Intermediate Goods Trade, Technology Choice and Productivity

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Abstract: We develop a dynamic model of intermediate goods trade in which the pattern and the extent of intermediate goods trade are endogenous. We consider a small open economy whose final good production employs an endogenous array of intermediate goods, from low technology (high cost) to high technology (low cost). The underlying intermediate goods technology evolves over time. We allow for endogenous markups and consider the effect of trade policy on both the intensive and extensive margins. The existence of trade barriers means that there is a nondegenerate range of intermediate goods that are nontraded. The ranges of imports, exports and nontraded intermediate goods, as well as the entire range of intermediate products used are all endogenously determined. The responses of these ranges, markups and productivity to domestic and foreign trade liberalization are then analyzed.

Keywords: Intermediate Goods Trade, Technology Choice.

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1 Introduction

Over the past sixty years there has been a dramatic increase in the volume of international trade. Two main causes of this have been identified. First, trade policy has been liberalized through the WTO process, via regional trade agreements and by unilateral policy change. Second, technology has dramatically lowered transportation costs. There is recent work documenting the benefits of this increased trade. The availability of micro data sets in many countries has enabled scholars to conclude that trade liberalization leads to productivity improvement and faster economic growth.[1]

In addition to the overall increase in trade the role of intermediate goods trade has increased. In fact, the empirical evidence suggests that reductions in intermediate good tariffs generate larger productivity gains than final good tariff reductions.[2] [3] Specifically, Keller (2000) shows empirically that the benefit of technology can be transferred through intermediate goods trade. In addition, there have been many other closely related empirical findings: (i) more substantial productivity gains are found in firms using newly imported intermediate inputs (see Goldberg, Khandelwal, Pavcnik and Topalova 2011 for the case of India); (ii) trade liberalization results in lower mark-ups and greater competition (see Krishna and Mitra 1998 for the case of India), (iii) firms facing greater competition incur significantly larger productivity gains (see Amiti and Konings 2007 for the case of Indonesia).

In this paper, we develop a dynamic model of intermediate goods trade that can be used to assess the impact of tariff liberalization on intermediate goods trade to address the aforementioned empirical facts. In a seminal work, Ethier (1982) argues that the expansion of the use of intermediate goods is crucial for improving the productivity of final goods production. This has become known as the variety effect. We depart from the Ethier framework in several significant aspects. First, we account for endogenous technology choice in order to highlight the role of intermediate good trade as suggested by Keller (2000). Second, we allow for endogenous markups to allow them to respond to trade liberalization. Finally, we build a tractable framework that is used to analyze the effect of

[1] For example, after trade liberalization in the 1960s (Korea and Taiwan), 1970s (Indoesia and Chile), 1980s (Colombia) and 1990s (Brazil and India), the economic growth over the decade is mostly 2% or more higher than the previous decades. Sizable productivity gain resulting from trade liberalization is documented for the cases of Korea (Kim 2000), Indonesia (Amiti and Konings 2007), Chile (Pavcnik 2002), Colombia (Fernandes 2007), Brazil (Ferreira and Rossi 2003) and India (Krishna and Mitra 1998; Topalova and Khandelwal 2011).

[2] As documented by Hummels, Ishii and Yi (2001), the intensity of intermediate goods trade measured by the VS index has risen from below 2% in the 1960s to over 15% in the 1990s.

[3] The larger effects of intermediate input tariffs have been found in Colombia (Fernandes 2007), Indonesia (Amiti and Konings 2007) and India (Topalova and Khandelwal 2011).

trade liberalization on both the intensive and extensive margins of exports and imports.

Consider a small open economy whose final good production employs an endogenous array of intermediate goods, in which the pattern and the extent of intermediate goods trade are endogenous. Define intermediate goods from low technology (high cost) to high technology (low cost), where intermediate goods technology endogenously evolves over time. The small open economy is assumed to be less advanced in intermediate goods production in the following sense. It imports intermediate goods that are produced using more advanced technology while exporting those using less advanced technology. To allow for endogenous markups and endogenous ranges of exports and imports in a tractable manner, we depart from CES aggregators, and instead use a generalized quadratic production technology that extends the earlier work by Peng, Thisse and Wang (2006).

The existence of trade barriers means that there may be a range of intermediate goods that are nontraded. The ranges of imports, exports and nontraded intermediate goods, as well as the entire range of intermediate products used are all endogenously determined. The responses of these ranges and aggregate productivity to domestic and foreign trade liberalization are then analyzed.

Here are the main findings. Although domestic trade liberalization increases imported intermediate inputs on the intensive margin, final goods producers react to it by shifting imports to lower technology intermediate inputs to minimize production cost, thereby reducing the overall length of the production line. Such an effect via the extensive margin of import demand plays an important role in our results. Foreign trade liberalization also results in a decrease in the overall length of the production line, but the underlying mechanism is different. A lower foreign tariff increases exports on the intensive margin, which reduces intermediate goods available for domestic use and encourages final goods producers to shift to lower types of intermediate inputs. When the effect via the extensive margin is strong, a decrease in either the domestic or foreign tariff reduces the range of exports. Moreover, either type of trade liberalization narrows the range of domestic intermediate goods production. Since both the range of domestic production and the overall length of the production line decrease, the effect of trade protection on the range of imports is generally ambiguous. Furthermore, with a sufficiently strong extensive margin effect on import demand, trade liberalization reduces intermediate producer markups and increases average productivity in additon to increasing productivity for newly imported intermediate inputs. Finally, if the technology gradient is not too flat, trade liberalization results in lower aggregate and average technology for final goods producers. These findings are consistent with the empirical work cited above.

We compute some numerical examples and find that, within reasonable ranges of parameters, the effects via the extensive margin are dominant. Under the benchmark parametrization, the range of imports increases slightly when domestic tariffs are reduced but narrows slightly in response to foreign trade liberalization. In response to a lower domestic tariff, the total volume of exports falls but the total volume of imports increases. A lower foreign tariff causes both the total volume of exports and the total volume of imports to go down. Under WTO type trade liberalization with lower domestic and foreign tariffs, intermediate goods trade yields large benefits to final goods producers. As a result, not only the final good output but also the measured productivity rise sharply.

Related Literature

On the empirical side, in addition to those cited above, the reader is referred to two useful survey articles by Dornbusch (1992) and Edwards (1993).

On the theoretical side, Yi (2002) and Peng, Thisse and Wang (2006) also examine the pattern of intermediate goods trade, but the range of intermediate products and the embodied technologies are exogenous. While Ethier (1982) determines the endogenous range of intermediate products with embodied technologies, there is no trade in intermediate goods. Flam and Helpman (1987) construct a North-South model of final goods trade in which the North produces an endogenous range of high quality goods and South produces an endogenous range of low quality goods. Although their methodology is similar to ours, their focus is on final goods trade. In contrast with these papers, our paper determines endogenously both the pattern and the extent of intermediate goods trade with endogenous technology choice. Moreover, we characterize intermediate good producer markups and the productivity gains from trade liberalization on both the intensive and extensive margins.

2 The Model

We consider a small country model in which the home (or domestic) country is less advanced technically than the large foreign country (Rest of the World.) Both the home and foreign country (ROW) consists of two sectors: an intermediate sector that manufactures a variety of products and a final sector that produces a single nontraded good using a basket of intermediate goods as inputs. All foreign (ROW) variables are labelled with the superscript *. We focus on the efficient production of the final good using either self-produced or imported intermediate goods. Whether to produce or import depends on the home country's technology choice decision and the international intermediate good markets.

Since our focus is on the efficient production of the final good using a basket of intermediate goods, we ignore households' intertemporal consumption-saving decisions and labor-market equilibrium. Thus, both the rental rate and the wage rate are exogenously given. Assume that the final good price is normalized to one.

2.1 The Final Sector

The output of the single final good at time t is produced using a basket of intermediate (capital) goods of measure M_t, where each variety requires ϕ units of labor. The more varieties used in producing the final good the more labor is required to coordinate production. Hence, denoting the mass of labor for production-line coordination at time t as D_t, we have:

$$M_t = \frac{1}{\phi} D_t \tag{1}$$

Thus, M measures the length of the production line. Each unit of labor is paid at a market wage $w > 0$.

The production technology of the final good at time t is given by:

$$Y_t = \alpha \int_0^{M_t} x_t(i)di - \frac{\beta - \gamma}{2} \int_0^{M_t} [x_t(i)]^2 \, di - \frac{\gamma}{2} \left[\int_0^{M_t} x_t(i)di \right]^2 \tag{2}$$

where $x_t(i)$ measures the amount of intermediate good i that is used and $\alpha > 0$, $\beta > \gamma$. Therefore, Y_t displays strictly decreasing returns. In this expression, α measures final good productivity, whereas $\beta > \gamma$ means that the level of production is higher when the production process is more sophisticated. We thus refer to $\beta - \gamma > 0$ as the *production sophistication effect*, which measures the positive effect of the sophistication of the production process on the productivity of the final good. For a given value of β, the parameter γ measures the complementarity/substitutability between different varieties of the intermediate goods: $\gamma >$ (resp., $<$) 0 means that intermediate good inputs are Pareto substitutes (resp., complements).

