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. We show that either domestic or foreign trade liberalization reduces the range of exports and the range of domestic intermediate goods production. Either type of trade liberalization reduces intermediate producer markups and increases final good output and average productivity, with stronger positive productivity effects for newly imported intermediate inputs. However, domestic trade liberalization results in lower aggregate and average technology for domestic intermediate good producers.

Keywords: Intermediate Goods Trade, Technology Choice, Extensive versus Intensive Margin Effect of Trade liberalization.

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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 changes. Second, technological advancements have dramatically lowered transportation and communication costs. There is a vast literature documenting the benefits of this increased trade as well as its consequences for the speed and the pattern of economic development.

More recently, 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, there have been many other interesting empirical findings, including three particularly related to the present work: (i) more substantial productivity gains are found in firms using newly imported intermediate inputs (see Goldberg *et al.* 2010 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).[2] These empirical findings call for a thorough study under which such observations can be explained within a unified framework.

In addition to the overall increase in trade, the importance 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.[3] [4] Keller (2000) helps explain this in a paper which shows empirically that the benefit of technology can be transferred through intermediate goods trade. We thus take Keller's empirical insight and develop a dynamic model of intermediate goods trade that we use to assess the impact of trade liberalization on technology levels and productivity through the intermediate goods trade. In addition, with this model we will be able to also address the empirical facts mentioned above.

Specifically, we consider a small open economy whose final good production uses an endogenous

[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] For additional references to empirical regularities, the reader is referred to two useful survey articles by Dornbusch (1992) and Edwards (1993).

[3] 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.

[4] 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).

range of intermediate goods. For concreteness we define intermediate goods from low technology (high cost) to high technology (low cost). For both domestic and foreign intermediate goods, the technology endogenously evolves over time. The small open economy is assumed to be less advanced in intermediate goods production and hence, 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 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. Accordingly, the ranges of imports, exports and nontraded intermediate goods, as well as the entire range of intermediate products used are all endogenously determined. We analyze the responses of these ranges, aggregate productivity and aggregate technology to domestic and foreign trade liberalization.

There are two ways final goods producers can take advantage of advanced technology. One way is to buy intermediate goods from domestic firms. The other way is to import more advanced intermediate goods from a more technologically advanced country. Domestic firms actively invest in research and development to improve their level of technology. So, while it may be more profitable in the short run to *import* technology, this may reduce the incentive to invest in technological improvement for domestic firms and therefore, decrease *domestic* technological advancement in the long run. This tension plays a crucial role in our results and will play an important role in assessing the steady-state effects of trade liberalization.

We establish a set of sufficient conditions for the following to occur. Both domestic and foreign trade liberalization lead to a reduction in the overall length of the production line, or the number of intermediate goods used. Domestic trade liberalization causes the import price schedule to decrease, the domestic producer price schedule to increase leading to a smaller range of exported intermediate goods and a smaller range of domestically produced intermediate goods. For the case of a lower foreign tariff, the export price schedule and the domestic producer price schedule both increase. This causes both the export range and the range of domestic production to shrink. For both domestic and foreign trade liberalization the impact on the range of imports is indeterminate. We show using numerical methods, that these responses are larger for less developed, less technologically advanced countries.

Trade liberalization (either domestic or foreign) reduces domestic intermediate producer markups and increases final good output and average productivity. However, aggregate domestic technology levels fall. Hence, we see the tension that trade liberalization brings. Lower tariffs make more advanced technology cheaper leading to productivity gains. However, these come at the expense of domestic technology levels which fall in the steady state because the incentive for domestic firms to invest in improving their own technology is weakened. We find, numerically, that the negative effect on technology is smaller in less developed countries. So, the bottom line is that trade liberalization is good for productivity but bad for the domestic level of technology.

Using numerical methods we verify all the conditions required for carrying out our theoretical analysis. In particular, we find that within reasonable ranges of parameters, the sufficient conditions hold. Under the benchmark parametrization, the range of imports increases slightly when domestic or foreign tariffs are reduced. However, the extensive margin is by far the dominant force for the effect of domestic trade liberalization on aggregate imports. The case of aggregate exports is different. Here the intensive margin effects for the effect of foreign trade liberalization on aggregate exports are important and we find numerically that foreign trade liberalization will increase aggregate exports. 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. Our numerical exercises also verify that our theoretical predictions are consistent with the empirical findings cited above. Moreover, the results suggest that domestic trade liberalization in a less developed country with less advanced technology will have a larger impact on international trade, a smaller detrimental effect on aggregate technology, and smaller output and productivity gains than a similar liberalization would have on a high income country.

