Endogenous Technological Capability and Cumulative Causation

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Abstract

Industrialization may feature entry into high-tech sectors ('high-tech industrialization'), or expansion of low-tech manufacturing ('low-tech industrialization'). By endogenizing technological capability within a coordination failure framework, we uncover mechanisms that help explain the differences between these types of industrialization. The process of development is characterized through a sequence of take-offs. In the first instance, an 'industrial take-off' triggers industrialization. Subsequently, a 'technological take-off' activates investment in technological capability. If wages rise too steeply after crossing the industrial take-off, the economy misses a window of opportunity, and the technological take-off is bypassed. In this case, industrialization proceeds without entry into high-tech sectors, and the economy ends up with lower income than otherwise. Trade policy is found to be an effective instrument to trigger industrialization.

Keywords: Trade policy; Technological capability; Industrialization; Cumulative causation; Coordination failure.

JEL classification: F12, F13, L16, O14.

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1. Introduction

Two important classes of models used to study the process of economic development are economic growth and coordination failure models. Economic growth models analyze development by focussing on the time path of the economy. Coordination failure models characterize the process of development as a transition between a low-income equilibrium and a high-income equilibrium[1].

Within the economic growth framework, Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992), endogenized innovation at the level of the firm. Meanwhile, in the coordination failure literature such an extension has not been forthcoming, and the models remain based on exogenously determined technology. The main contribution of this paper with respect to the coordination failure literature is the introduction of endogenously determined technological capability, at the level of the firm. This is achieved by merging the models in Venables (1996) and Sutton (1991, ch. 3). The Sutton-Venables model brings forth a novel characterization of the industrialization process. As industrialization takes place, the economy needs to cross a sequence of take-offs in order to achieve a high-income equilibrium. Moreover, for the economy to cross these take-offs, certain conditions must be satisfied. Otherwise, some of the take-offs could be bypassed, and the industrialization process would be thwarted. In particular, we introduce an *industrial take-off* and a *technological take-off*. The industrial take-off activates an industrial expansion. Once this process has been triggered, the economy may (or may not) cross a second take-off point: technological take-off. If the economy crosses the technological take-off, it will achieve a rise in technological capability and a higher income level than would have been the case otherwise.

The notion of a sequence of take-offs is reminiscent of Rostow's 'stages of development' (Rostow, 1956, 1959). The key idea is that the economy crosses a series of phases in its development process. However, that is probably as far as the similarities run, as the workings of the economy and the phases themselves bear little resemblance to Rostow's original characterization[2]. More recently, Hausmann, Pritchett and Rodrik (2005), find that growth often occurs in

[1]The literature on economic growth is vast. Excellent reviews can be found in Aghion and Durlauf (2005). The coordination failure field is considerably smaller, and began with the works of Rosenstein-Rodan (1943) and Lewis (1954), with subsequent contributions by Okuno-Fujiwara (1988), Murphy, Shleifer and Vishny (1989), Matsuyama (1991, 1992), Rodriguez-Clare (1996), Rodrik (1996), Venables (1996) and Graham and Temple (2006). There are, of course, models of economic growth which also feature multiple equilibria and poverty traps (for example, Becker, Murphy and Tamura, 1990; Galor and Weil, 2000). Our interest lies with the coordination failure literature.

[2]This theory ignited a lively debate, many aspects of which remain active today. For detailed expositions, see the conference proceedings in Rostow (1963), in particular, the contributions of Kuznets (p. 22-43) and Solow (p. 468-474). For a recent perspective, see Graham and Temple (2006). Galor and Weil (2000) and Maddison (2006) take a long run perspective and explain important aspects of the past millenium. The focus here is considerably more modest, we focus on industrialization episodes occuring after the Industrial Revolution (late 18^{th} century).

spurts of limited duration. Our model goes towards providing theoretical foundations for this empirical regularity. In our framework, the growth spurts would be associated with the crossing of the take-offs.

Our point of departure is that not all industrialization processes are alike. For example, the industrialization processes followed by some North-East Asian economies (Japan, South Korea, and Taiwan) during the 20^{th} century differ markedly from those followed in most developing nations. Of course, this is not to say that Japan, South Korea, and Taiwan followed identical paths; and substantive differences between these economies must be acknowledged. Nonetheless, the notion of a sequence of take-offs can help us to uncover some of the mechanisms behind the industrial success of Japan, South Korea, and Taiwan, as opposed to other developing economies. The key observation is that the North-East Asian economies successfully entered into high-technology industries, whereas other, less successful industrializers were characterized, on average, by expansion of low-technology manufacturing. Firms like Samsung, Hyundai, Sony, and Toyota are evidence of North-East Asian entry into high-tech sectors. Why are there are so few such firms outside the OECD and North-East Asia? This is an issue worthy of attention, and we shall investigate its analytical underpinnings. For our purposes, the difference between 'high-tech' and 'low-tech' industries is that low-tech industries do not make extensive use of research and development (technological capability is, therefore, exogenous). Conversely, in high-tech industries firms spend resources on research and development, thereby endogenizing technological capability.

Within the coordination failure framework, Murphy, Shleifer and Vishny (1989) formalized Lewis' (1954) dual-economy analysis: there is a traditional sector with constant returns to scale and a modern sector which features increasing returns to scale. Initially, the economy produces only in the traditional sector. Due to a coordination failure, it is not profitable to enter the modern sector. If this coordination failure can be overcome (possibly by some central coordination mechanism), workers shift to the modern sector, their wages increase and demand for modern goods rises in parallel. Thus, a 'Big Push' of industrialization is achieved. Rodrik (1995, 1996) provides an interpretation of the East Asian Miracle based on coordination failures. He proposes that these economies had the required resources to operate at a high level of income, but were unable to do so because they were subject to a coordination failure. In Rodrik's view, East Asian governments coordinated a switch from a low-income equilibrium to a high-income equilibrium, and it was this transition which sparked growth. Notwithstanding its important contributions, the coordination failure literature does not consider the *type* of industry which is expanding. Is it low-tech manufacturing? Or is it high-tech? What are the implications? These are the central questions of this study.

2. The Model

The economy consists of three sectors. There are demand and cost linkages between two sectors, producing final and intermediate goods, respectively. In addition to these sectors, there is a residual (rest of the economy) sector, which is used to close the model. The intermediate goods industry is oligopolistic, and operates under increasing returns to scale. This industry uses labor to produce intermediate goods and to achieve a certain level of technological capability.[3] The final goods industry is perfectly competitive and exhibits constant returns to scale. It uses intermediate goods and labor to produce final output. The demand and cost linkages give rise to a pecuniary externality. On the one hand, an increase in final output benefits intermediate firms by raising demand for intermediate goods. On the other hand, an expansion in the intermediate industry leads to lower price/quality ratios for intermediate goods through either reduced concentration, or enhanced technological capability.

The model is closed by considering the labor market and the 'rest of the economy' sector. For simplicity, labor supply is assumed to be perfectly inelastic. Labor demand derives both from the intermediate and final goods sectors, as well as from the 'rest of the economy'. Labor productivity in the 'rest of the economy' is diminishing: as demand for labor from the other industries rises, less labor is used in the 'rest of the economy', its marginal productivity rises, and, since labor is perfectly mobile, wages increase for the whole economy. There is a fixed labor cost in the 'rest of the economy', and this ensures that this sector features zero profits.

Since we are modelling a small open economy, the rest of the world is taken to be exogenous. We assume that there is a sufficiently large wedge between the price of domestic intermediate goods and their international price, ruling out the possibility of exports. This simplifies matters by confining attention to the domestic market.

2.1. Final Goods Industry

This industry is perfectly competitive and features constant returns to scale. The production function for final goods is given by $Y = (L_y/\alpha)^{\alpha} \left[\sum_{i=1}^{N+1} x_i/(1-\alpha)\right]^{1-\alpha}$, where L_y is labor input, x_i is intermediate good i (produced solely by intermediate firm $i = 1, ..., N$), and α is the share of labor in costs ($0 \leqslant \alpha \leqslant 1$). Costs are given by $wL_y + \sum_{i=1}^{N} p_i x_i$, where w is the wage rate, and p_i is the price of intermediate good i.