It is important to note that, with the conventional Spence-Dixit-Stiglitz-Ethier setup, ex post symmetry is imposed to get closed form solutions. In our analysis it is crucial to allow different intermediate goods in the production line to have different technologies. A benefit of using this production function is that even without imposing symmetry, we can still solve the model analytically. Moreover, under this production technology, intermediate producer markups become endogenous, varying across different firms.

2.2 The Intermediate Sector

Each variety of intermediate goods is produced by a single intermediate firm that has local monopoly power as long as varieties are not perfect substitutes. Consider a Ricardian technology in which production of one unit of each intermediate good $y_t(i)$ requires η units of nontraded capital (e.g., building and infrastructure) to be produced:

$$k_t(i) = \eta y_t(i) \tag{3}$$

where $i \in I$ that represents the domestic production range (to be endogenously determined).

In addition to capital inputs, each intermediate firm $i \in I$ also employs labor, both for manufacturing and for R&D purposes. Denote its production labor as $L_t(i)$ and R&D labor as $H_t(i)$. Thus, an intermediate firm i's total demand for labor is given by,

$$N_t(i) = L_t(i) + H_t(i) \tag{4}$$

With the required capital, each intermediate firm's production function is specified as:

$$y_t(i) = A_t(i) L_t(i)^{\theta} \tag{5}$$

where $A_t(i)$ measures the level of technology and $\theta \in (0, 1)$. By employing R&D labor, the intermediate firm can improve the production technology according to,

$$A_{t+1}(i) = (1 - \nu) A_t(i) + \psi_t(i) H_t(i)^{\mu} \tag{6}$$

where $\psi_t(i)$ measures the efficacy of investment in technological improvement, ν represents the technology obsolescence rate, and $\mu \in (0, 1)$. To ensure decreasing returns, we impose: $\theta + \mu < 1$.

3 Optimization

When a particular intermediate good is produced domestically but not exported to the world market (to be endogenously determined), such an intermediate producer has local monopoly power. Thus, we will first solve for the final sector's demand for intermediate goods and then each intermediate firm's supply and pricing decisions for the given demand schedule. Throughout the paper, we assume the final good sector and the intermediate good sector devoted to producing the industrial good under consideration is a small enough part of the entire economy that they take all factor prices as given.

3.1 The Final Good Sector

For now, assume that the home country produces all intermediate goods in the range $\left[0, n_t^P\right]$ and they export intermediates in the range $\left[0, n_t^E\right]$ where $n_t^E \leq n_t^P$ while intermediates in the range

$[n_t^P, M_t]$ are imported (see Figure 1 for a graphical illustration). We will later verify this assertion and solve for n_t^E , n_t^p, and M_t endogenously.

The firm that produces the final good has the following first-order condition with respect to intermediate goods demand $x_t(i)$ given by,

$$\frac{dY_t}{dx_t(i)} = \alpha - (\beta - \gamma)x_t(i) - \gamma \left[\int_0^{M_t} x_t(i^{'})di^{'} \right] = p_t(i), \ \forall \ \ i \in [0, M_t] \tag{7}$$

or,

$$p_t(i) = \begin{cases} PE_t(i) \equiv \frac{p_t^*(i)}{1+\tau^*}, \ \forall \ \ i \in [0, n_t^E] \\ PP_t(i) \equiv \alpha - \beta x_t(i) - \gamma \widetilde{X}_t^{-i} = \alpha - (\beta - \gamma)x_t(i) - \gamma \widetilde{X}_t, \ \ \forall \ i \in [n_t^E, n_t^P] \\ PM_t(i) \equiv (1+\tau)p_t^*(i), \ \ \forall \ \ i \in [n_t^P, M_t] \end{cases} \tag{8}$$

where $\widetilde{X_t} \equiv \int_0^{M_t} x_t(i^{'})di^{'}$, $\widetilde{X}_{t,}^{-i} \equiv \int_{i' \neq i} x_t(i^{'})di^{'} = \widetilde{X_t} - x(i)$. One can think of $\widetilde{X_t}$ as a measure of aggregate intermediate good usage. This implies the following Proposition.

Proposition 1: (Demand for Intermediate Goods) *Within the nontraded range $[n_t^E, n_t^P]$, the demand for intermediate good is downward sloping. If intermediate goods are Pareto substitutes ($\gamma > 0$), then the larger aggregate intermediate goods is (higher $\widetilde{X}_t$), the less individual intermediate good demand will be.*

Using Leibniz's rule, the final firm's first-order condition with respect to the length of the production line (M_t) can be derived as:[4]

$$\frac{dY_t}{dM_t} = \left[\alpha - \frac{\beta - \gamma}{2} x_t(M_t) - \gamma \widetilde{X_t} \right] x_t(M_t) = w\phi + p_t(M_t)x_t(M_t) \tag{9}$$

Manipulating these expressions yields the relative inverse demands for intermediate goods and the demand for the M^{th} intermediate good:

$$p_t(i) - p_t(i^{'}) = \begin{cases} \frac{1}{1+\tau^*}[p_t^*(i) - p_t^*(i^{'})], \ \ \forall \ i, i^{'} \in [0, n_t^E] \\ -(\beta - \gamma)[x_t(i) - x_t(i^{'})], \ \forall \ i, i^{'} \in [n_t^E, n_t^P] \\ (1+\tau)[p_t^*(i) - p_t^*(i^{'})], \quad \ \forall \ i, i^{'} \in [n_t^P, M_t] \end{cases} \tag{10}$$

From (9), we have:

$$\frac{\beta - \gamma}{2}[x_t(M_t)]^2 - [\alpha - \gamma \widetilde{X_t} - (1+\tau)p_t^*(M_t)]x_t(M_t) + w\phi = 0 \tag{11}$$

Given $\beta > \gamma$, the solution to relative demand exists if $[\alpha - \gamma \widetilde{X_t} - (1+\tau)p_t^*(M_t)]^2 > 2(\beta - \gamma)w\phi$.

[4] It is assumed there is a very large M^* being produced in the world so that any local demand for M can be met with imports from the rest of the world.

Proposition 2: (Relative Demand for Intermediate Goods) *Within the nontraded range* $[n_t^E, n_t^P]$*, the relative demand for intermediate goods is downward sloping. Additionally, the stronger the production sophistication effect is (higher* $\beta - \gamma$*), the less elastic the relative demand will be.*

Next, we determine how the intermediate goods sector works.

3.2 The Intermediate Sector

With local monopoly power, each intermediate firm can jointly determine the quantity of intermediate good to supply and the associated price. By utilizing (3) and (4), its optimization problem is described by the following Bellman equation:

$$\begin{aligned} \underset{\forall\ i\in[n_t^E, n_t^P]}{V(A_t(i))} &= \max_{p_t(i),\ y_t(i),\ L_t(i),\ H_t(i)} [(p_t(i)-\eta)y_t(i)] - w_t\left[L_t(i)+H_t(i)\right] + \frac{1}{1+\rho}V(A_{t+1}(i)) \quad (12) \\ & \quad \text{s.t.} \quad (5), (6) \text{ and } (8) \end{aligned}$$

Before solving the intermediate firm's optimization problem, it is convenient to derive marginal revenue:

$$\begin{aligned} \frac{d[(p_t(i)-\eta)y_t(i)]}{dy_t(i)} &= p_t(i) - \eta + y_t(i)\frac{dp_t(i)}{dy_t(i)} \\ &= p_t(i) - \eta - \beta y_t(i) \\ &= p_t(i) - \eta - \beta A_t(i) L_t(i)^\theta \end{aligned} \quad (13)$$

where $p_t(i)$ can be substituted out with (8).

Now we solve for the value functions for both nontraded intermediate goods $i \in [n_t^E, n_t^P]$ and exported intermediate goods $i \in [0, n_t^E]$. The first-order conditions with respect to the two labor demand variables is,

$$[p_t(i) - \eta - \beta A_t(i) L_t(i)^\theta]\theta A_t(i) L_t(i)^{\theta-1} = w_t \quad \forall\ i \in [n_t^E, n_t^P] \quad (14)$$

$$\frac{\mu}{1+\rho} V_{A_{t+1}}(i)\psi_t(i) H_t(i)^{\mu-1} = w_t \ \ \forall\ i \in [n_t^E, n_t^P] \quad (15)$$

The Benveniste-Scheinkman condition with respect to the state variable $A_t(i)$ is given by,

$$V_{A_t} = [p_t(i) - \eta - \beta A_t(i) L_t(i)^\theta] L_t(i)^\theta + \frac{1-\nu}{1+\rho} A_{t+1}(i) \quad \forall\ i \in [n_t^E, n_t^P] \quad (16)$$

Similarly, we have the value function for $i \in [0, n_t^E]$, as

$$\begin{aligned} \underset{\forall\ i\in[0, n_t^E]}{V(A_t(i))} &= \max_{p_t(i),\ y_t(i),\ L_t(i),\ H_t(i)} \left\{ [\frac{p_t^*(i)}{1+\tau^*} - \eta] A_t(i) L_t(i)^\theta - w_t\left[L_t(i)+H_t(i)\right] \right. \\ & \qquad \left. + \frac{1}{1+\rho} V_{t+1}[(1-\nu)A_t(i) + \psi_t(i) H_t(i)^\mu] \right\} \end{aligned} \quad (17)$$

where we have used (6) and (8) for $i \in [0, n_t^E]$. We can obtain the first-order conditions with respect to $L_t(i)$ and $H_t(i)$, respectively, as follows:

$$\theta[\frac{p_t^*(i)}{1+\tau^*} - \eta]A_t(i)L_t(i)^{\theta-1} = w_t, \qquad \forall\, i \in [0, n_t^E] \tag{18}$$

$$\frac{\mu}{1+\rho}V_{A_{t+1}}(i)\psi_t(i)H_t(i)^{\mu-1} = w_t, \ \ \forall\, i \in [0, n_t^E] \tag{19}$$

The Benveniste-Scheinkman condition with respect to the state variable $A_t(i)$ is given by,

$$V_{A_t} = [\frac{p_t^*(i)}{1+\tau^*} - \eta]L_t(i) + \frac{1-\nu}{1+\rho}V_{A_{t+1}}(i) = 0, \qquad \forall\, i \in [0, n_t^E] \tag{20}$$

We now turn to solving the system for a steady state.