Before turning to our model economy, it may be informative to position our paper into the literature to better understand the contributions of our paper. In a seminal paper, Ethier (1982) argues that the expansion of the use of intermediate goods is crucial for improving the productivity of final goods production. While Ethier (1982) determines the endogenous range of intermediate products with embodied technologies, there is no trade in intermediate goods. Yi (2002) and Peng, Thisse and Wang (2006) examine the pattern of intermediate goods trade, the range of intermediate products with exogenous embodied technology. In Flam and Helpman (1987), a North-South model of final goods trade is constructed 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 again on final goods trade. In contrast with all these papers, our paper determines endogenously both the pattern and the extent of intermediate goods trade with endogenous technology choice. Thus, our framework focuses on the trade-off between importing technology embodied in intermediate goods and advancing domestic technology. Furthermore, we characterize intermediate good producer markups and the productivity gains from trade liberalization on both the intensive and extensive margins.

The remainder of the paper is organized as follows. In Section 2, we construct the model with a small country conducting international trade of intermediate goods embedded with different technologies. The optimization problems facing final and intermediate producers are solved in Sections 3. We then define and characterize the steady state equilibrium in Section 4, focusing on technology choice, pattern of production and trade and the consequences of trade liberalization. Our numerical implementation of the model is in Section 5 and Section 6 concludes.

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 traded 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. As it is seen below, the endogenous determination of the overall length of the production line M_t plays a crucial role in assessing the "extensive margin" effects of trade liberalization on the respective ranges of export, import and domestic production. We will relegate the implication of a fixed overall length to Section 4.3.

Each variety requires ϕ units of labor and each unit of labor is paid at a market wage $w > 0$. The more varieties used in producing the final good the more labor is required to coordinate production. This follows Becker and Murphy (1992). Denoting the mass of labor for production-line coordination at time t as D_t, we have:

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

In the absence of coordination cost ($\phi \to 0$), the length of the production line M_t goes to infinity. Notably, in Melitz and Ottaviano (2008), there is a choke price which set an upper bound on M_t. In our model, higher M_t is associated with better technology and lower prices, so there is no choke price. Thus, in order to have an interior solution for M_t, we introduce a coordination cost associated with final good production.

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. For our purposes 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 are 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: $\theta + \mu < 1$.

Remark 1: It should be emphasized here, that we have technology choice, not technology adoption or technology spillovers. These concepts are sometimes confused. Technology adoption permits the use of foreign technologies to produce goods domestically by paying licensing fees. Technology spillovers are uncompensated positive effects of foreign technologies on domestic technologies. What we mean by technology choice, is that domestic producers of final goods implicitly choose the level of technology they use through their choice of intermediate goods used in the production process. They can use lower technology, domestically produced intermediate goods as well as imported higher technology intermediate goods produced using foreign technologies. The trade-off these firms face is that adopting higher technology production means a larger range of intermediate goods resulting in higher coordination costs.

One may easily extend our setup to incorporate technology spillovers. In particular, consider the case in which foreign technologies embodied in imported intermediate goods also contribute to domestic technology improvements via reverse engineering. We can modify equation (6) to allow for spillovers

$$A_{t+1}(i) = (1 - \nu) A_t(i) + [(1 - \varsigma) \psi_t(i) + \varsigma \psi_t^*(i)] H_t(i)^{\mu}$$

where $\varsigma \geq 0$ indicates the strength of international technology spillovers. While we will discuss the implication of this modification in Section 5 below, it is clear that such an extension would not affect our main findings so long as ς is not too large.

3 Optimization

When a particular intermediate good is produced domestically but not exported to the world market, 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 $\left[n_t^P, M_t\right]$ 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,

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

which enables us to derive intermediate good prices $p_t(i)$ as:

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

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. Given these results we have the following Lemma.

Lemma 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 larger aggregate intermediate goods (higher $\widetilde{X}_t$) imply individual intermediate good demand will be smaller.*

Using Leibniz's rule, the final good producing firm's first-order condition with respect to the length of the production line (M_t) can be derived as:[5]

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

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

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

[5] 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.

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 $[\alpha - \gamma\widetilde{X_t} - (1+\tau)p_t^*(M_t)]^2 > 2(\beta-\gamma)w\phi$.

Lemma 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:

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

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,

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

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

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

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

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

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

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:

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

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

By using (5), the Benveniste-Scheinkman condition is given by,

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

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:

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

This expression implies a positive relationship between the investment in domestic technology in forms of $H(i)$ and the steady-state level of domestic technology $A(i)$ over the range $i \in [0, n^P]$. Since $V_{A_t}(i) = V_{A_{t+1}}(i)$, we can also use (21) to rewrite (19) as:

$$V_A = \frac{(1+\rho) w H(i)^{1-\mu}}{\mu \psi(i)}, \quad i \in [0, n^P]$$

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

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

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

$$\frac{(\rho+\nu)w}{\mu\psi\left(i\right)}\left[\frac{\nu A\left(i\right)}{\psi\left(i\right)}\right]^{\frac{1-\mu}{\mu}}=\frac{wL(i)}{\theta A(i)}$$

or, manipulating,

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

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 $\psi\left(i\right)$ as the technology gradient that measures how quickly technology improves as i increases.