The production technology implies that intermediate goods are perfect substitutes, so final goods producers choose the intermediate good with the lowest price/quality ratio and make all their planned purchases from the firm offering the chosen variety. This implies that in order to achieve positive market share, intermediate firms must have identical price/quality ratios:

[3] The notion of technological capability refers to the knowledge of workers within the firm (Sutton 2004, Tong 2005). The technological capability of a firm can also be used to represent the firm's product quality, and in this study the terms will be used interchangeably.

$p_i/u_i = \lambda$, for all i.

Solving the final goods producers' cost minimization problem yields the cost function, $C(w, p/u, Y) = w^{\alpha} p^{1-\alpha} Y$. Constant returns to scale and perfect competition imply zero profits at equilibrium, so average and marginal costs coincide with price. Whence, the price of final output (denoted by q) can be expressed as follows:

$$q = w^{\alpha} p^{1-\alpha}. \tag{1}$$

Along this schedule final goods producers minimize costs and earn zero profits. Equation (1) will be one of the conditions used to characterize the equilibrium of the economy. Throughout the analysis, q will be exogenously given, and $1 \leqslant q \leqslant w$ is assumed[4]. For a symmetric equilibrium, equation (1) allows us to express conditional factor demands in terms of final goods industry revenue (qY), in the following form:

$$L_y = \alpha \frac{qY}{w}, \tag{2}$$

$$X = (1-\alpha)\frac{qY}{p}. \tag{3}$$

This completes the description of the final goods industry.

2.2. Intermediate Goods Industry

Intermediate firms play a three-stage game. In the first stage the entry decision is made. In the second stage, firms incur fixed outlays to attain a certain technological capability (that is, product quality). In the third stage firms compete *à la* Cournot. In this stage, firms with higher technological capability enjoy a greater level of demand for a given price. We seek a Subgame Perfect Nash Equilibrium, and the game is solved by backward induction.

In the third stage, intermediate firms choose quantity (x_i) in order to maximize gross profits, $\pi_i = (p_i - wc)x_i$, taking rivals' quantities, technological capabilities, and market structure as given. The labor requirement for production of an extra unit of x_i is a constant (c). Intermediate firms offer a unique price/quality ratio, defined by $p_i/u_i = \lambda$ for all i. Intermediate industry revenue can then be written as $S = \sum_{j=1}^{N} p_j x_j = \lambda \sum_{j=1}^{N} u_j x_j$, from which $\lambda = S/\sum_{j=1}^{N} u_j x_j$. The third stage profit function for intermediate firms can be written as $\pi_i = (\lambda u_i - wc)\, x_i$. Differentiating with respect to x_i, we obtain the first order condition:

$$\lambda u_i + \frac{\partial \lambda}{\partial x_i} u_i x_i = wc. \tag{4}$$

[4]The usual practice of setting $q = 1$ will not be followed, since (exogenous) changes in q will be interpreted as trade policy for the final goods industry (section 4).

Routine calculations (shown in Appendix A) yield the following solutions for the final stage quantity, price and profit function:

$$x_i = \frac{S}{wc}\frac{N-1}{\sum_{j=1}^{N}\frac{u_i}{u_j}}\left(1-\frac{N-1}{\sum_{j=1}^{N}\frac{u_i}{u_j}}\right); \tag{5}$$

$$p_i = \lambda u_i = \frac{wc}{N-1}\sum_{j=1}^{N}\frac{u_i}{u_j};\text{ and} \tag{6}$$

$$\pi_i = S\left(1-\frac{N-1}{\sum_{j=1}^{N}\frac{u_i}{u_j}}\right)^2. \tag{7}$$

Quantity, price and profit are increasing in the firm's own technological capability, and decreasing in its rivals' technological capabilities[5]. Equation (6) will serve as the basis for one of the equilibrium conditions used to solve the model. If firms choose symmetric technological capabilities, setting $u_i = u_j$ yields $x = wc\,(N-1)\,/N^2$, $p = wcN/\,(N-1)$ and $\pi = S/N^2$, the usual results under Cournot competition. It is straightforward to see that quantity, price and profit are decreasing in the number of firms[6]. Moreover, total output of intermediate goods, given by Nx, is increasing in the number of firms.

In the second stage, firms choose u_i to maximize net profit: $\pi_i - F(u_i)$, where π_i is given in (7) and $F(u_i)$ denotes the fixed outlays function, $F(u_i) = w\varepsilon u_i^{\beta}$. ε is a minimum labor requirement for entry. The labor requirement to achieve technological capability level u_i is given by εu_i^{β}, a convex function of u_i ($\beta > 1$). We assume $u_i \geqslant 1$ and $\varepsilon \geqslant 1$. Zero investment in technological capability implies $u_i = 1$ and $F = w\varepsilon$, an exogenous entry cost. We label this the 'exogenous technological capabilities' case. The case of $u_i > 1$ is labelled 'endogenous technological capabilities'.

Before solving for the optimal technological capability, let us solve for industry revenue from equation (3). This yields

$$S = (1-\alpha)qY. \tag{8}$$

The first order condition for the second stage is given by $\partial\pi_i/\partial u_i = \partial F(u_i)/\partial u_i$, from which we solve for the symmetric (Nash) equilibrium level of technological capability:

$$u = \max\left\{1, \left[\frac{2\,(1-\alpha)\,Y}{\varepsilon\beta}\left(\frac{q}{w}\right)\frac{(N-1)^2}{N^3}\right]^{\frac{1}{\beta}}\right\}. \tag{9}$$

[5] The effect on quantity would appear to be non-monotonic. However, differentiating x_i with respect to u_i, it becomes clear that x_i is increasing in u_i so long as the market harbors at least two firms.

[6] Quantity is decreasing in the number of firms so long as there are at least two firms in the intermediate goods industry.

Equilibrium in the entry stage requires that gross profits (7) just cover fixed outlays, $F(u_i)$. Substituting (9) into the free entry (zero profit) condition, $\pi_i = F(u_i)$, we can solve for the number of entrants:

$$N = \sqrt{S/w\varepsilon} \qquad \text{if } u = 1; \text{ and} \tag{10}$$

$$N = \beta/4\left(1 + \sqrt{1 + 8/\beta}\right) + 1 \qquad \text{if } u > 1. \tag{11}$$

For simplicity, the number of firms is treated throughout as a continuous variable[7]. If $u = 1$, the number of firms is increasing in market size and decreasing in wages and entry costs. This is a familiar result from Cournot competition with (exogenous) entry costs, in which a larger market size leads to an increasingly fragmented market structure. In the limit, as $S/\varepsilon \to \infty$, $N \to \infty$, and price converges to marginal cost (wc). This is the *convergence property*: market structure converges to the competitive solution as entry costs become small or industry revenue becomes large. If $u > 1$, the number of firms depends only on β, and is independent of market size. In the literature on market structure this has been labelled the *non-convergence property* (Shaked and Sutton, 1983). It refers to the notion that as market size becomes large, market structure does not become fragmented. As the market expands, incumbents increase their investments in technological capability (see equation 9), effectively preventing further entry.