4 Steady-State Equilibrium

Since our focus is on efficient production of the final good using a basket of intermediate goods, we ignore households' intertemporal consumption-saving decision and labor-market equilibrium. Thus, both the rental rate and the wage rate are exogenously given in our model economy. These assumptions simplify our analysis of labor allocation and technology choice.

4.1 Labor Allocation

In steady-state equilibrium, all endogenous variables are constant over time. Thus, (6) implies:

$$H\left(i\right) = \left[\frac{\nu A\left(i\right)}{\psi\left(i\right)}\right]^{\frac{1}{\mu}}, \quad i \in [0, n^P] \tag{21}$$

We can also rewrite (19) as:

$$V_A = \frac{(1+\rho)wH(i)^{1-\mu}}{\mu\psi\left(i\right)}, \qquad i \in [0, n^P]$$

which can then be plugged into (20) to obtain:

$$\frac{(\rho+\nu)wH(i)^{1-\mu}}{\mu\psi\left(i\right)}\left(\frac{\nu A\left(i\right)}{\psi\left(i\right)}\right)^{\frac{1-\mu}{\mu}} = [\frac{p^*(i)}{1+\tau^*} - \eta]L\left(i\right)^{\theta}, \quad \forall \ \ i \in [0, n^E]$$

Using (18) and (21) to simplify the above expression, we have:

$$A\left(i\right) = \overline{A}\psi\left(i\right)L\left(i\right)^{\mu}, \ \ \forall \ \ i \in [0, n^P] \tag{22}$$

where

$$\overline{A} \equiv \frac{1}{\nu^{1-\mu}}\left[\frac{\mu}{\theta(\rho+\nu)}\right]^{\mu} > 0.$$

One can think of $\overline{A}$ as the technology scaling factor and $\psi(i)$ as the technology gradient that measures how quickly technology improves as i increases.

Next, we substitute (8) and (22) into (18) to eliminate $p(i)$ and $A(i)$, yielding the following expression in $L(i)$ alone:

$$\theta[\frac{p^*(i)}{1+\tau^*} - \eta]\overline{A}\psi(i)\, LE(i)^{\theta+\mu-1} = w, \quad \forall \quad i \in [0, n^E] \tag{23}$$

which can be used to derive labor demand for $i \in [0, n^E]$: $LE(i) = \{\frac{\theta}{w}[\frac{p^*(i)}{1+\tau^*} - \eta]\overline{A}\psi(i)\}^{\frac{1}{1-\theta-\mu}}$.

$$\underset{\forall\ i\in[n^E,n^P]}{MPL(i)} = \theta\overline{A}\psi(i)\, LP(i)^{-(1-\mu-\theta)}\left[\alpha - \eta - \gamma\widetilde{X}^{-i} - 2\beta\overline{A}\psi(i)\, LP(i)^{\mu+\theta}\right] = w \tag{24}$$

It is clear that $MPL(i)$ is strictly decreasing in $L(i)$ with $\lim_{L(i)\longrightarrow 0} MPL(i) \longrightarrow \infty$ and $\lim_{L(i)\longrightarrow L_{\max}}$ $MPL(i) = 0$, where

$$L_{\max} \equiv \left[\frac{\alpha - \eta - \gamma\widetilde{X}^{-i}}{2\beta\overline{A}\psi(i)}\right]^{\frac{1}{\theta+\mu}}$$

Figure 2 depicts the $MPL(i)$ locus, which intersects w to pin down labor demand in steady-state equilibrium (point E). It follows that $\frac{dL(i)}{dw} < 0$ and $\frac{dL(i)}{d\alpha} > 0$, $\frac{dL(i)}{d\eta} < 0$, $\frac{dL(i)}{d\beta} < 0$ and $\frac{dL(i)}{d\gamma} < 0$.

That is, an increase in the final good productivity (α), or a decrease in the unit capital requirement (η), the magnitude of variety bias (β), or the degree of substitutability between intermediate good varieties (γ) increases the intermediate firm's demand for labor. Note that the direct effect of improved efficiency of investment in intermediate good production technology ($\psi(i)$) is to increase the marginal product of labor and induce higher labor demand by intermediate firms. This we call the induced demand effect. However, there is also a labor saving effect. Under variable monopoly markups, a better technology enables the intermediate firm to supply less and extract a higher markup which will save labor inputs. Thus, the overall effect is generally ambiguous. Finally, and also most interestingly, when final good production becomes more sophisticated (larger M), it is clear that the $\widetilde{X}^{-i}$ will rise, thereby shifting the $MPL(i)$ locus downward and lowering each variety's labor demand for a given wage rate. Summarizing these results we have:

Proposition 3: (Labor Demand for Intermediate Goods Production) *Within the nontraded range $[n^E, n^P]$, labor demand is downward sloping. Moreover, an increase in final good productivity (α) or a decrease in the overall length of the final good production line (M), the unit capital requirement (η), the magnitude of variety bias (β), or the degree of substitutability between intermediate good varieties (γ) increases the intermediate firm's demand for labor in the steady state.*

Next, we can use (4), (21) and (23) to derive R&D labor demand and total labor demand by each intermediate firm as follows:

$$H(i) = \left(\nu \overline{A}\right)^{\frac{1}{\mu}} L(i), \quad \forall \;\; i \in [0, n^E] \tag{25}$$

$$N(i) = L(i) + H(i) = \left[1 + \left(\nu \overline{A}\right)^{\frac{1}{\mu}}\right] L(i), \quad \forall \;\; i \in [0, n^E] \tag{26}$$

Combining the supply of and the demand for the M^{th} intermediate good, (5) with $i = n^P$ and (6), we have

$$y(i) = \overline{A}\psi\left(i\right) L\left(i\right)^{\theta+\mu}, \;\; i \in [0, n^P] \tag{27}$$

In equilibrium, we can re-write the supply of intermediate good i as:

$$y(i) = \begin{cases} x(i) + z^*(i) > x(i), & & i \in [0, n^E] \\ x(i), & \text{if} & i \in [n^E, n^P] \\ x(i) = z(i) > 0 & & i \in [n^P, M] \end{cases} \tag{28}$$

where $z^*(i)$ is home country exports of intermediate good i and $z(i)$ is home country imports of intermediate good i. Substituting (27) into (8), we have:

$$\begin{aligned} z^*(i) &= y(i) - x(i) \\ &= \overline{A}\psi\left(i\right) L\left(i\right)^{\theta+\mu} - \frac{\alpha - \gamma\widetilde{X} - \frac{p^*(i)}{1+\tau^*}}{\beta - \gamma}, \quad \forall i \in [0, n^E] \end{aligned} \tag{29}$$

From (8) and (23), we can derive aggregate intermediate good usage as:

$$\widetilde{X} = \int_0^{n^P} \overline{A}\psi\left(i\right) L\left(i\right)^{\theta+\mu} di + \int_{n^P}^{M} z(i) di - \int_0^{n^E} z^*(i) di \tag{30}$$

The aggregate labor demand is given by,

$$\overline{N} = \phi M + \left[1 + \left(\nu \overline{A}\right)^{\frac{1}{\mu}}\right] \left[\int_0^{n^P} L(i) di\right] \tag{31}$$

We assume that labor supply in the economy is sufficiently large to ensure the demand is met.

4.2 Technology Choice and Pattern of Production and Trade

The local country's technology choice with regards to intermediate goods production depends crucially on whether local production of a particular variety is cheaper than importing it. For convenience, we arrange the varieties of intermediate goods from the lowest technology to highest technology. Without loss of generality, it is assumed that

$$\psi(i) = \overline{\psi}(1 + \delta \cdot i), \quad \psi^*(i) = \overline{\psi}^*(1 + \delta^* \cdot i) \tag{32}$$

where $\psi_0 \leq \psi_0^*$ and $\delta < \delta^*$.

From (7) and (8), we have:

$$x(i) = \begin{cases} xE(i) \equiv \frac{\alpha - \gamma\widetilde{X} - \frac{p^*(i)}{1+\tau^*}}{\beta-\gamma} & i \in [0, n^E] \\ xP(i) \equiv \overline{A}\psi(i)\, L(i)^{\theta+\mu} \quad \text{if} & i \in [n^E, n^P] \\ xM(i) \equiv \frac{\alpha - \gamma\widetilde{X} - (1+\tau)p^*(i)}{\beta-\gamma} & i \in [n^P, M] \end{cases} \tag{33}$$

where $L(i)$, $i \in [n^E, n^P]$, is pinned down by (23). Thus, the value of net exports of intermediate goods is:

$$E = \frac{1}{1+\tau^*}\int_0^{n^E} p^*(i)xE(i)di - (1+\tau)\int_{n^P}^{M} p^*(i)xM(i)di \tag{34}$$

Trade balance therefore implies that domestic final good consumption is given by,

$$C = Y + E \tag{35}$$

That is, when the intermediate goods sector runs a trade surplus, the final good sector will have a trade deficit.