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

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

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

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

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

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

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 ($\psi\left(i\right)$) 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 good 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 uses more sophisticated technology (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:

Lemma 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

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

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

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

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:

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

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 Lemma.

Lemma 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:[6]

$$\widetilde{X} = \frac{\overline{A}\int_{n^E}^{n^P} \psi(i)\, L(i)^{\theta+\mu}\, di + \frac{\alpha}{\beta-\gamma}(M + n^E - n^P) - \frac{1}{\beta-\gamma}\left[(1+\tau)\int_{n^P}^{M} p^*(i)di + \frac{1}{1+\tau^*}\int_0^{n^E} p^*(i)di\right]}{1 + \frac{\gamma}{\beta-\gamma}(M + n^E - n^P)} \tag{36}$$

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:

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

Under the following world price specification:

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

the second-order condition becomes:

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

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. This condition

[6] More specifically, we use (27)-(29) and (33) to derive:

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

which yields the $\widetilde{X}$ expression.

requires that the gradient of the tariff augmented imported intermediate goods prices be properly flat.

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

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

where the intermediate producer i's markup is defined as:

$$\Lambda(i) \equiv \frac{p(i) - \eta}{\theta[1 + (\nu\overline{A})^{1/\mu}]\,[p(i) - \eta - \beta x\,(i)]} - 1 \tag{38}$$

For $i \in [0, n^E]$, we have:

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

where the markup becomes constant given by

$$\Lambda_0 \equiv \frac{1}{\theta[1 + (\nu\overline{A})^{1/\mu}]} - 1$$

Note that in this general quadratic setup, when price $(p(i)-\eta)$ increases, the marginal cost $(\theta[1+(\nu\overline{A})^{1/\mu}]\,[p(i) - \eta - \beta x\,(i)])$ increases more than proportionately, thus yielding a lower markup. This differs sharply from the constant markup CES aggregator. By using (33) and (8), markup can be expressed as,

$$\begin{aligned} \Lambda(i) &= \frac{1}{\theta[1 + (\nu\overline{A})^{1/\mu}]\left[1 - \beta\frac{x(i)}{p(i)-\eta}\right]} - 1 \\ &= \frac{1}{\theta[1 + (\nu\overline{A})^{1/\mu}]\left[1 - \frac{\beta}{\frac{\alpha-\eta-\gamma\widetilde{X}_t}{\overline{A}\psi(i)L(i)^{\theta+\mu}} - (\beta-\gamma)}\right]} - 1 \end{aligned}$$

which is positively related to $L(i)$ and $\widetilde{X}_t$ for $i \in [n^E, n^P]$. It is noteworthy that while the demand for labor (for producing intermediate goods), $L(i)$, is purely an intensive margin effect, aggregate intermediate goods, $\widetilde{X}_t$, involves both an intensive and an extensive margin. When either the demand for labor or aggregate intermediate good supply is higher, then the supply of the individual intermediate good i is higher and hence its price falls, which in turn increases markups because the convex cost effect dominates the linear price effect. It is clear that the intermediate good supply schedule $(xP(i) = \overline{A}\psi\,(i)\,L\,(i)^{\theta+\mu})$ is upward sloping, as is $\Lambda(i)$. By similar arguments, an increase in the technology scaling factor $(\overline{A})$ or the technology gradient $(\psi\,(i))$ reduces the marginal cost more than the price of intermediate good, thus leading to a higher markup.

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 use the definition of $\overline{A}$ to specify the following condition to ensure positive profitability:

Condition N: (Nonnegative Profit) $\frac{\mu\nu}{\rho+\nu} < 1-\theta$.

This condition requires that the technology obsolescence rate be small enough. We then have:

Lemma 5: (Producer Markup Schedule) Under Condition N, the steady-state intermediate good markup schedule possesses the following properties:

(i) it is upward sloping in ordered varieties (i) within the nontraded range $[n^E, n^P]$, but is a constant Λ_0 over the exporting range $[0, n^E]$;

(ii) an increase in labor demand and intermediate good supply via either the intensive or extensive margin lowers the producer price schedule and raises the markup schedule;

(iii) an increase in the technology scaling factor or the technology gradient leads to a higher producer markup schedule.

We next turn to the determination of the length of the production line. This is best illustrated by the MM and XX loci as drawn in Figure 3. The MM locus (equation (37)) and the XX locus (equation (36)) are the loci that relate $\widetilde{X}$ to M and both are positively sloped. To begin, consider the MM locus. Notice that since intermediate goods are Pareto substitutes, the direct effect of an increase in aggregate intermediate goods, $\widetilde{X}$, reduces 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.