2.3. The Labor Market and the Rest of the Economy

Labor supply is perfectly inelastic at L_e. Labor demand comes from the final and intermediate goods industries and a 'rest of the economy' sector. Labor market clearing can be stated as

$$L_e = L_x + L_y + L_r,$$

where L_x, L_y and L_r denote, respectively, employment in the intermediate and final goods industries, and in the rest of the economy. Labor demand from the final goods industry is given by (2). Labor demand from the intermediate industry can be written as $L_x = N(xc + \varepsilon u^\beta)$. The 'rest of the economy' exhibits diminishing marginal productivity of labor: as demand for labor rises in the intermediate and final goods sectors, less labor is available to the rest of the economy and its marginal productivity rises. Since labor is perfectly mobile between industries, this pushes up the wage rate for the whole economy. To capture this pattern, we follow Venables (1996) in closing the model with the following real wage function:

$$\frac{w}{q} = MPL(L_r) \qquad MPL' < 0,\ MPL'' < 0, \tag{12}$$

[7] The model can be readily extended to a discrete number of entrants by taking the integer part of N and allowing for non-zero profits in the intermediate industry (as discussed in Venables, 1996). The insights gained by this exercise are not substantially different from those presented here.

where $MPL(.)$ denotes the marginal product of labor in the 'rest of the economy', MPL' and MPL'' denote (respectively) first and second derivatives, q is the price of the final good, and w is the nominal wage rate per unit of labor endowment. Whence, the real wage rate is a decreasing and concave function of the amount of labor used in the 'rest of the economy'. To see why concavity is required, note that a rising wage imposes an external diseconomy on the intermediate and final goods sectors. For industrialization to take place, this effect needs to be curtailed: the marginal productivity of labor (MPL) must not fall too steeply, so that the wage rate does not rise too sharply as intermediate and final outputs expand (thereby reducing employment in the 'rest of the economy'). We assume that profits in the 'rest of the economy' sector are exhausted by labor costs. This is ensured by the presence of a fixed labor cost, included in L_r.

There is a negative, monotonic relationship between employment in the 'rest of the economy' and the output of final goods. Therefore, a function $\omega(Y)$ can be defined as follows: $\omega(Y) \equiv MPL(L_r)$, with $\omega' > 0$, $\omega'' < 0$,where ω' and ω'' denote the first and second derivatives.[8] Rather than choose a specific functional form for $MPL(L_r)$, it is analytically convenient to impose a suitable functional form on $\omega(Y)$ as follows:

$$\frac{w}{q} = \omega(Y) = Y^{1/\theta} \quad \text{with } \theta > 1. \tag{13}$$

This completes the description of the model.

3. Equilibrium

An equilibrium consists of a price for intermediate goods (p), a technological capability for intermediate firms (u), a number of intermediate firms (N), a wage (w) and an allocation of labor (L_x, L_y and L_r) such that the intermediate industry is in a Subgame Perfect Nash Equilibrium, firms in the final goods industry minimize costs and earn zero profits, the labor market clears and goods markets clear. The following assumptions are introduced in order to simplify the analysis:

A1a. $w > w^* = q\left(\frac{\varepsilon}{1-\alpha}\right)^{\frac{1}{\theta-1}}$, where $w^* > 1$.
A1b. $p_m < q\left(\frac{1-\alpha}{\varepsilon}\right)^{\frac{\alpha}{(\theta-1)(1-\alpha)}}$.
A2. $\theta - 1 > \beta$.

The role of A1a is to avoid division by zero in equilibrium condition SS (below). In order to confine subsequent analysis to values of w lying above w^*, A1b places an upper bound on the

[8] Note that there is no need to include intermediate output (X) in $\omega(.)$, since X is a monotonically increasing function of final output (Y). Furthermore, inclusion of technological capability (u) or market structure ($N+1$) is also redundant, since X is a monotonic function of these.

price of imports (p_m). A2 ensures that equilibrium condition $S'S'$ (below) is downward sloping. Although other cases are admissible, A2 ensures a clearer insight (further details are provided in section 3.2).

Remark 1: Technological Take-Off

There is a technological take-off at which investment in technological capability becomes profitable. Using (13) to replace Y in (9), we can see that u is increasing in w. Hence, there is a wage rate associated with the technological take-off, denoted by w_T. Setting $u = 1$ to solve for w_T yields

$$w_T = q\left[\frac{\varepsilon\beta}{2(1-\alpha)}\frac{N^3}{(N-1)^2}\right]^{\frac{1}{\theta-1}}. \tag{14}$$

For $w \leqslant w_T$, we have $u = 1$. In this case the number of firms is given by (10) and all other equations simplify by setting $u = 1$. For $w > w_T$, investment in technological capability is activated and the number of firms is given by (11). The technological take-off (w_T) is increasing in q, ε, α, β and decreasing in θ.

Equilibria for this economy are characterized by three conditions. The first condition ensures equilibrium in the final goods industry, that is, firms in the final goods industry minimize costs and earn zero profits. This is obtained by solving for p/u from equation (1). This condition is labelled $D'D'$, and it holds for $w > w_T$. For $w \leqslant w_T$ we have $u = 1$, and the condition is labelled DD:

$$p = \left(\frac{q}{w^\alpha}\right)^{\frac{1}{1-\alpha}} \quad \text{if } w \leqslant w_T \quad (u = 1);\ \text{and} \tag{DD}$$

$$\frac{p}{u} = \frac{1}{u}\left(\frac{q}{w^\alpha}\right)^{\frac{1}{1-\alpha}} \quad \text{if } w > w_T \quad (u > 1). \tag{D'D'}$$

DD and $D'D'$ are downward sloping in w: in order to break even, and for a given price of final output (q), a higher wage rate (w) allows a smaller price/quality ratio to be paid for intermediate goods[9]. DD and $D'D'$ are convex with respect to w.

The second condition ensures labor market clearing and a Subgame Perfect Nash Equilibrium in the intermediate industry. Subgame perfection implies that no firm can find an optimal deviation in either quantity or technological capability (as implied by the first order conditions for stages 2 and 3 of the intermediate industry game), and no firm wishes to enter or exit (as implied by the zero profit condition in stage 1). To obtain the second equilibrium condition, divide the symmetric counterpart to (6) by u. For $w \leqslant w_T$, we set $u = 1$ and use (10) to substitute N, and (13) to replace Y. This results in the SS schedule, shown below. For $w > w_T$,

[9] To see that $D'D'$ is downward sloping in w, substitute (13) and (9) into $D'D'$.

the condition is given by $S'S'$, in which the number of firms is given by (11), technological capability is given by (9), and Y is solved from (13):

$$p = \frac{wc}{1 - \sqrt{\frac{\varepsilon}{1-\alpha}\left(\frac{q}{w}\right)^{\theta-1}}} \qquad \text{if } w \leqslant w_T \quad (u=1); \text{ and} \tag{SS}$$

$$\frac{p}{u} = \frac{wc}{u}\frac{N}{N-1} \qquad \text{if } w > w_T \quad (u>1). \tag{S'S'}$$

There are two effects at work in the SS schedule. The first is that as w increases, the marginal cost of intermediate goods rises linearly, thereby increasing price. This effect will make SS upward sloping at high values of the wage rate, and can be observed in the numerator of SS (wc). The second effect operates through the number of firms: the wage rate increase reflects higher demand for labor by the intermediate and final goods sectors, which means higher production levels in both sectors. As sales in the intermediate industry rise, the number of entrants increases, and the price of intermediate goods falls, making SS downward sloping in w. This effect can be observed in the denominator of SS, and is prevalent at low values of the wage rate. In $S'S'$ the number of firms is fixed for a given β. As before, $S'S'$ is increasing linearly in the wage rate through the effect in the numerator. The second effect now operates through technological capability. Technological capability increases with the wage rate[10], and this tends to make $S'S'$ downward sloping in w.
The third equilibrium condition is that the domestic price/quality ratio of intermediate products be less than the price/quality ratio of imports, denoted by p_m/u (Otherwise, intermediate firms would not achieve a positive market share.).

To characterize the equilibria of the economy, consider first the case of $w \leqslant w_T$ $(u=1)$. Equating the DD and SS schedules yields

$$c = \left(\frac{q}{w}\right)^{\frac{1}{1-\alpha}} - \sqrt{\frac{\varepsilon}{1-\alpha}\left(\frac{q}{w}\right)^{\theta+\frac{1+\alpha}{1-\alpha}}}. \tag{15}$$

We will see below (Proposition 1), that (15) has, at most, two positive real roots.