Notice that $p(i)$ is decreasing in $\psi(i)$, which implies that better technology corresponds to lower costs and hence lower intermediate good prices. As a result, it is expected that $\frac{dp(i)}{di} < 0$; that is, the intermediate good price function is downward-sloping in ordered varieties (i). Thus, we have the following proposition.

Proposition 4: (Producer Price Schedule) *Within the nontraded range $[n^E, n^P]$, the steady-state intermediate good price schedule is downward sloping in ordered varieties (i).*

This can then used to compute aggregate intermediate goods:

$$\begin{aligned}
\widetilde{X} &= \int_0^{n^P} \overline{A}\psi(i)\, L(i)^{\theta+\mu} di + \int_{n^P}^{M} z(i)di - \int_0^{n^E} z^*(i)di \\
&= \int_0^{n^P} \overline{A}\psi(i)\, L(i)^{\theta+\mu} di + \int_{n^P}^{M} \frac{\alpha - \gamma\widetilde{X} - (1+\tau)p^*(i)}{\beta-\gamma} di \\
&\quad - \int_0^{n^E}\left[\overline{A}\psi(i)\, L(i)^{\theta+\mu} - \frac{\alpha - \gamma\widetilde{X} - \frac{p^*(i)}{1+\tau^*}}{\beta-\gamma}\right] di \\
&= \overline{A}\int_{n^E}^{n^P} \psi(i)\, L(i)^{\theta+\mu} di - \frac{1}{\beta-\gamma}\left[(1+\tau)\int_{n^P}^{M} p^*(i)di + \frac{1}{1+\tau^*}\int_0^{n^E} p^*(i)di\right] \\
&\quad + \frac{\alpha - \gamma\widetilde{X}}{\beta-\gamma}(M + n^E - n^P)
\end{aligned}$$

or,

$$\widetilde{X}=\frac{\overline{A}\int_{n^E}^{n^P}\psi\left(i\right)L\left(i\right)^{\theta+\mu}di+\frac{\alpha}{\beta-\gamma}(M+n^E-n^P)-\frac{1}{\beta-\gamma}\left[(1+\tau)\int_{n^P}^{M}p^*(i)di+\frac{1}{1+\tau^*}\int_{0}^{n^E}p^*(i)di\right]}{1+\frac{\gamma}{\beta-\gamma}(M+n^E-n^P)} \tag{36}$$

which we call the *intermediate-good aggregation* (XX) locus. In addition, by substituting (33) into (11), we can get the boundary condition at M:

$$\alpha-\gamma\widetilde{X}-(1+\tau)p^*(M)=\sqrt{2(\beta-\gamma)w\phi} \tag{37}$$

which will be referred to as the *production-line trade-off* (MM) locus.

Before characterizing the relationship between M and $\widetilde{X}$, it is important to check the second-order condition with respect to the length of the production line. From (11), and (36), we can derive the second-order condition as:

$$\frac{\gamma Mx(M)}{(1+\tau)p^*(M)}>-\frac{M}{p^*(M)}\frac{dp^*(M)}{dM}$$

Under the following world price specification:

$$p^*(i)=\overline{p}-b\cdot i$$

the second-order condition becomes:

Condition S: $b<\frac{\gamma}{1+\tau}\sqrt{\frac{2w\phi}{\beta-\gamma}}$.

Thus, it is necessary to assume that intermediate goods are Pareto substitutes in producing the final good ($\gamma>0$), which we shall impose throughout the remainder of the paper.

The next condition to check is the nonnegative profit condition for the intermediate-good firms. For $i\in[n^E,n^P]$, we have:

$$\pi(i)=[\alpha-\gamma\widetilde{X}^{-i}-\eta-\beta x(i)]\overline{A}\psi\left(i\right)L\left(i\right)^{\theta+\mu}-wL(i)[1+(\nu\overline{A})^{\frac{1}{\mu}}]=\Lambda(i)wN(i) \tag{38}$$

where the markup is defined as $\Lambda(i)\equiv\frac{p(i)-\eta}{\theta[1+(\nu\overline{A})^{1/\mu}][p(i)-\eta-\beta x(i)]}-1$. For $i\in[0,n^E]$, we have:

$$\begin{aligned}\pi(i)&=[\frac{p^*(i)}{1+\tau^*}-\eta]\overline{A}\psi\left(i\right)L\left(i\right)^{\theta+\mu}-wL(i)[1+(\nu\overline{A})^{\frac{1}{\mu}}]\\&=\overline{A}\psi\left(i\right)L\left(i\right)^{\theta+\mu}[\frac{p^*(i)}{1+\tau^*}-\eta]\{1-\theta[1+(\nu\overline{A})^{\frac{1}{\mu}}]\}\end{aligned}$$

Therefore, to ensure nonnegative profit, we must impose $\frac{p(i)-\eta}{p(i)-\eta-\beta x(i)}>\theta[1+(\nu\overline{A})^{\frac{1}{\mu}}]$ (i.e., $\Lambda(i)>0$) for $i\in[n^E,n^P]$ and $\theta[1+(\nu\overline{A})^{\frac{1}{\mu}}]<1$ for $i\in[0,n^E]$. Since the latter condition always implies the former, we can simply specify the following condition to ensure positive profitability:

Condition N: $\theta[1 + (\nu\overline{A})^{\frac{1}{\mu}}] < 1$.

The MM and XX loci are drawn in Figure 3. The MM locus (equation (37)) and the XX locus (equation (36)) are the loci that relate $\widetilde{X}$ to M are both positively sloped. First, consider the MM locus. Notice that since intermediate goods are Pareto substitutes, the direct effect of an increase in aggregate intermediate goods, $\widetilde{X}$, is to reduce the demand for each intermediate good. As M increases, the price of the intermediate good at the boundary, $p^*(M)$, falls, as does the cost of using this intermediate good. This encourages the demand for $x(M)$ and, to restore equilibrium in (37), one must adjust $\widetilde{X}$ upward, implying that the MM locus is upward sloping. The intuition underlying the XX locus is more complicated. For illustrative purposes, let us focus on the direct effects. As indicated by (36), the direct effect of a more sophisticated production line (higher M) is to raise the productivity of manufacturing the final good as well as the cost of intermediate inputs. While the productivity effect increases aggregate demand for intermediate goods, the input cost effect reduces it. On balance, it is not surprising that the positive effect dominates as long as such an operation is profitable. Nonetheless, due to the conflicting effects, the positive response of $\widetilde{X}$ to M is not too large and, as a result, the XX locus is flatter than the MM locus. The equilibrium is illustrated in Figure 3 by point E.

4.3 Trade Liberalization

4.3.1 Effects on Pattern of Production and Trade

We now consider the effects of trade liberalization. We begin by determining the effect of trade liberalization on the overall length of the production line. Consider first a decrease in the domestic tariff (τ). This decrease in domestic protection lowers the domestic cost of imported intermediate inputs i, $(1 + \tau)p^*(i)$ and hence increases demand. This causes the MM locus to shift up (see Figure 3a). The effect on the XX locus is, however, ambiguous. While there is a direct positive effect of domestic trade liberalization on $\widetilde{X}$, there are many indirect channels via the endogenous cutoffs, n^E and n^P. While we will return to this later, our numerical results show that the shift of the XX locus is small compared to the shift in the MM locus. Therefore, in this case one expects the net effect of domestic trade liberalization to decrease the overall length of the production line (lower M) as seen in Figure 3a. This suggests that although domestic trade liberalization increases imported intermediate inputs on the intensive margin, final producers react to it by shifting away from imports of higher types to the cheaper lower type intermediate inputs, thereby decreasing the overall length of the production line. This latter effect is via the *extensive margin* of import demand.

Next consider a decrease in the foreign tariff τ^*. From (37), one can see that a change in τ^* will not alter the MM locus. However, inspection of equation (36), indicates that the direct effect of a decrease in $\tau^*$is to shift the XX locus down (see Figure 3b). Intuitively, foreign trade liberalization increases exports on the *intensive margin*, which reduces the amount of intermediate goods available for domestic use. As a consequence, aggregate intermediate demand by domestic final producers decreases and this leads to a reduction of the overall length of the production line.

We summarize these results in Proposition 5.

