phi}\right)^{\epsilon},$$

where w and ϕ are independent variables. Then $q(\phi) = Q(w(\phi),\phi)$. The partial derivatives are

$$\frac{\partial Q(w,\phi)}{\partial w} = -\frac{Q(w,\phi)}{w} + \epsilon Q_1(w,\phi), \quad \frac{\partial Q(w,\phi)}{\partial \phi} = \epsilon Q(w,\phi)Q_2(w,\phi),$$

where

$$Q_1(w,\phi) = \frac{(2\sigma-1)w^{\alpha\sigma} + (1+w^{2\alpha\sigma})\phi - (1+\alpha\sigma)w^{\alpha\sigma}\phi^2}{(w^{\alpha\sigma}-\phi)(w-w^{1+\alpha\sigma}\phi)},$$

$$Q_2(w,\phi) = \frac{w^{2\alpha\sigma+1} - w}{(w^{\alpha\sigma} - \phi)(w - w^{1+\alpha\sigma}\phi)}.$$

Meanwhile, according to the L'Hopital's rule, (1) and (2) and Lemma 4, we have

$$\lim_{\phi\to 1} \frac{w^{\alpha\sigma} - \phi}{w - w^{1+\alpha\sigma}\phi} = \lim_{\phi\to 1} \frac{-1}{-w^{1+\alpha\sigma}} = 1,$$

$$\lim_{\phi\to 1} Q(w,\phi) = 1,$$

$$\lim_{\phi\to 1} Q_1(w,\phi) = -(1+\alpha\sigma),$$

$$\lim_{\phi\to 1} Q_2(w,\phi) = \alpha\sigma w''(1).$$

Therefore, from Lemma 4,

$$q'(1) = \frac{\partial Q(1,1)}{\partial w} w''(1) + \frac{\partial Q(1,1)}{\partial \phi} = (-1-\epsilon)w''(1) < 0.$$

■

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