Second, consider the case $w > w_T$ $(u>1)$. The equilibrium conditions are now $D'D'$ and $S'S'$. Combining (13), (9), $S'S'$, and $D'D'$, yields an explicit solution for the equilibrium wage rate:

$$\widehat{w} = q\left(\frac{1}{c}\frac{N-1}{N}\right)^{1-\alpha}. \tag{16}$$

We are now ready to provide an account of how the model works. This is done with the aid

[10] To see that technological capability is increasing in the wage rate, substitute Y from (13) into (9), and recall that $\theta > 1$.

of Figure 1. Schedules DD and SS are shown as thick lines up to w_T. To the right of w_T, the actual equilibrium conditions are given by $D'D'$ and $S'S'$, and DD and SS are shown as thin lines.

Figure 1.

3.1 Exogenous Technological Capability (Venables, 1996)

In this case, the focus is on the DD and SS schedules, including their continuations (thin lines), with $u = 1$. The DD schedule implies cost minimization and zero profits for the final goods industry. Pairs (p, w) lying below DD yield positive profits for final goods producers, while pairs lying above imply negative profits. Any equilibria must lie on the DD locus, since that is the only way the final goods industry can be in equilibrium.

SS ensures labor market clearing and a Subgame Perfect Nash Equilibrium in the intermediate industry. With exogenous technological capability, a Subgame Perfect Nash Equilibrium in the intermediate industry requires Cournot-Nash quantities in the final stage subgame, and zero profits in the first stage subgame (The subgame involving choice of technological capability is assumed inactive in this subsection.). For given intermediate output and number of intermediate firms, pairs (p, w) lying below SS imply negative profits in the intermediate industry and firms exit. As intermediate firms exit, the price of intermediate goods rises until SS is reached. Conversely, pairs (p, w) above SS imply positive profits in the intermediate industry and entry follows. This drives down the price of intermediate goods, returning to SS.

The (post-tariff) price/quality ratio for imports of intermediate goods is shown as a horizontal line at p_m/u. For $u = 1$, this is simply the price of imports (as opposed to the price/quality ratio). In equilibrium, the price of intermediate goods is given by the lesser of p_m and SS. Accordingly, the portion of SS above point A cannot be part of an equilibrium: If intermediate firms set their price above the price of imports, their market share is zero. Thus, to the left of point A, the price of intermediate goods is fixed at p_m. Nonetheless, with a fixed price for intermediate goods, the intermediate industry can still achieve a Subgame Perfect Nash Equilibrium, even out of the SS locus. In this case, the number of intermediate firms falls in order to make profits zero, but the subsequent (upward) price adjustment does not take place (price is fixed at p_m). In this case the number of intermediate firms is smaller than when prices can fluctuate freely (as is the case when the economy lies *on* the SS schedule).

As in Venables (1996), there are two equilibria for $u = 1$: E_1 and E_2. E_1 is the low-income equilibrium, while E_2 is the high-income equilibrium. E_1 features a high price for intermediate goods (set marginally below p_m), low output of intermediate and final goods, a large 'rest of the economy' sector, and a low wage rate. A high price for intermediate goods is associated with few firms in the intermediate sector. In turn, high concentration is supported by small intermediate industry sales. The number of intermediate firms at E_1 is smaller than the number implied by SS at wage w_{E1}. This is because (p, w) pairs lying below SS imply negative profits for intermediate firms, so exit ensues until profits with price p_m are driven to zero. To see that E_1 is an equilibrium, note that to the left of E_1, DD lies above p_m. At price p_m the final goods industry exhibits positive profits, its output expands and intermediate output increases. As intermediate and final outputs rise, less labor is used in the 'rest of the economy', and wages rise, shifting the economy back to E_1. To the right of E_1, DD is below p_m. The price of intermediates is now given by DD, and intermediate firms exhibit negative profits. This induces exit, increasing the price of intermediate goods. Output falls in both sectors, the 'rest of the economy' expands, and wages fall, shifting the economy back to E_1.

E_2 is characterized by a low price for intermediate goods, high output in both industries, low output in the rest of the economy, and a high wage rate. Low concentration in the intermediate industry generates an intermediate goods price which is lower than p_m. A low intermediate price supports high output of final goods, which in turn implies high intermediate output. Again, there is no optimal deviation for any individual firm from this equilibrium: to the left of E_2, DD is above SS, intermediate firms earn positive profits, and entry follows. This reduces intermediate price, intermediate and final outputs increase, the rest of the economy shrinks, wages rise, and the economy shifts back to E_2. To the right of E_2, DD is below SS, intermediate firms earn negative profits, exit ensues, the price of intermediate goods rises, output of intermediate and final goods contracts, the rest of the economy expands, wages fall, and the economy returns to E_2.

Remark 2: Industrial Take-Off

There is a crossing of DD and SS at w_I, labelled 'industrial take-off'. To the left of w_I, we have $DD < SS$. This implies negative profits for intermediate firms and exit follows. This increases the price of intermediate goods, reducing sales of intermediate goods together with final output. As labor demand from the intermediate and final goods industries contracts, the rest of the economy expands, reducing wages. This process shifts the economy to E_1. To the right of w_I, we have $DD > SS$, implying positive profits. In this case firms enter the intermediate industry, reducing the price of intermediate goods. Output of intermediate and final goods rises, reducing employment in the rest of the economy and raising wages until E_2 is reached.

There is an optimal *collective* deviation from E_1. If intermediate firms are able to coordinate on a collective increase in output, and this increase in output is sufficiently large to shift the economy past w_I, then the economy switches to E_2. Nonetheless, if intermediate firms are located at E_1 but cannot achieve such a collective deviation, we have a coordination failure.[11]

[11] E_1 and E_2 are sometimes classified as 'stable' equilibria. In this terminology the industrial take-off point

3.2 Endogenous Technological Capability

Once the technological take-off is crossed ($w > w_T$), investment in technological capability is triggered ($u > 1$), and the relevant equilibrium conditions are given by $D'D'$ and $S'S'$. As before, $D'D'$ ensures cost minimization and zero profits in the final goods industry. Pairs (p, w) lying below $D'D'$ generate positive profits for final goods producers, and pairs (p, w) lying above $D'D'$ are associated with negative profits. Hence, equilibria must lie on the $D'D'$ locus. Since technological capability is increasing in the wage rate, $D'D'$ is steeper than DD.

Similarly to SS, $S'S'$ implies labor market clearing and a Subgame Perfect Nash Equilibrium in the intermediate goods industry. A Subgame Perfect Nash Equilibrium for the intermediate goods industry now requires Cournot-Nash production in the final stage subgame, a Nash equilibrium in technological capabilities in the second stage subgame, and zero profits in the first stage subgame. Pairs (p, w) lying above $S'S'$ are associated with positive profits for intermediate firms. This increases technological capability, output expands, and the price/quality ratio falls back to $S'S'$. Likewise, pairs (p, w) lying below $S'S'$ lead to negative profits for intermediate firms. In this case technological capability and intermediate output fall and the price/quality ratio of intermediate goods rises until $S'S'$ is reached. Notice that the number of firms does not change throughout this process. This occurs because the adjustment now takes place through fixed outlays, and this happens so that after stage 2 is played (choice of technological capability), there is no incentive for entry or exit.

As before, there are two equilibria. The first is E_1, as in the exogenous technological capability case. For $w > w_T$, investment in technological capability gives a 'second breath' to the industrialization process and E_2 is replaced by $E_{\widehat{w}}$. This is associated with the wage rate found in (16). It is easy to check that there is no optimal deviation from $E_{\widehat{w}}$. To the left of $E_{\widehat{w}}$, we have $D'D' > S'S'$. This leads to positive profits in the intermediate industry. Technological capability rises, the price/quality ratio of intermediate products falls, output of intermediate and final goods increases, less labor is employed in the 'rest of the economy', and wages rise. This shifts the economy back to $E_{\widehat{w}}$. Conversely, to the right of $E_{\widehat{w}}$, we have $D'D' < S'S'$. This leads to losses in the intermediate goods industry. Technological capability falls, the price/quality ratio of intermediate goods rises, intermediate and final outputs fall, more workers are employed in the 'rest of the economy', wages fall, and the economy returns to $E_{\widehat{w}}$.