Proposition 5: (The Length of the Production Line) *Under Assumptions S and N, the steady-state overall length of the production line is determined by the XX and MM loci. Moreover,*

(i) *it decreases in response to domestic trade liberalization (lower τ) if the extensive margin of import demand is sufficiently strong;*

(ii) *it decreases in response to foreign trade liberalization (lower τ^*).*

We next turn to determining the effect of domestic and foreign tariffs on the pattern of domestic production and export. From (8) and (33), we can obtain the following two key relationships that determine the cutoff values, n^E and n^P, respectively:

$$PP(n^E) = \alpha - \gamma\widetilde{X} - (\beta-\gamma)\overline{A}\psi\left(n^E\right)LP\left(n^E\right)^{\theta+\mu} = \frac{p^*(n^E)}{1+\tau^*} = PE(n^E) \tag{39}$$

$$PP(n^P) = \alpha - \gamma\widetilde{X} - (\beta-\gamma)\overline{A}\psi\left(n^P\right)LP\left(n^P\right)^{\theta+\mu} = (1+\tau)p^*(n^P) = PM(n^P) \tag{40}$$

The two loci are plotted in Figure 4 along with the locus for $PM(i)$ given by equation (8). The equilibrium price locus is captured by $\widetilde{ABCD}$. Namely, the equilibrium price is an envelope that is pinned down by $PE(i)$ over $[0, n^E]$, by $PP(i)$ over $[n^E, n^P]$ and by $PM(i)$ over $\left[n^P, M\right]$.

To better understand the comparative statics with respect to the effects of trade liberalization on the two cutoffs, we separate the conventional effects via the intensive margin from the effects via the extensive margin on the overall length of the production line. We first consider the effects on non-traded intermediate goods, i.e. those in the range $[n^E, n^P]$.

$$\begin{aligned}
\frac{dPP(i)}{d\tau} &= \frac{\partial PP(i)}{\partial\tau} + \frac{\partial PP(i)}{\partial LP(i)}\frac{dLP(i)}{d\tau} + \frac{\partial PP(i)}{\partial M}\frac{dM}{d\tau} \\
\frac{dPP(i)}{d\tau^*} &= \frac{\partial PP(i)}{\partial M}\frac{dM}{d\tau^*} < 0
\end{aligned}$$

Since domestic trade liberalization increases imported intermediate good demand, it induces reallocation of labor toward imported intermediates, which causes the $PP(i)$ locus to shift up. In addition, on the extensive margin, the overall length of the production line shrinks, thereby decreasing aggregate intermediate inputs and also causing the $PP(i)$ locus to shift up. Nonetheless, from (37), there is a direct positive effect of domestic trade liberalization on $\widetilde{X_t}$ via the demand for $x(M)$ on the intensive margin, which in turn shifts the $PP(i)$ locus down. When the effect via the extensive margin is strong (as is observed empirically; see an illustration in Figures 5-1a,b), on balance trade liberalization will lead to a upward shift in the $PP(i)$ locus, i.e., $\frac{dPP(i)}{d\tau} > 0$ (see Figures 5-2a,b). Since foreign trade liberalization has no effect on the intensive margin, its negative effect on M shifts the $PP(i)$ locus up (see Figures 5-3a,b).

The responses of $PE(i) = \frac{p^*(i)}{1+\tau^*}$ and $PM(i) = (1+\tau)p^*(i)$ are clear-cut. While domestic trade liberalization rotates the $PM(i)$ locus downward, foreign trade liberalization rotates the $PE(i)$ locus upward. We now examine the first cutoff pinned down by (39), which determines the range of exports.

$$\begin{aligned} \frac{dn^E}{d\tau} &= \frac{\partial n^E}{\partial \tau} + \frac{\partial n^E}{\partial M}\frac{dM}{d\tau} \\ \frac{dn^E}{d\tau^*} &= \frac{\partial n^E}{\partial \tau^*} + \frac{\partial n^E}{\partial M}\frac{dM}{d\tau^*} \end{aligned}$$

From the discussion above, lower domestic tariffs yield a negative direct effect on the $PP(i)$ locus, which leads to a higher cutoff n^E and hence a larger range of exports. However, there is a general equilibrium labor reallocation effect and an extensive margin effect via the overall length of the production line, both shifting the $PP(i)$ locus upward. When the effect via the extensive margin is strong, the cutoff n^E decreases and the range of exports shrinks.

Next, consider the effect of foreign trade liberalization on n^E. First, there is no direct effect of foreign trade liberalization. However, there is a positive indirect effect via the extensive margin on $PP(i)$. As in the standard case, a lower foreign tariff increases $PE(i)$, which, under a fixed value of M, increases n^E and the range of exports. With a strong effect via the extensive margin, however, the results would be reversed, that is, lower foreign tariffs could lead to a smaller range of exports.

We now turn to the second cutoff n^P. Based on (40) we can determine the range of domestic production of intermediate inputs and the range of imports.

$$\begin{aligned} \frac{dn^P}{d\tau} &= \frac{\partial n^P}{\partial \tau} + \frac{\partial n^P}{\partial M}\frac{dM}{d\tau} \\ \frac{dn^P}{d\tau^*} &= \frac{\partial n^P}{\partial M}\frac{dM}{d\tau^*} \end{aligned}$$

Recall that, when the effect via the extensive margin is strong, a lower domestic tariff causes the

$PP(i)$ locus to shift up. In addition, the $PM(i)$ locus rotates downward. Both result in a lower cutoff n^P and hence a smaller range of domestic production. Should the overall length M be unchanged, the range of imports would increase. But, since M shrinks, the net effect on the range of imports is generally ambiguous.

In response to a lower foreign tariff, the only change is the upward shift in the $PP(i)$ locus via the shrinkage of M on the extensive margin. It is therefore, unambiguous to have a lower cutoff n^P and a smaller range of domestic production. This effect is absent in the conventional trade literature. To summarize, foreign trade liberalization does not affect the range of domestic imports. Again, since M shrinks, the range of imports need not increase.

We illustrate these comparative statics in Figures 5-1a,b and 5-2a,b and summarize the results in Proposition 6.

Proposition 6: (The Range of Exports, Domestic Production and Imports) *Under Assumptions S and N, the steady-state pattern of international trade features exporting over the range* $[0, n^E]$ *and importing over the range* $[n^P, M]$ *where the range* $[n^E, n^P]$ *is nontraded. Moreover, the steady-state equilibrium possesses the following properties:*

(i) *in response to domestic trade liberalization (lower* τ*),*

- **a.** *the import price* $PM(i)$ *falls whereas the domestic producer price* $PP(i)$ *increases if the effect via the extensive margin is strong;*
- **b.** *both the range of exports* $[0, n^E]$ *and the range of domestic production* $[0, n^P]$ *shrink if the effect via the extensive margin is strong;*

(ii) *in response to foreign trade liberalization (lower* τ^**),*

- **a.** *while the export price* $PE(i)$ *always increases, the domestic producer price* $PP(i)$ *also increases if the effect via the extensive margin is strong;*
- **b.** *while the range of domestic production* $[0, n^P]$ *always shrinks, the range of exports* $[0, n^E]$ *shrinks if the effect via the extensive margin is strong;*

(iii) *in response to either domestic or foreign trade liberalization, the range of imports is generally ambiguous.*

4.3.2 Markups, Productivity and Technology

We next turn to consideration of the effect of trade liberalization on markups. In the domestic exporting range $\left[0, n^E\right]$, an intermediate firm's markup becomes trivial, depending positively on foreign tariff. That is, foreign trade liberalization will reduce domestic markups. In the nontraded range $i \in [n^E, n^P]$, we can see from (38) that markups will respond endogenously to trade policy. As shown in Proposition 6, in response to a reduction in the domestic tariff τ, the domestic producer price $PP(i)$ rises when the effect via the extensive margin is strong. Moreover, there is a shift from domestic to imported intermediate inputs and hence $x(i)$ falls. Both lead to lower markups received by domestic intermediate good firms. Thus, we have:

Proposition 7: (Markups) *Under Assumptions S and N, domestic intermediate firms' markups in the steady-state equilibrium always decrease in response to foreign trade liberalization (lower τ^*) and fall in response to domestic trade liberalization (lower τ) if the effect via the extensive margin is strong.*

We turn to determining how trade liberalization affects productivity and technology. It can be seen from Proposition 6 that under domestic trade liberalization, the range of domestic production $\left[0, n^P\right]$ shrinks if the effect via the extensive margin is strong. Thus, some higher technology intermediate goods are now imported, which are produced in the North with lower costs, thereby resulting in unambiguous productivity gains. The effect on average productivity is, however, not obvious. Define the aggregate technology used by domestic producers as $\widetilde{A} = \int_0^{n^P} A\left(i, M\right) di$. Utilizing (22), we can write:

$$\widetilde{A} = \overline{A} \int_0^{n^P} \psi\left(i\right) LP\left(i\right)^{\mu} di \tag{41}$$

Consider the benchmark case where the extensive margin of import demand is sufficiently strong. Then, domestic trade liberalization (lower τ) will reduce the overall length of the production line as well as the range of domestic production. While the latter decreases aggregate technology, the former raises individual labor demand and hence individual technology used for each intermediate good employed by the domestic final producer (recall Proposition 3). Thus, to domestic producers, when the extensive margin of import demand is strong, domestic trade liberalization can reduce average technology $\frac{\widetilde{A}}{n^P}$ as long as the technology gradient $\psi\left(i\right)$ is not too flat. Nonetheless, average productivity measured by $\frac{Y}{\widetilde{X}}$ will increase due to the use of more advanced imported intermediate inputs with a sufficiently strong extensive margin. Applying Proposition 6, we can see that foreign trade liberalization will lead to a similar outcome in average technology and average productivity. These results can be summarized in the following proposition.