Since the MM locus is the boundary condition pinning down the overall length of the production line, it is expected to be more responsive to changes in M compared to the XX locus. As a result, we claim that the XX locus is flatter than the MM locus. This slope requirement is formally specified as:

Condition C: (Correspondence Principle) $\left.\frac{d\widetilde{X}}{dM}\right|_{XX\ locus} < \left.\frac{d\widetilde{X}}{dM}\right|_{MM\ locus}$

This condition is particularly important for producing reasonable comparative statics in accordance with Samuelson's Correspondence Principle.[7] Specifically, consider an improvement in technology (higher $\overline{\psi}$ or δ, or lower ν). While the MM locus is unaffected, the XX locus will shift upward. Should the XX locus be steeper than the MM locus, better technology would cause the aggregate supply of intermediate goods ($\widetilde{X}$) to fall, which is counter-intuitive. Thus, based on Samuelson's Correspondence Principle, one may rule out this type of equilibrium. The equilibrium satisfying Samuelson's Correspondence Principle is illustrated in Figure 3 by point E. In Section 5, we will further support these arguments with numerical examples.

Defining the expression in (36) as $\widetilde{X}(M)$, we can substitute it into (11) to obtain:

$$\Gamma(M) \equiv \gamma\widetilde{X}(M) + (1+\tau)p^*(M) = \alpha - \sqrt{2(\beta-\gamma)w\phi} \tag{39}$$

By examining $\Gamma(M)$, it is seen that M has two conflicting effects: a positive effect via the aggregate intermediate goods input $\widetilde{X}(M)$ and a negative effect via the import price $p^*(M)$. Specifically, an increase in the overall length of the production line raises the aggregate intermediate goods input but lowers the import price. Since the XX locus is flatter than the MM locus as discussed above, the negative effect via the import price dominates the positive effect via the aggregate intermediate goods input. We summarize this result below.

Lemma 6: (The Length of the Production Line) *Under Conditions S, N, and C the steady-state overall length of the production line is uniquely determined by the XX and MM loci.*

4.3 Trade Liberalization

We now consider the effects of trade liberalization on the pattern of production and trade, the intermediate firms' markups, aggregate and average technology as well as overall productivity.

4.3.1 Effects on Pattern of Production and Trade

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

[7] Samuelson (1947) highlights the purpose of Correspondence Principle as: "to probe more deeply into its analytical character, and also to show its two-way nature: not only can the investigation of the dynamic stability of a system yield fruitful theorems in statical analysis, but also known properties of a (comparative) statical system can be utilized to derive information concerning the dynamic properties of a system."

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. On the one hand, domestic trade liberalization increases imported intermediate inputs on the *intensive margin*. However, final producers react to it by importing intermediate goods at n^P and shifting resources away from this higher type to lower type intermediate inputs $i < n^P$. Given ϕ, this implies a decrease in the overall length of the production line. This latter effect is via the *extensive margin* of import demand. Mathematically, we can differentiate (39) to obtain:

$$\frac{dM}{d\tau} = \frac{p^*}{(1+\tau)b - \gamma(d\widetilde{X}/dM)}$$

which is positive if $(1+\tau)b > \gamma d\widetilde{X}/dM$. Therefore we have Condition **E.**

Condition E: (Strong Extensive Margin Effect) $(1+\tau)b > \gamma d\widetilde{X}/dM$

Thus, if Condition **E** holds, domestic trade liberalization leads to a shorter production line. This condition holds if the positive response of $\widetilde{X}$ to M is not too large, the degree of substitution between different varieties of intermediate goods is not too strong (low γ) and the price gradient is sufficiently steep (high b).

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 1.

Proposition 1: (The Length of the Production Line) *Under Conditions S, N, C and E the steady-state overall length of the production line possesses the following properties:*

(i) *it decreases in response to domestic trade liberalization (lower τ).*

(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:

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

$$PP(n^P) = \alpha - \gamma\widetilde{X} - (\beta-\gamma)\overline{A}\psi\left(n^P\right)LP\left(n^P\right)^{\theta+\mu} = (1+\tau)p^*(n^P) = PM(n^P) \tag{41}$$

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 $\widetilde{ABCD}$. To see this, notice that the equilibrium price is pinned down by $PE\left(i\right)$ over $[0, n^E]$. In that range, producers of intermediate goods can sell their output for a higher price if they export than if they sell to domestic customers ($PE\left(i\right)$ is above $PP\left(i\right)$.) In the range $[n^E, n^P]$ we see that $PP\left(i\right)$ lies above $PE\left(i\right)$ indicating that producers receive a higher price by selling in the domestic market than if they export. Finally, in the range $\left[n^P, M\right]$ it is clear that $PP\left(i\right)$ is above $PM(i)$ indicating that imports are cheaper than domestically produced intermediate goods.

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 $[n^E, n^P]$.

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

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), 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 (40), which determines the range of exports.

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

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 (41) we can determine the range of domestic production of intermediate inputs and the range of imports.

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

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 results in Figures 5-1a,b and 5-2a,b and summarize the results in Proposition 2.