This completes the discussion of equilibria. We now discuss in more detail the consequences of assumption A2 (namely, that $\theta - 1 > \beta$). Substituting (13) and (9) into $S'S'$, it can be seen that $S'S'$ will be downward sloping in w if $\theta - 1 > \beta$, upward sloping in w if $\theta - 1 < \beta$, and constant with respect to w if $\theta - 1 = \beta$. Recall that the slope of $S'S'$ with respect to w depends on two effects. First we have that $S'S'$ rises linearly with w, through increases in the marginal

would be an 'unstable' equilibrium.

cost of intermediate products (wc). Secondly, technological capability is rising in w, and this tends to make $S'S'$ downward sloping in w. If $\theta - 1 > \beta$, the increasing technological capability effect dominates the increasing marginal cost effect. Assumption A2 ($\theta - 1 > \beta$) has an intuitive interpretation. If θ is large, the wage function (equation 13) is not very steep. On the other hand, a small value of β implies that the marginal cost of building technological capability is relatively low. In this scenario the switch from E_1 to $E_{\widehat{w}}$ is accompanied by a relatively small rise in wages, and a relatively large rise in technological capability, which ensure that that $S'S'$ is downward sloping. Conversely for $\theta - 1 \leqslant \beta$.

Remark 3: A Window of Opportunity

For the switch from the low-income equilibrium (E_1) to the high-income equilibrium to be accompanied by an increase in technological capability, $w_T \in [w_I, w_{E2}]$ is required. The interval $[w_I, w_{E2}]$ is a window of opportunity for the economy to trigger rises in technological capability. If the economy fits through this window of opportunity, it achieves a higher wage rate than would have been the case otherwise (Proposition 4, below). The formal condition for $w_T \in [w_I, w_{E2}]$ is condition C6 in section 4.

We close this section by considering the different configurations of equilibria that may arise in the current framework. This is set out in Proposition 1. To formulate the proposition, we need to specify some conditions, as follows:

C1. $c < \left\{ \frac{1-\alpha}{\varepsilon} \frac{4}{[2+(1-\alpha)(\theta-1)]^2} \right\}^{\frac{1}{(\theta-1)(1-\alpha)}} \frac{(1-\alpha)(\theta-1)}{2+(1-\alpha)(\theta-1)}.$

C2. $\lim\limits_{w \to \infty} \frac{DD}{SS} < 1.$

C3. $\lim\limits_{w^+ \to w^*} \frac{DD}{SS} < 1.$

C4. There is exactly one change of sign in the slope of SS for $w \in (w^*, \infty)$.

Proposition 1: Equilibrium Configurations

For $w \leqslant w_T$:

I) If C1 holds, then under A1a, A1b, C2, C3 and C4, there are two equilibria. One is given by an intersection of DD and SS (denoted by E_2). The other is given by the intersection of DD and p_m (denoted by E_1).

II) If C1 does not hold, then the unique equilibrium is given by the intersection of DD and p_m (E_1).

For $w > w_T$, the equilibrium wage rate is given by $\widehat{w}$.

The proof is provided in Appendix B. In the following section, we analyze the impact of trade policy and its role in relieving coordination failure.

4. Trade Policy

We interpret a change in tariffs for intermediate goods as a shift in the value of p_m, and a change in tariffs for final goods as a shift in the value of q.

Proposition 2: Tariffs on Intermediate Goods with $u = 1$ (Venables, 1996)

At E_1, a tariff reduction (increase) for intermediate goods raises (lowers) output in both sectors. If tariffs fall sufficiently, a switch from E_1 to E_2 is triggered. If the fall in the price of intermediate imports is sufficiently large, it will eliminate the intermediate industry and shift the final goods industry to a high production level, at the crossing of DD and p_m.

Proof: The effect of increasing tariffs is to raise p_m. Hence E_1 shifts leftward along DD, reducing intermediate and final outputs and the wage rate (see Figure 1). Hence, increasing tariffs for intermediate goods generates a contraction of both industries. Reducing tariffs on intermediate goods lowers p_m and moves E_1 to the right, increasing output in both sectors.

If the tariff reduction is sufficient to shift p_m past the industrial take-off, then the economy switches to E_2.

Let $w_{\min} = q\left[\frac{\varepsilon}{1-\alpha}\frac{(1+\theta)^2}{4}\right]^{\frac{1}{\theta-1}}$. This specifies the minimum of SS for $w \in (w^*, \infty)$. If p_m falls below the price level associated with SS at $w_{\min}$, then the price of imports after tariffs is too low for the domestic intermediate industry to operate and the new equilibrium is given by the intersection of DD and p_m ■.

Tariff reductions for intermediate goods can help domestic industry to expand. Moreover, if the fall in p_m is sufficiently large, the industry is eliminated, leaving the country with only the final goods and rest of the economy sectors. This is associated with a higher wage rate than if the intermediate goods industry had survived, since the non-competitive nature of this industry imposes a negative (pecuniary) externality on final goods producers.

Proposition 3: Tariffs on Final Goods with $u = 1$ (Venables, 1996)

Increasing tariffs for final goods raises output for both sectors. If the economy is initially located at E_1 and the tariff increase is sufficient, a switch from equilibrium E_1 to E_2 can be triggered.

Proof: Since q is fixed throughout the analysis, thus the horizontal axis in Figure 1 can be relabelled as w/q. Then changes in q will shift DD, while reflecting movements *along* SS (as well as along DD). To see this, note that q enters SS only through w/q in the denominator. DD can be written as $p = q\left(\frac{q}{w}\right)^{\frac{\alpha}{1-\alpha}}$ from which it is clear that changes in q not only generate movements along DD but also shifts in DD, in $(p, w/q)$-space.

A tariff increase for final goods is equivalent to increasing q. This will shift DD upward. Equilibria E_1 and E_2 are shifted to the right, whereas the industrial take-off point moves leftward and upward. Production increases for both sectors, regardless of whether the economy is at E_2 or E_1. However, if DD shifts past the intersection of p_m and SS (point A in Figure 1), then a switch to E_2 is triggered ■.

Now consider the effects of trade policy when technological capability is endogenous. The following conditions are used to set up Proposition 4:

C5. $$c \leqslant \left[\frac{2(1-\alpha)}{\varepsilon\beta}\frac{(N-1)^{1+\theta-\alpha(\theta-1)}}{N^{2+\theta-\alpha(\theta-1)}}\right]^{\frac{1}{(\theta-1)(1-\alpha)}}; \text{ and}$$

C6. $$c \leqslant \left[1-\sqrt{\frac{2}{\beta}\frac{N-1}{N^{3/2}}}\right]\left[\frac{2(1-\alpha)}{\varepsilon\beta}\frac{(N-1)^2}{N^3}\right]^{\frac{1}{(1-\alpha)(\theta-1)}}.$$

Proposition 4: Tariffs on Intermediate Goods with $u > 1$

Let the economy be at E_1 and let C1-C6 hold, then:

I) A sufficiently large reduction in intermediate output tariffs generates an industrial expansion which will shift the economy to $E_{\widehat{w}}$, and increase intermediate firms' technological capabilities.

II) $E_{\widehat{w}}$ will feature a higher wage than E_2.

III) If tariffs are lowered sufficiently, the intermediate industry ceases to exist.

Additionally,

i) $w_T \leqslant \widehat{w} \Leftrightarrow C5$,

ii) $w_I \leqslant w_T \leqslant w_{E2} \Leftrightarrow C6$, *and*

iii) $w_{E2} \leqslant \widehat{w} \Leftrightarrow C5 \wedge C6$.