Proposition 8: (Productivity) *Under Assumptions S and N with a sufficiently strong extensive margin of import demand, domestic trade liberalization results in productivity gains for newly imported intermediate goods as well as an increase in average productivity. Moreover, foreign trade liberalization also leads to higher average productivity. If, in addition, the technology gradient is not too flat, both aggregate and average technology by domestic producers are lower in response to domestic or foreign trade liberalization (lower τ or τ^*).*

This result is interesting because it points out that productivity and technology do not always move together. In this model, trade liberalization leads to higher productivity because input prices fall. This fall in input prices leads to a lower level of technology being chosen in equilibrium as lower productivity inputs are used more intensively while the range of intermediate goods used decreases. This latter effect means that a lower level of technology is used by producers.

5 Numerical Analysis

Since some of the theoretical results are ambiguous we present some numerical examples to illustrate how trade liberalization might work. For our baseline economy we set the time preference rate as $\rho = 7.5\%$ and the technology obsolescence rate as $\nu = 25\%$. We select the intermediate sector production parameters as $\theta = 0.5$ and $\mu = 0.2$, which satisfies the requirement for decreasing returns to scale, $\theta + \mu < 1$. We choose the final sector production parameters as $\alpha = 10$, $\beta = 0.2$ and $\gamma = 0.1$, satisfying the requirements, $\beta - \gamma > 0$. Normalize $\eta = 1$ and set $\phi = 0.05$. The technology and world price schedules are given by: $\psi(i) = 5\,(1 + 0.1 \cdot i)$ and $p^*(i) = 2.5 - 0.05 \cdot i$. Letting $w = 50$, this insures that both Conditions S and N are satisfied. Finally, we choose $\tau = 7.5\% > \tau^* = 5\%$.

The computed ranges of exports, nontraded intermediate goods and imports turn out to be: $[0, n^E] = [0, 9.04]$, $[n^E, n^P] = [9.04, 12.05]$ and $[n^p, M] = [12.05, 21.62]$, respectively. The average markup of domestic non-exporting producers is: $\frac{\tilde{\Lambda}}{n^P - n^E} \equiv \frac{\int_{n^E}^{n^P} \Lambda(i)di}{n^P - n^E} = 0.768$. While aggregate intermediate goods turns out to be $\widetilde{X} = 77.68$, aggregate and average technology used by domestic producers are $\widetilde{A} = 963.94$ and $\frac{\widetilde{A}}{n^P} = 80.00$, respectively. The computed final good output is $Y = 301.84$ and the corresponding productivity measure is $\frac{Y}{\widetilde{X}} = 3.89$. By including the domestic tariff revenue $R = \tau \int_{n^P}^{M} p^*(i)x(i)di$, the augmented productivity measure becomes $\frac{Y+R}{\widetilde{X}} = 3.99$.

Moreover, total values of intermediate goods exports and imports are 172.47 and 120.65, respectively, and net exports are 51.81, implying that the final good is imported import for balanced trade. Per capita final good consumption turns out to be 0.0311. In this benchmark economy, the extensive margin of import demand is sufficiently strong for the overall length of the production line to play a dominant role.

Now consider domestic trade liberalization in the form of a one percentage point decrease in the domestic tariff which lowers τ to 6.5%. The overall length of the production line M shrinks from 21.62 to 20.66. Again, with strong effects via M on the extensive margin, both the range of exports and the range of domestic production decrease. In particular, the computed range of exports falls to $[0, n^E] = [0, 7.78]$. The range of nontraded intermediate goods is $[n^E, n^P] = [7.78, 10.95]$ which means the range increases from 3.01 to 3.17, however, the overall range of home produced goods shrinks. The range of imports is now $[n^p, M] = [10.95, 20.66]$ which is a slightly increased range. So trade liberalization increases the range of non-traded and imported goods, but the range of exports decreases by a large amount leading to a smaller range of intermediate goods used to produce the final good. Aggregate intermediate goods usage falls slightly to $\widetilde{X} = 77.31$ indicating that the increase in the intensive margin does not quite compensate for the decrease in the extensive margin. Since in our benchmark economy, the technology gradient is not too flat, aggregate and average technology used by domestic producers actually fall to $\widetilde{A} = 782.35$ and $\frac{\widetilde{A}}{n^P} = 71.47$. Moreover, the average markup of domestic non-exporting producers decreases sharply to $\frac{\tilde{\Lambda}}{n^P - n^E} = 0.711$. What happens to output and productivity? Both of them increase significantly. Computed final good output increases to $Y = 357.53$ and productivity increases to $\frac{Y}{\widetilde{X}} = 4.62$. Including the domestic tariff revenue, augmented productivity measure increases to $\frac{Y+R}{\widetilde{X}} = 4.72$. Exports decrease to 148.94 while imports increase slightly to 125.09, thereby causing intermediate goods net export to fall to 23.85. In this case, per consumption rises sharply to 0.0444.

Next, starting from our benchmark equilibrium, consider foreign trade liberalization, in the form of a one percentage point decrease in the foreign tariff to $\tau^* = 4\%$. The overall length of the production line M shrinks from 21.62 to 19.84. Again, with strong effects via M on the extensive margin, both the range of exports and the range of domestic production decrease. Moreover, the range of imports is also narrowed slightly. In aggregate quantities, both total exports and total imports drop whereas net export of intermediate goods shrinks sharply from 51.81 to 5.63. As a result of the reduced length of the production line, aggregate intermediate goods fall, but, not surprisingly, the reduced tariff distortion causes final good output to increase to $Y = 397.50$ and measured productivity to rise sharply to $\frac{Y}{\widetilde{X}} = 5.18$. Moreover, the average markup of domestic non-exporting producers falls to 0.681, the average technology used by domestic producers decreases to 62.80, whereas per capita consumption increases to 0.0603.

We have done several other numerical exercises but will only report one additional experiment. Specifically, we consider an environment with global trade liberalization such as WTO or bilateral/multilateral trade agreements, say, with both domestic and foreign tariff falling by 10%. In this case, both the final good output and the measured productivity rise sharply, from $Y = 301.84$ and $\frac{Y}{\widetilde{X}} = 3.89$, to $Y = 391.11$ and $\frac{Y}{\widetilde{X}} = 5.09$, respectively, despite a reduction in average technology used by domestic producers and average markup of domestic non-exporting producers. Notably, a moderate 10% reduction in trade costs globally can lead to large production and efficiency gains where both aggregate output and average productivity rise by about 30%.

6 Concluding Remarks

We have constructed a dynamic model of intermediate goods trade to determine both the pattern and the extent of intermediate goods trade. We have established that, although domestic trade liberalization increases imported intermediate inputs on the intensive margin, final goods producers react to it by shifting imports to lower types of intermediate inputs to lower the production cost. This decreases the overall length of the production line.

When such an effect via the extensive margin is strong, both domestic and foreign trade liberalization lead to a reduction of the ranges of export and domestic production, but their effects on the range of imports are generally ambiguous. We have shown that, when the extensive margin effect of import demand is sufficiently strong, domestic trade liberalization leads to lower markups and greater competition and results in productivity gains. If, in addition, the technology gradient is not too flat, then such productivity gains from trade liberalization can be associated with lower aggregate and average technology by domestic intermediate goods producers. We have also established numerically that trade liberalization (lower domestic and foreign tariffs) can yield large benefits to final goods producers, resulting in sharp increases in both the final good output and measured productivity.

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Figure 1. Determination of Intermediate Goods Allocation