Proposition 2: (The Range of Exports, Domestic Production and Imports) *Under Conditions S, N, C and E, the steady-state pattern of international trade features exporting over the range*

$\left[0, n^E\right]$ *and importing over the range* $\left[n^P, M\right]$ *with the range* $\left[n^E, n^P\right]$ *being 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;*
- **b.** *both the range of exports* $\left[0, n^E\right]$ *and the range of domestic production* $\left[0, n^P\right]$ *shrink;*

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

- **a.** *the export price* $PE(i)$ *and the domestic producer price* $PP(i)$ *increase;*
- **b.** *the range of domestic production* $\left[0, n^P\right]$ *and the range of exports* $\left[0, n^E\right]$ *shrink;*

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

Remark 2: (Exogenous Length of the Production Line) When the length of the production line M is fixed, domestic trade liberalization increases aggregate intermediate goods whereas foreign trade liberalization decreases it (see Figures A1a and A1b in the Appendix). In this case, domestic trade liberalization causes producer prices to drop, thus expanding the export range (as shown in Figure A2a). In contrast, foreign trade liberalization raises export prices and lowers the range of domestic production (Figure A2b). Because the overall length is fixed, the import range ($M - n^P$) must increase as a consequence. Recall that in the case with endogenous length of production line, domestic trade liberalization shortens the overall length and forces the export range to shrink, whereas foreign trade liberalization causes both the domestic production range and the overall length to fall, thereby leading to an ambiguous effect on the import range.

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 is constant over i and depends positively on the 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 2, 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 3: (Markups) *Under Conditions S, N, C and E, domestic intermediate firms' markups in the steady-state equilibrium always decrease in response to either foreign trade liberalization (lower τ^*) or domestic trade liberalization (lower τ).*

Remark 3: It is noted that, with exogenous overall length of the production line, the markup becomes higher with domestic trade liberalization, which seems counter-intuitive.

We now turn to determining how trade liberalization affects productivity and technology. It can be seen from Proposition 2 that under domestic trade liberalization, the range of domestic production $\left[0, n^P\right]$ shrinks. 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 technology is, however, not obvious. Define the aggregate technology used by domestic producers as $\widetilde{A} = \int_0^{n^P} A(i, M)\, di$. Utilizing (22), we can write:

$$\widetilde{A} = \overline{A} \int_0^{n^P} \psi(i)\, LP(i)^{\mu}\, di \tag{42}$$

Consider the benchmark case where Conditions *S, N, C and E* hold. 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, for domestic producers, domestic trade liberalization will reduce average technology $\frac{\widetilde{A}}{n^P}$. Nonetheless, average productivity measured by $\frac{Y}{\widetilde{X}}$ will increase due to the use of more advanced imported intermediate inputs. Applying Proposition 2, we can see that foreign trade liberalization will lead to a similar outcome in aggregate technology and average productivity. These results are summarized in the following proposition.

Proposition 4: (Productivity) *Under Conditions S, N, C and E, 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. Both aggregate and average technology of domestic producers are lower in response to domestic trade liberalization (lower τ). For* the case of foreign trade liberalization (lower τ^**) aggregate technology of domestic producers falls.*

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 implies that it is profitable to import intermediate goods from a more technologically advanced country, rather than buying intermediate goods from domestic producers who are actively investing in improving the level of technology. As a result, it leads to a lower level of technology for domestic producers in steady-state equilibrium, as can be seen from (21). Thus, there is a tension between producing final goods with the highest level of productivity and encouraging the development of domestic technology.

5 Numerical Analysis

While we would like to use existing data to back out the intermediate good price, quantity, endogenous markup and endogenous technology schedules we do not have suitable data available to do so. Without the option for a full calibration of the model, we have to rely on simple numerical analysis based on reasonable selection of parameters and subsequent sensitivity analysis. In so doing, we would, given Conditions *S, N, C and E* being satisfied, gain some feel for the relative magnitudes of extensive and intensive margins as well a quantitative feel for how much how trade liberalization may affect trade patterns (in both values and ranges of exports and imports), average markup, domestic technology and overall productivity.

For our baseline economy we set the time preference rate as $\rho = 5\%$, as in the literature. Given that the physical depreciation rate is usually set at 10%, the technology obsolescence rate is set at a higher rate $\nu = 25\%$. We select the intermediate sector production parameters as $\theta = 0.6$ and $\mu = 0.2$, which satisfies the requirement for decreasing returns to scale, $\theta + \mu < 1$ and leads to an overall markup of 70%, through the entire production process, over the final good producer, which is a reasonable figure. Turning now to the final sector production parameters, we set $\alpha = 10$, $\beta = 0.17$ and $\gamma = 0.1$, which satisfy the requirements $\beta - \gamma > 0$, as well as Condition C. Normalize $\eta = 1$ and set $\phi = 0.04$ so that Condition N is met. To meet Condition E, the technology and world price schedules are given by: $\psi(i) = 16\,(1 + 0.04 \cdot i)$ and $p^*(i) = 2.5 - 0.05 \cdot i$. Letting $w = 50$, this insures that Condition S is met. Finally, we choose $\tau = 7.5\% > \tau^* = 5\%$. Under this parametrization, Conditions S, N, C and E are all met.[8] We summarize the numerical results in Table 1.