The proof can be found in Appendix B. Proposition 4 specifies the consequences of reducing p_m/u. In Figure 1, once p_m/u falls below the industrial take-off point, an industrial expansion follows, and the economy switches to either E_2 (if $w_T \notin [w_I, w_{E2}]$) or to $E_{\widehat{w}}$ (if $w_T \in [w_I, w_{E2}]$). In the latter case, the equilibrium switch triggers a rise in technological capability once the economy crosses the technological take-off, associated with w_T.

If p_m/u were to fall sufficiently below $E_{\widehat{w}}$, the intermediate industry could not compete with imports and would cease to exist. In this case, equilibrium would lie at the intersection of p_m/u and $D'D'$, and the economy would feature an even higher wage rate (which is the first best, as in the case of exogenous technological capabilities). To see this in Figure 1, shift p_m/u downward past $E_{\widehat{w}}$, and look for the new intersection of p_m/u and $D'D'$.

Proposition 5: Tariffs on Final Goods with $u > 1$

Tariff increases for final goods will expand output in both sectors, and if sufficient, can trigger a switch from E_1 to $E_{\widehat{w}}$.

Proof: Recall that tariff increases for final goods can be modelled as an increase in q. Relabel the horizontal axis in Figure 1 as w/q. In $(p/u, w/q)$-space, $S'S'$ does not shift with changes in q, while $D'D'$ does.

Increasing q will shift $D'D'$ upward. E_1 and $E_{\widehat{w}}$ shift rightward, and the industrial take-off moves leftward and upward. Production increases in both sectors, regardless of whether the economy is at $E_{\widehat{w}}$ or E_1. If $D'D'$ shifts past the crossing between p_m and SS (point A in Figure 1), then an expansion to $E_{\widehat{w}}$ is triggered.

Regarding the technological take-off point (associated with w_T), note that increases in q cause proportionate shifts of w_T and $\widehat{w}$. This, together with the upward shift in $D'D'$, guarantees that if $w_T < w_{E2}$ held initially, it will continue to hold at the new level of q. Therefore, if the economy featured the possibility of technological take-off at the initial q, this will still hold at the new q ■.

Remark 4: The First Best

The first best entails elimination of the intermediate industry. From Figure 1 it is clear that industrialization would, at best, achieve E_2 *(for* $u = 1$*) or* $E_{\widehat{w}}$ *(for* $u > 1$*). Letting the price of imports fall sufficiently below the price levels associated with either of these equilibria leads to the demise of the intermediate industry (as shown in Propositions 2 and 4). In this case, wages are given by the intersection of* DD *and* p_m*. The economy would be constituted by a perfectly competitive industry and by the residual 'rest of the economy' sector. The extra labor demand generated through increased efficiency (that is, through reductions in the price of intermediate goods) more than compensates for the loss of jobs in the intermediate industry.*

6. Concluding Remarks

This paper endogenizes technological capability choice at the firm level, in the context of a coordination failure framework. The extension allows for a richer setting in which firms' development of technological capability is the result of a strategic choice. This uncovers new mechanisms central to the interaction between industrialization and firms' technological capabilities. In particular, Rostow's (1956, 1959) view of the development process as a series of stages which the economy must traverse is reassessed, and the revised view that emerges is somehow reminiscent of that theory. However, the take-offs themselves bear little resemblance to Rostow's original framework. We now have an *industrial take-off*, which triggers industrialization. Subsequently, there is a *technological take-off*, and an associated *window of opportunity*, which the economy must cross in order to achieve growth in technological capability. If the economy manages to cross both take-offs, industrialization proceeds along with entry into high-industries, and the economy will achieve a higher level of income than if it crosses the industrial take-off, but not the technological take-off. In the latter case, the industrialization process is foiled, and the economy cannot achieve entry into high-tech industries. Thus, industrialization is characterized by low-tech manufacturing.

The implications for trade policy are as follows. With exogenous technological capability, tariff reductions for intermediate goods and tariff increases for final goods raises output in both sectors, as well as the wage rate. If tariff reductions for intermediate goods (tariff increases for final goods) are large enough, an equilibrium switch can be triggered. These results are in line with those in Venables (1996). If the changes in tariffs are even larger, the intermediate industry may be eliminated, in which case the economy is left only with the perfectly competitive final goods industry and the rest of the economy sector. Since imperfect competition in the intermediate industry introduces inefficiency into the economy, the demise of this industry leads to the first best outcome, which is associated with higher wages.

In the endogenous technological capability setting, tariff reductions for the intermediate sector or tariff increases for the final goods sector still induce an industrial expansion, which could now be accompanied by an increase in technological capability. Investment in technological capability will take place if the technological take-off is associated with a sufficiently low wage rate. If the technological take-off wage rate is too high, the technological take-off is bypassed. In this case the economy misses the window of opportunity, and ends up with a thwarted process of industrialization in which technological capability does not rise. Thus, even though the economy industrializes, the industries into which it successfully enters will be technologically backward and the economy achieves a lower wage rate than if the technological take-off had been crossed. The key notion is that in order to avoid foiling the process of industrialization, the wage rate cannot rise too steeply along the transition towards the high-wage equilibrium. Otherwise, it runs the risk of impeding entry into technologically advanced industries.

The model sheds light on some possible reasons why many developing countries have managed to partially industrialize, while very few countries managed to enter successfully into high-technology industries. In particular, the importance of keeping wage growth in check has been highlighted. In a sense, this is bad news for development policy: it implies that in order to successfully enter into high-tech industries, the transition process may need to be accompanied by policies that restrain wage growth. Thus, one of the main mechanisms to sustain public support for industrialization needs to be curtailed. Moreover, nations with relatively higher initial wage rates are less likely to fit through the window of opportunity. Such relatively high initial wage rates could, perhaps, be due to factors such as favorable natural resource endowments: the 'resource curse' or 'dutch disease' (Corden, 1984). This may be particularly relevant to the case of Latin America, as compared to the North-East Asian economies. The importance of restraining wage growth has been emphasized by Amsden (1989). Analyzing the industrialization process for South Korea, Amsden comes to the conclusion that one of the factors which explains South Korean success, is that the rate of growth for wages was lower than that of labor productivity.

Extensions and Limitations

An interesting extension is to consider the possibility that domestic intermediate firms become sufficiently competitive to produce at a price/quality ratio which is equal to or less than the international price/quality ratio. The international price/quality ratio can be represented as a horizontal line in Figure 1, lying below the price/quality ratio of imports (the difference between the two lines being the wedge introduced by tariffs on intermediate goods). If domestic producers become sufficiently efficient to be able to access the international market, there will be a third take-off point: *international take-off*. As the economy crosses this point, it will capture a share of the international market.

Several restrictions on parameter values have been used. This raises questions about the likelihood of these restrictions holding in actual economies. In the absence of inference about the underlying distributions of these parameters, it is difficult to say anything about the matter. This issue seems something best settled empirically, and lies outside the scope of a theoretical study.

The model provides justification for targeted trade policy. Such results could be used by vested interests for rent seeking purposes. Moreover, in the light of the current framework of multilateral tariff agreements, is not at all clear how a small economy could go about implementing these policy prescriptions. Perhaps this calls for a reconsideration of how such multilateral agreements are designed.

In order to focus on firms' strategic choice of technological capability and its consequences for development, we have not considered issues relating to financial market imperfections or human capital. It is well known that both notions are crucial to the process of development, but their inclusion lies outside the scope of this study[12].

[12] A survey on financial markets and development can be found in Levine (1997). For human capital and development, see Benhabib and Spiegel (1994).