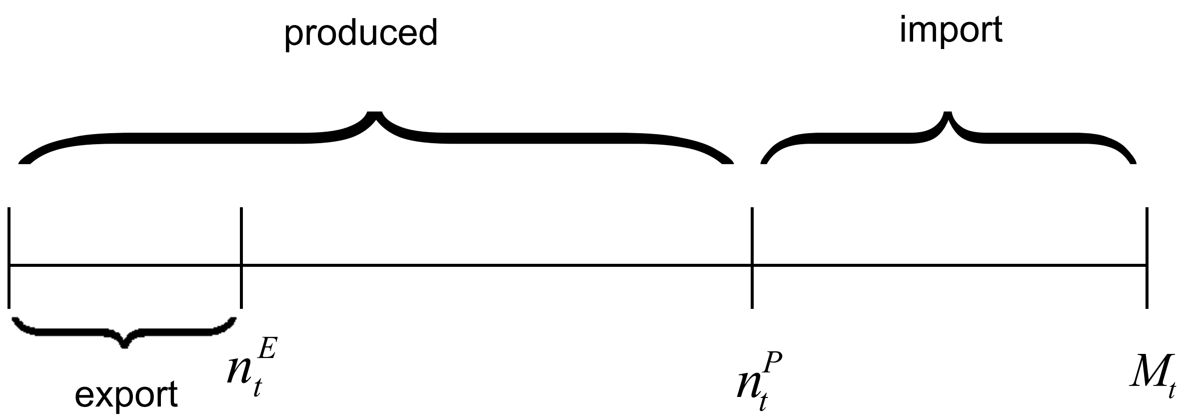


Figure 2. Labor Allocation

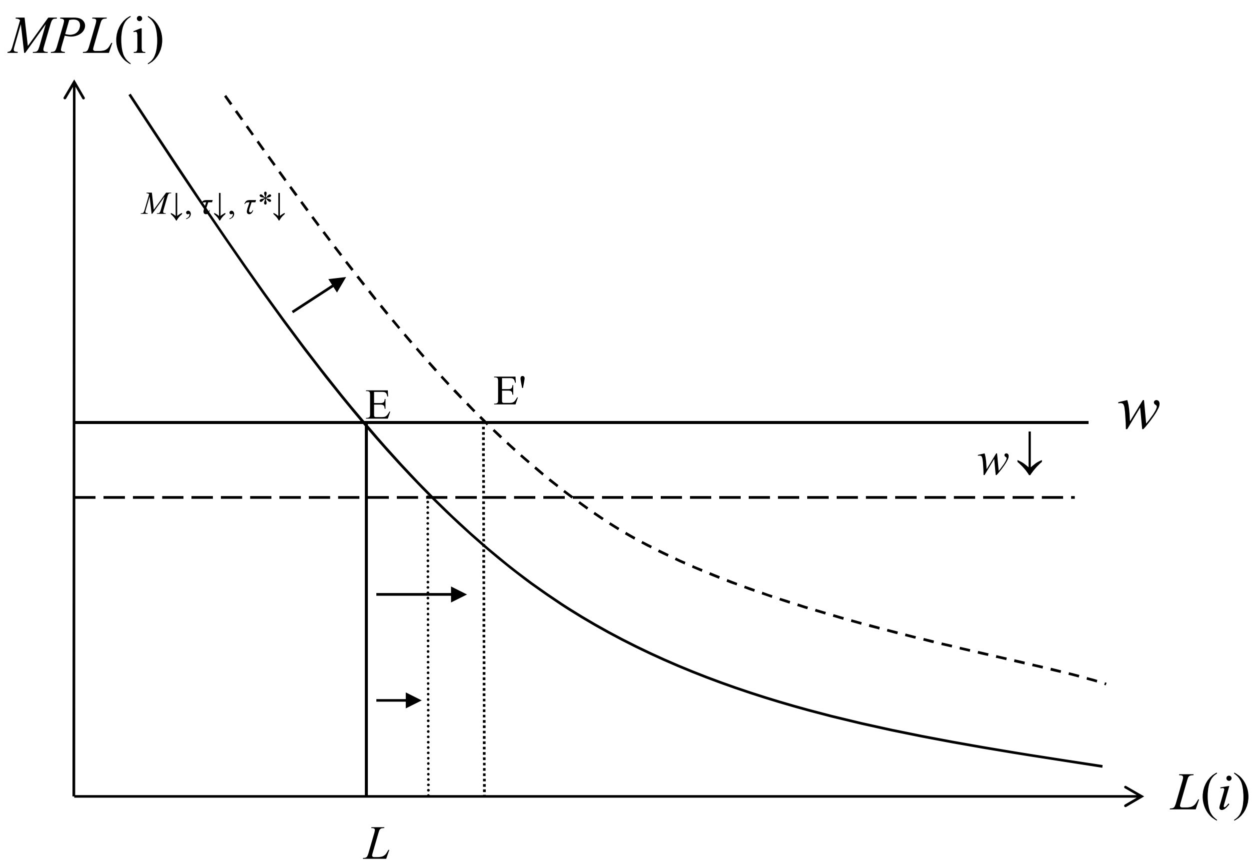
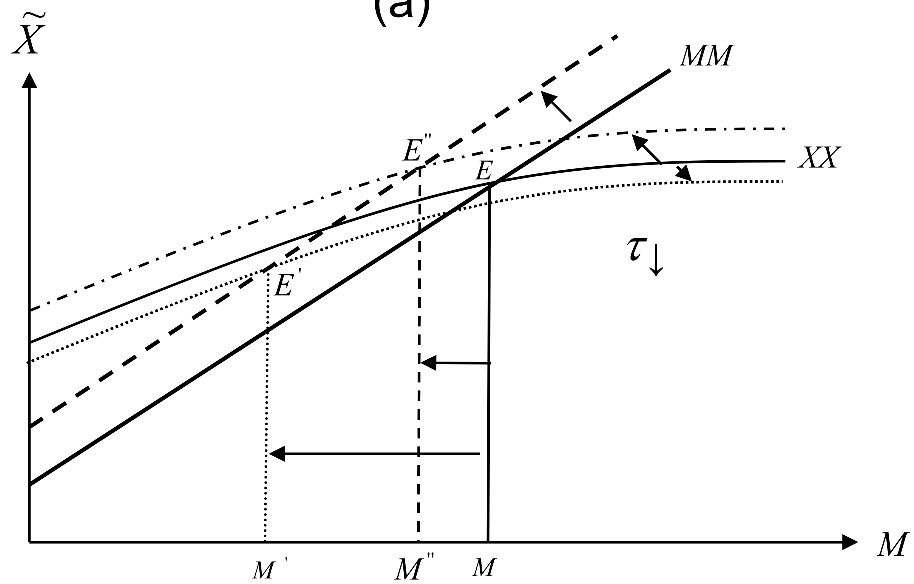


Figure 3. Determination of Length of Production Line

(a)



(b)