The computed ranges of exports, nontraded intermediate goods and imports turn out to be: $[0, n^E] = [0, 9.20]$, $[n^E, n^P] = [9.20, 14.24]$ and $[n^p, M] = [14.24, 20.56]$, respectively. While aggregate intermediate goods demand and production turn out to be $\widetilde{X} = 78.89$ and $Xp \equiv \int_0^{n^E} yE\,(i)\,di + \int_{n^E}^{n^P} yP\,(i)\,di = 243.91$, aggregate and average technology used by domestic producers are $\widetilde{A} = 594.88$ and $\frac{\widetilde{A}}{n^P} = 41.78$, respectively. The average markup of domestic non-exporting producers

[8] Specifically, we have: $\gamma\sqrt{\frac{2w\phi}{\beta-\gamma}} - (1+\tau)\,b = 0.7022$; $1 - \theta - \frac{\mu\nu}{\rho+\nu} = 0.2333$; $\left.\frac{d\widetilde{X}}{dM}\right|_{XX\ locus} = 0.3655 < \left.\frac{d\widetilde{X}}{dM}\right|_{MM\ locus} = 0.5375$; and, $(1+\tau)b - \gamma d\widetilde{X}/dM = 0.0172$.

is: $\frac{\tilde{\Lambda}}{n^P} \equiv \frac{n^E \Lambda_0 + \int_{n^E}^{n^P} \Lambda(i) di}{n^P} = 0.710$. The computed final good output is $Y = 307.51$ and the corresponding productivity measure is $\frac{Y}{\widetilde{X}} = 3.90$. 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 10% decrease in the domestic tariff τ. The overall length of the production line M shrinks from 20.56 to 19.50. Both the range of exports and the range of domestic production decrease. In particular, the computed range of exports falls to $[0, n^E] = [0, 8.39]$. The range of nontraded intermediate goods is $[n^E, n^P] = [8.39, 13.28]$ which shrinks slightly. The range of imports is now $[n^p, M] = [13.28, 19.50]$ which decreases slightly from 6.33 to 6.23 as a result of a shortened production line. Aggregate intermediate goods demand and production fall to $\widetilde{X} = 78.43$ and $Xp = 224.62$ due to the decrease in the extensive margin. Aggregate and average technology used by domestic producers fall to $\widetilde{A} = 546.85$ and $\frac{\widetilde{A}}{n^P} = 41.19$. Moreover, the average markup of domestic intermediate producers decreases to $\frac{\tilde{\Lambda}}{n^P} = 0.677$. What happens to output and productivity? Both of them increase significantly. Computed final good output increases to $Y = 357.49$ and productivity increases to $\frac{Y}{\widetilde{X}} = 4.56$. Total exports decrease to 127.16 and imports fall slightly to 47.07. These numerical results show that domestic trade liberalization leads to higher final good output and productivity by reducing the range of intermediate goods used while increasing the intensity with which each variety is used thereby saving on the coordination cost associated with final good production. In the end, average technology used by domestic producers falls but productivity is higher.

The results concerning the effect of trade liberalization on domestic technology and productivity are surprising but they make sense. Domestic technology measures the technology level used by domestic firms producing intermediate goods. Despite the fact that these firms invest in improving their own technology, trade liberalization results in higher technology imports being available more cheaply. This discourages investment in domestic technology improvements and in the steady state leads to a lower level of technology chosen.

Recall that productivity is measured by dividing final good output by aggregate intermediate good usage. Our results show that trade liberalization increases productivity by a significant amount. The reason for this is that the price for more technologically advanced inputs, available through trade, has decreased. They take advantage by buying these advanced intermediate goods more intensively and this results in more output per unit input, i.e. higher productivity.

The story for a reduction in the foreign tariff is similar. Starting from our benchmark equilibrium, consider foreign trade liberalization, in the form of a 10% decrease in the foreign tariff τ^*. The overall length of the production line, M, shrinks from 20.56 to 19.90. Both the range of exports and the range of domestic production decrease. Moreover, both the range of nontraded goods and the range of imports shrink slightly. As a result of the reduced length of the production line, aggregate intermediate goods demand and production both fall, but, not surprisingly, the reduced tariff causes final good output to increase to $Y = 336.70$ and measured productivity to rise to $\frac{Y}{\widetilde{X}} = 4.29$. Moreover, the average markup of domestic producers falls to 0.693, whereas the aggregate technology $\widetilde{A} = 573.37$ falls and because n^P falls, average technology used by domestic producers increases slightly to 41.84. In this case, total exports increase to 140.56 while imports fall to 46.83. The story here is similar to domestic trade liberalization. Foreign trade liberalization leads to a smaller range of intermediate good usage, more intense usage of each variety leading to a savings in coordination cost of final good production. This results in higher output, productivity and average technology, but lower aggregate technology.