Appendix

A. Deriving the solved-out profit function

By perfect substitutability, intermediate firms set $p_i/u_i = \lambda$. From section 2.2,

$$\lambda = \frac{S}{\sum_{j=1}^{N} u_j x_j}. \tag{A.1}$$

Firms maximize $\pi_i = (p_i - wc)\, x_i = (\lambda u_i - wc)\, x_i$, by choosing x_i. The first order condition is given by:

$$\lambda u_i - \frac{\lambda^2 u_i}{S} u_i x_i = wc. \tag{A.2}$$

From (A.2) solve for $u_i x_i$ and sum this over all firms. This yields:

$$\sum_{j=1}^{N} u_j x_j = S\left(\frac{N}{\lambda} - \frac{wc}{\lambda^2}\sum_{j=1}^{N}\frac{1}{u_j}\right). \tag{A.3}$$

Substitute $\sum_{j=1}^{N} u_j x_j$ from (A.1) into (A.3) and solve for λ to obtain:

$$\lambda = \frac{wc}{N-1}\sum_{j=1}^{N}\frac{1}{u_j}. \tag{A.4}$$

This can be substituted into (A.2) to obtain solutions for p_i and x_i and π_i, shown in equations (5), (6) and (7) in the main body of the paper.

B. Longer Proofs

Proof of Proposition 1:

Let us analyze the case $w \leqslant w_T$ first. We examine the basic properties that are required of DD, SS and p_m, and then show how these properties are met. Finally, it is shown that the cases of zero or strictly more than two equilibria can be ruled out. It will be useful to keep Figure 1 in mind.

Consider C1-C3. To obtain two crossings between DD and SS, there must be three ranges for w. Firstly, for $w \in (w^*, w_I)$, $SS > DD$ (C3). Secondly, for $w \in [w_I, w_{E2}]$, $SS \leqslant DD$ (C1). Finally, for $w \in (w_{E2}, \infty)$, $SS > DD$ (C2). This guarantees at least two crossings (at least one tangency point, if C1 holds with equality). Including C4 guarantees *exactly* two crossings (*exactly* one tangency point, if C1 holds with equality).

Let us analyze C1, assuming C2-C4 hold. To guarantee that SS and DD cross, a range where $SS < DD$ is required. This range is defined by two wage rates, as follows: $w \in [w_I, w_{E2}]$. C1 ensures $SS < DD$. To see this, consider the case when SS is tangent to DD. In this case $\frac{DD}{SS}$ has a maximum at $SS = DD$, defined by $\left.\frac{\partial\left(\frac{DD}{SS}\right)}{\partial w}\right|_{w_p} = 0$. This yields

$w_p = q\left\{\frac{[2+(1-\alpha)(\theta-1)]^2}{4}\frac{\varepsilon}{1-\alpha}\right\}^{\frac{1}{\theta-1}}$. Substituting w_p, into $\frac{DD}{SS}$ and imposing the condition $\frac{DD}{SS} > 1$, yields C1.

Now consider C2: as $w \to \infty$, $\frac{DD}{SS} \to 0$ and C2 holds. To check that C3 holds, let $w \to w^*$ from above. Then $SS \to \infty$ and $DD \to DD(w^*)$, which is finite. This yields $SS > DD$. To check C4, set $\frac{\partial SS}{\partial w} = 0$. For $w > w^*$, SS achieves a unique minimum at $w_{\min} = q\left[\frac{\varepsilon}{1-\alpha}\frac{(1+\theta)^2}{4}\right]^{\frac{1}{\theta-1}}$.

In order to have at least one firm in the intermediate industry, A1a implies an upper bound on p_m, which is defined by $p_m < DD(w^*)$. Performing this calculation yields A1b. For $w > w^*$ there is at least one firm in the intermediate industry. For p_m higher than the upper bound, the domestic intermediate industry is non-existent (as it would contain less than one firm).

It remains to show that zero and more than two equilibria cannot exist. Consider the zero equilibrium case. If there is no equilibrium, p_m and DD do not cross (E_1 does not exist) *and* C1 does not hold. p_m is simply a horizontal line, while DD is a hyperbola, hence they will always cross - unless p_m is exactly zero (an unfeasible price). Therefore, E_1 always exists.

To exclude strictly more than two equilibria, note that E_1 always exists. We know (Remark 2) that the industrial take off point is not an equilibrium. So what is required is that there be more than two crossings of SS and DD. By C2 and C3, the number of crossings of SS and DD will be even. To see this, note that $SS > DD$ as $w \to w^*$ and as $w \to \infty$, hence an odd number of crossings is not possible. To exclude an even number of crossings higher than two, note that this would require more than one change in the slope of SS, but this would violate C4.

For $w > w_T$ the equilibrium wage rate ($\widehat{w}$) is given by equation (16) ■.

Proof of Proposition 4:

The configuration shown in Figure 1 accords with Proposition 4. C1-C4 hold to guarantee that DD and SS cross exactly twice (see Proposition 1).

Part I follows similar reasoning to Proposition 2: If tariffs for intermediate goods are reduced sufficiently (p_m/u falls below the industrial take-off), equilibrium E_1 ceases to exist and the economy switches to $E_{\widehat{w}}$.

To see how i, ii and iii relate to parts I, II, and III, consider each of the former:

i) For an endogenous increase in technological capabilities to take place, w_T must lie below $\widehat{w}$. This will hold if and only if $\widehat{w}/w_T \geqslant 1$. Substituting $\widehat{w}$ and w_T from (16) and (14), respectively, yields C5.

ii) Industrialization will be characterized by an increase in technological capabilities if and only if $w_T \in [w_I, w_{E2}]$. Substituting w_T into the equilibrium condition (15) yields C6.

iii) In order to have $\widehat{w} \geqslant w_{E2}$ (part II), it is useful to plot the expression in (15). This can be seen in Figure 2, where the left hand side (labelled LHS, equal to c) has been plotted against the right hand side (labelled RHS, equal to $\left(\frac{q}{w}\right)^{\frac{1}{1-\alpha}} - \sqrt{\frac{\varepsilon}{1-\alpha}\left(\frac{q}{w}\right)^{\theta+\frac{1+\alpha}{1-\alpha}}}$).

Figure 2.

In Figure 2 it can be seen that for $w \geqslant w_{E2}$ to hold, we require LHS$\geqslant$RHS. This is also the condition required for $\widehat{w} \geqslant w_{E2}$. However, the latter also holds for $\widehat{w} \leqslant w_I$. In order to rule out this case, both C5 (or 'i') and C6 (or 'ii') are necessary. Substituting $\widehat{w}$ into the equilibrium condition (15), setting LHS$\geqslant$RHS and simplifying yields

$$1 \geqslant \frac{N-1}{N}\left[1 - \left\{\left(\frac{\varepsilon}{1-\alpha}\right)\left[c\frac{N-1}{N}\right]^{(1-\alpha)(\theta-1)}\right\}^{\frac{1}{2}}\right]$$

which holds for all admissible parameter values. C5 and C6 are each necessary for 'iii', and together they are sufficient. Parts II and 'iii' are equivalent.

For part III, if the tariff is reduced such that $p_m/u < S'S'(\widehat{w})$, the intermediate industry will not be able to attain a positive market share unless $S'S'$ shifts down to p_m/u. The number of firms needs to adjust in order to shift $S'S'$ down. To see whether the number of firms needs to rise or fall, note that

$$\begin{aligned}
(a)\ \partial S'S'/\partial N &< 0 \Longleftrightarrow N < 3+\beta, \\
(b)\ \partial S'S'/\partial N &= 0 \Longleftrightarrow N = 3+\beta, \text{ and} \\
(c)\ \partial S'S'/\partial N &> 0 \Longleftrightarrow N > 3+\beta.
\end{aligned}$$

Moreover, it also follows that at equilibrium $E_{\widehat{w}}$, $N = \beta/4\left(1+\sqrt{1+\beta/8}\right)+1 < 3+\beta$. This places the analysis in case (a). So for $S'S'$ to shift down, the number of firms must rise ($\frac{\partial S'S'}{\partial N} < 0$). If, whilst rising, N reaches $3+\beta$, then $\frac{\partial S'S'}{\partial N} = 0$ and $S'S'$ cannot shift down any further. Moreover, if $N > 3+\beta$, then $\frac{\partial S'S'}{\partial N} > 0$ and what is required in order to shift $S'S'$ down is a *fall* in the number of firms. However, this can make $N < 3+\beta$, in which case the number of firms must *rise*. Thus, unless $S'S'$ reaches p_m/u whilst $N < 3+\beta$ still holds, intermediate industry market structure cannot adjust, and the intermediate industry does not achieve a positive market share. As with exogenous technological capabilities, the economy achieves a higher wage rate in this case (the first best). Also, note that, relative to the exogenous technological capabilities case, the intermediate industry becomes more *resilient* to falls in p_m/u below the high wage equilibrium. In the exogenous technological capabilities case, to eliminate the intermediate industry all that was required was to have p_m smaller than the minimum of SS (see Proposition 2). In the endogenous technological capabilities case, however, the fall in p_m/u must be large enough to make the adjustment in the number of intermediate firms insufficient for $S'S'$ to reach p_m/u ■.