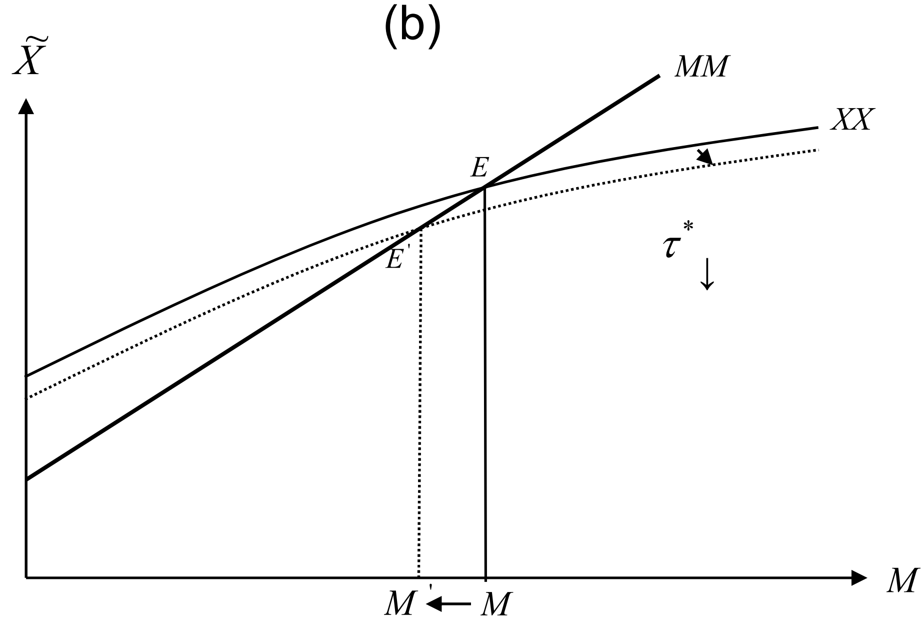


Figure 4. Technology Choice and Trade in Intermediate Goods

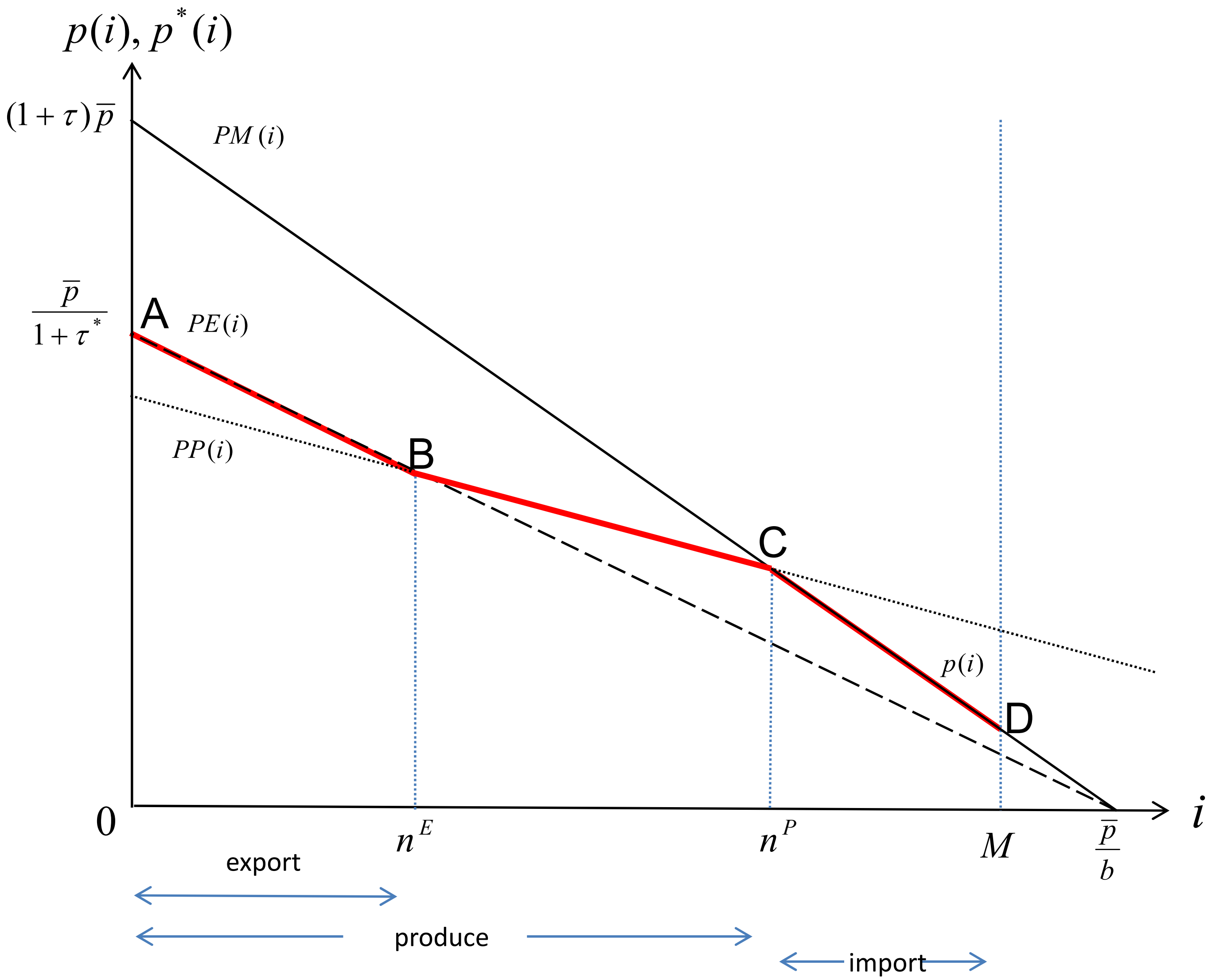
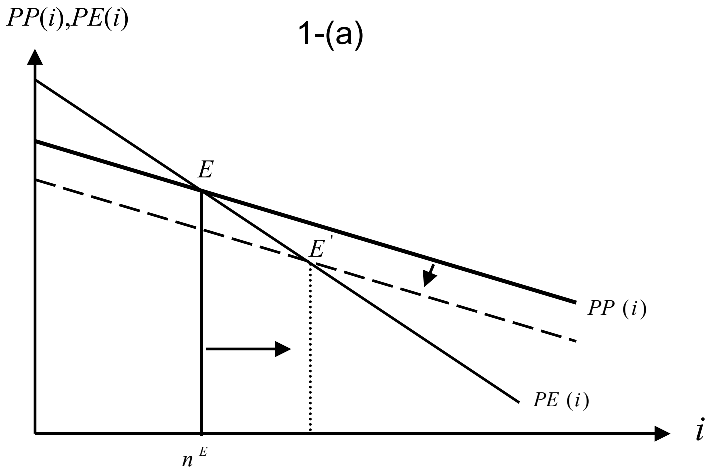


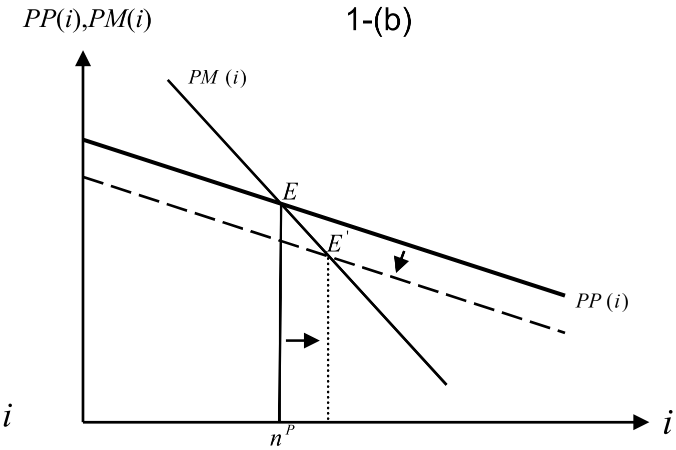
Figure 5. Determination of Technology and Trade Pattern



$M_t \uparrow \Rightarrow \tilde{X}_t \uparrow$

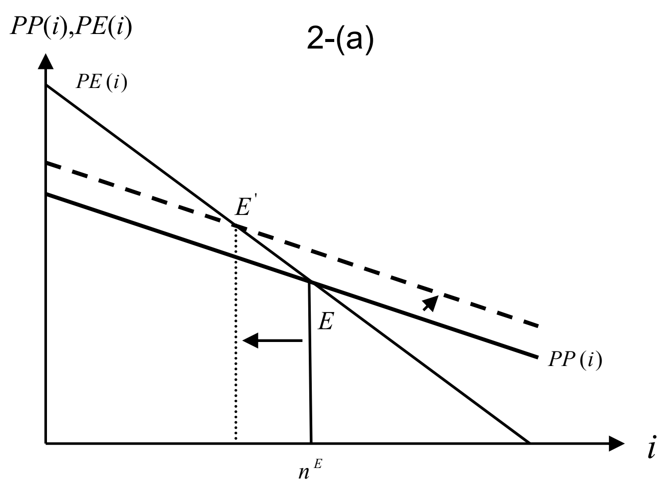
◎ Direct effect : $PP(i) \downarrow \Rightarrow n^E \uparrow$

◎ Indirect effect : $MPL(i) \uparrow \Rightarrow PP(i) \downarrow$



$M_t \uparrow \Rightarrow \tilde{X} \uparrow \Rightarrow PP(i) \downarrow \Rightarrow n^P \uparrow, PP(n^P) \downarrow$

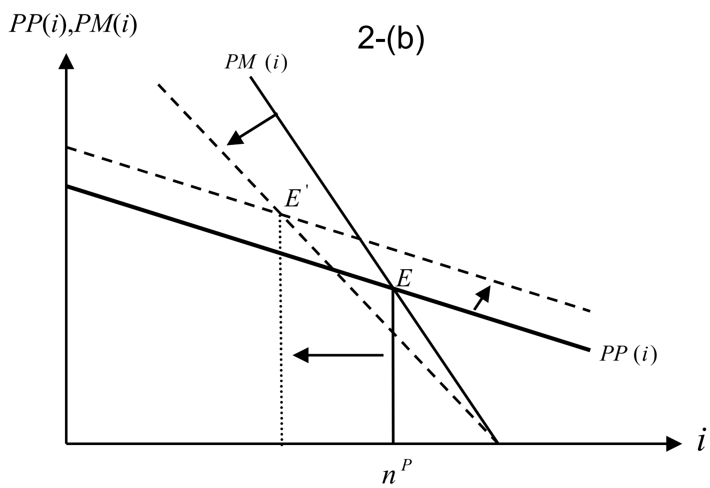
$\Delta n^E \rightarrow \Delta n^P$



τ↓

◎ $PE(i)$ no change

◎ $\tilde{X} \downarrow \Rightarrow MPL(i) \downarrow \Rightarrow PP(i) \uparrow$

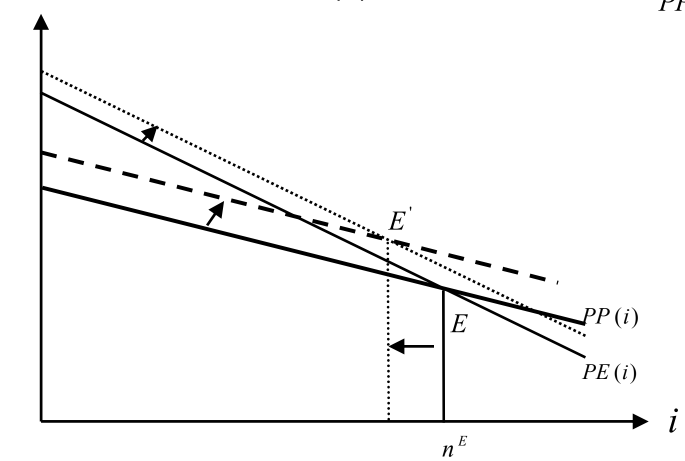


τ↓

◎ Direct effect : $PM(i) \downarrow, n^P \downarrow$

◎ Indirect effect : $\tilde{X} \downarrow \Rightarrow PP(i) \uparrow$

3-(a)

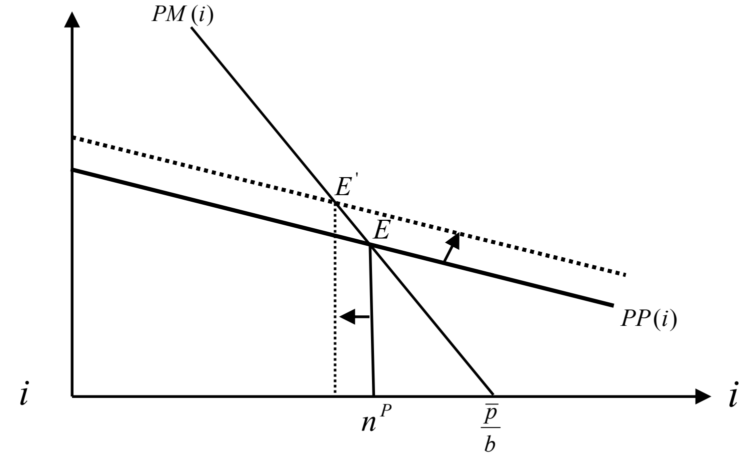


$\tau^* \downarrow$

Direct effect : $PE\,(i) \uparrow, PP\,(i) \uparrow \Rightarrow \; n^E \downarrow$

(if the direct effect is dominant)

3-(b)



$\tau^* \downarrow$

$PP\,(i) \uparrow$, $PM\,(i)$ no change, $\Rightarrow \; n^P \; \downarrow$