We consider an additional experiment, an environment with global trade liberalization such as seen with a WTO agreement, with both domestic and foreign tariff falling by 10%. In this case, both the final good output and the measured productivity rise sharply, from $Y = 307.51$ and $\frac{Y}{\widetilde{X}} = 3.90$, to $Y = 387.21$ and $\frac{Y}{\widetilde{X}} = 4.96$, 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 more than 25%.

Our numerical results lend support to the empirical findings summarized in the introduction. We show that either domestic or foreign trade liberalization causes some domestically produced intermediate goods to become imported. Such a change leads to a productivity gain, as observed by Goldberg *et al.* (2010). Moreover, we also show that trade liberalization directly leads to lower mark-ups, which is consistent with the empirical finding by Krishna and Mitra (1998).

Finally, we evaluate how the magnitudes of the effects of domestic and foreign tariff rates on the key variables change in response to changes in the main parameters. The numerical results are reported in Table 2. Focusing on the first three columns of Table 2 we see that better technology (higher $\overline{\psi}$ or δ or lower ν) cause production and trade ranges (n^E, n^P, M) to become less responsive to domestic or foreign trade liberalization. From the last two columns of Table 2, we also see that better technology causes aggregate imports to be less responsive to domestic trade liberalization and aggregate exports to be less responsive to foreign trade liberalization. This implies:

Result 1: (Trade Flows) *Trade liberalization in a less developed country with less advanced technology has a larger impact on international trade than a similar liberalization would have on a high income country.*

Recall from Table 1 that either domestic or foreign trade liberalization reduces aggregate technology $\widetilde{A}$. Now, looking at column 6 of Table 2 we can see that higher technology (higher $\overline{\psi}$ or

δ or lower ν) means that aggregate technology $\widetilde{A}$ is always less responsive to domestic or foreign trade liberalization. This means that trade liberalization reduces aggregate technology *less* in more developed countries. In other words, the disincentive effect from replacing domestic investment in technology with imported technology is quantitatively more severe in less developed economies. Now notice, again from Table 1, that either domestic or foreign trade liberalization leads to higher aggregate output Y and higher productivity $\frac{Y}{\widetilde{X}}$. We can see from examination of columns 9 and 10 of Table 2 that with better technology, both aggregate output and average productivity are more responsive to domestic or foreign trade liberalization. We thus have:

Result 2: (Technology and Productivity) *Trade liberalization in a less developed country with less advanced technology would have a larger detrimental effect on aggregate technology and generate smaller output and productivity gains than a similar liberalization would have on a high income, high technology country.*

Remark 4: (International Technology Spillovers) In the presence of international technology spillovers, we find that both domestic technology and production become more responsive to domestic trade liberalization, though the respective impact of foreign trade liberalization need not be larger.

Notice from Table 3 that the extensive margin is by far the dominant force for the effect of domestic trade liberalization on aggregate imports. With regard to the effect of foreign trade liberalization on aggregate exports, both the intensive and extensive margins are important. More specifically, while the effect of foreign trade liberalization on aggregate exports via the intensive margin is positive as in conventional studies, the effect via the extensive margin is negative as a result of a shortened production line. Quantitatively, the conventional effect via the intensive margin dominates and hence the net effect of foreign trade liberalization on domestic aggregate exports is positive. These can be summarized as follows:

Result 3: (Extensive vs. Intensive Margins) *For domestic trade liberalization, the extensive margin is by far the dominant force for aggregate imports. For foreign trade liberalization, both the intensive and extensive margins are important for aggregate exports.*

Remark 5: We have changed key parameter values $\left(\bar{\psi}, \delta, \nu, \mu, \phi, \beta - \gamma, \rho\right)$ up and down by 10% and found that all conditions are met, the unique steady-state equilibrium exists, and all of our comparative static results are robust (see the Appendix Table).

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.

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, domestic trade liberalization leads to lower markups and greater competition and results in productivity gains. Such productivity gains from trade liberalization are 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. Our results provide valuable empirical implications: if the extensive margin is important, trade liberalization may lead to very different effects on domestic technology and production from those predicted by the conventional literature.

What are the policy implications of our results? If a developing economy wants to upgrade its industries is it better to do so by improving technologies of domestic producers or by importing intermediate goods with better technologies? Our results suggest that trade liberalization will increase overall productivity, but with the side-effect of reducing the technology level of domestic industries. So there is a trade-off. Perhaps a combination of domestic trade liberalization with a direct subsidy to technology advancements would be a sensible development policy. This issue deserves attention in future research.