C. Comparative Statics

$\boldsymbol{\alpha}$: With exogenous technological capabilities and under A1a, the effect of increasing α is to shift SS up. DD will shift down if $q < w$. In this case, there is a value of α above which the only equilibrium is E_1. This is defined by C1, taking other parameters as given. Moreover, by reducing α a switch from E_1 to E_2 can be triggered. This defines a value of α below which the only equilibrium is E_2 (The reasoning is similar to Proposition 3.).

With endogenous technological capabilities, an explicit solution for w has been obtained in equation (16). Thus we can ascertain comparative statics by inspection of the latter. $\widehat{w}$ is decreasing in α. w_T is increasing in α (see 14). Thus, there exists a value of α above which an increase in technological capabilities does not occur.

$\boldsymbol{\theta}$: With exogenous technological capabilities, θ does not affect DD. Provided $w/q < 1$, $(w/q)^{\theta-1}$ is decreasing in θ and SS shifts downward as θ increases. The value of θ below which only E_1 exists, is given by C1 (other parameters being held constant). There is also a value of θ above which industrialization is triggered.

With endogenous technological capabilities, increases in θ shift both $D'D'$ and $S'S'$ down. $\widehat{w}$ is increasing in θ and $S'S'$ shifts by more than $D'D'$. w_T is decreasing in θ. There is a value of θ below which $w_T > \widehat{w}$ and it will not be optimal to invest in technological capability.

c : With exogenous technological capabilities, increasing c only affects SS by shifting it up. Thus, there exists a value of c (defined by C1) above which only E_1 exists. There is also a value of c below which the economy ends up at E_2.

With endogenous technological capabilities, changes in c do not affect $D'D'$. As with exogenous technological capabilities, increasing c shifts $S'S'$ up. This is reflected in $\widehat{w}$, which is decreasing in c. w_T does not depend on c. Consequently, there exists a value of c above which there is no investment in technological capability.

$\boldsymbol{\varepsilon}$: With endogenous technological capabilities, the effects are similar to those of c. The value of ε above which only E_1 exists is also defined by C1, other parameters being held constant. Values of ε below a certain threshold generate a shift towards E_2.

With endogenous technological capabilities, $\widehat{w}$ is decreasing in ε. Rising ε is associated with upward shifts in $D'D'$ and $S'S'$, with the shift in $S'S'$ being greater. w_T is increasing in ε. This means that there is a value of ε above which investment in technological capability does not take place.

$\boldsymbol{\beta}$: w_T is increasing in β. However, $\widehat{w}$ is non-monotonic in β. If A2 holds, $\widehat{w}$ is at first decreasing and later increasing in β. Thus there exists a value of β for which $\partial\widehat{w}/\partial\beta = 0$.

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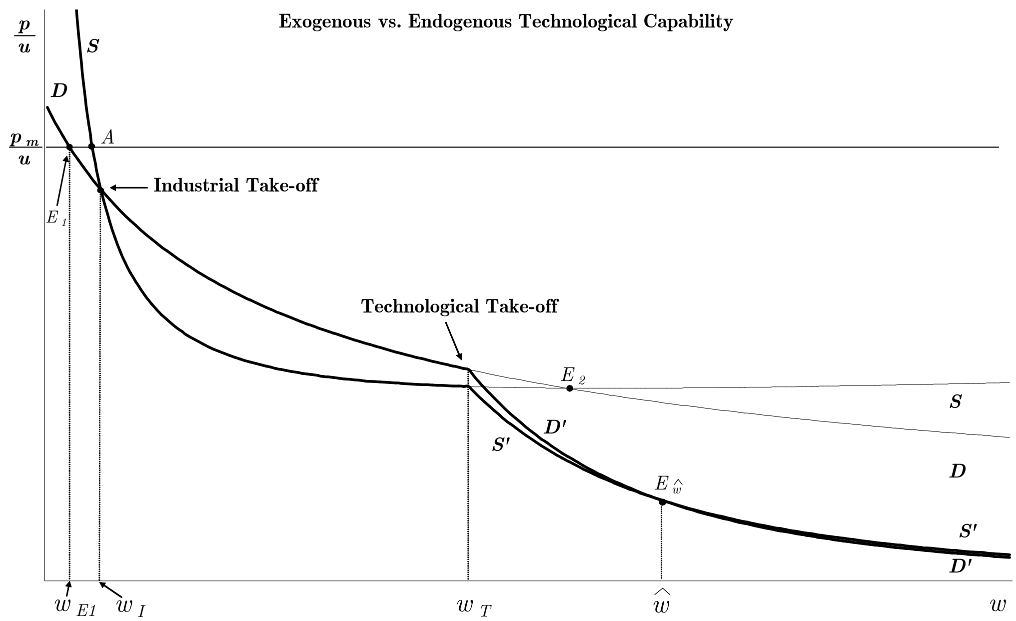

Figure 1. Equilibrium conditions: DD, $D'D'$, SS, $S'S'$ and import price/quality ratio (p_m/u).

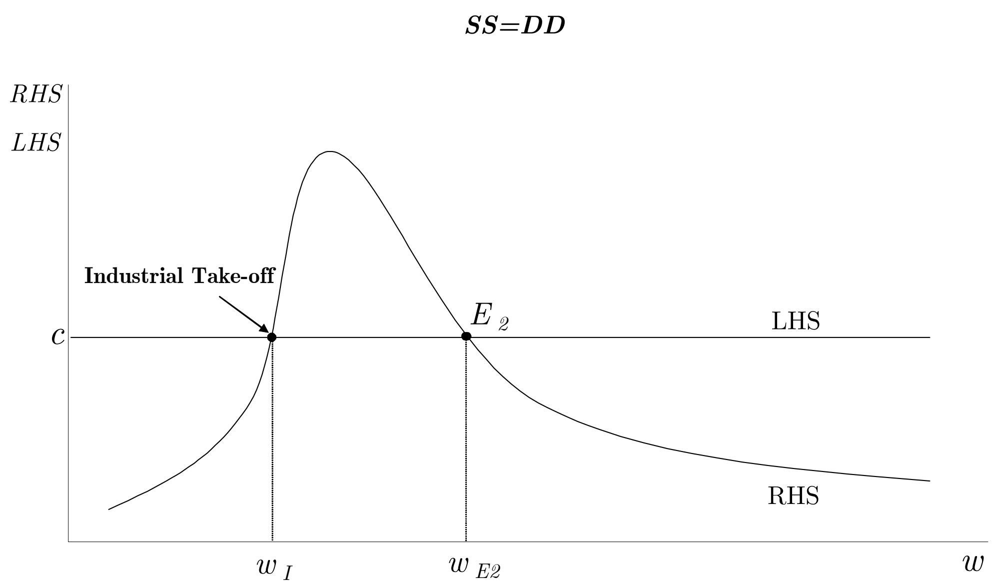

Figure 2. $SS = DD$ (equation 15), exogenous technological capability.