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Figure 1. Determination of Intermediate Goods Allocation

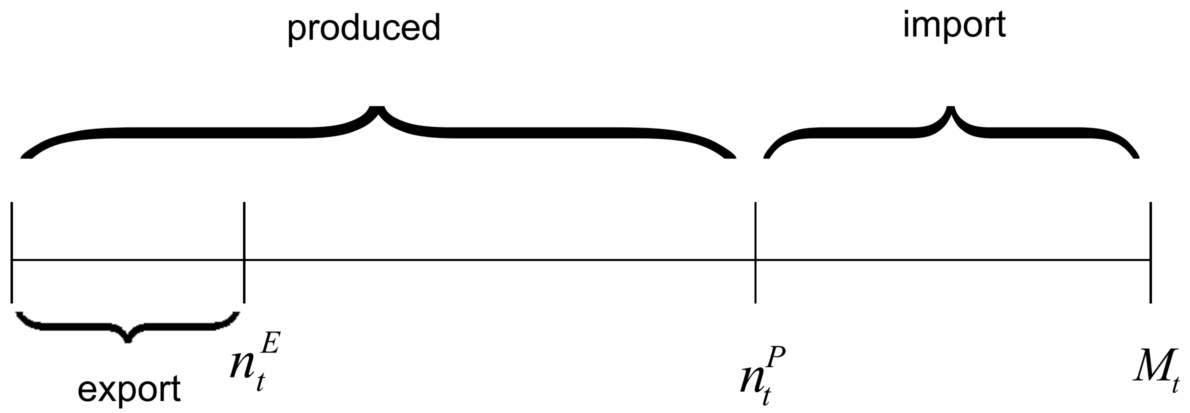


Figure 2. Labor Allocation

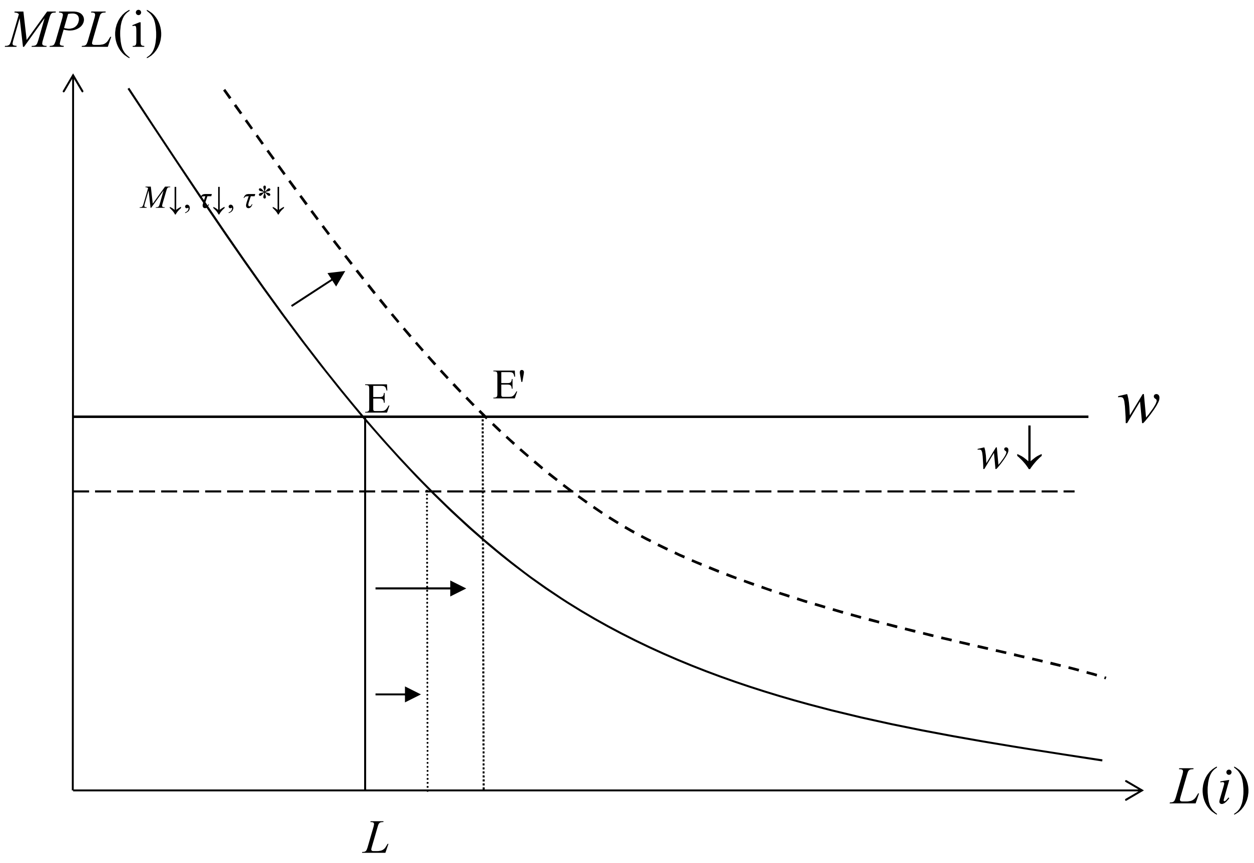
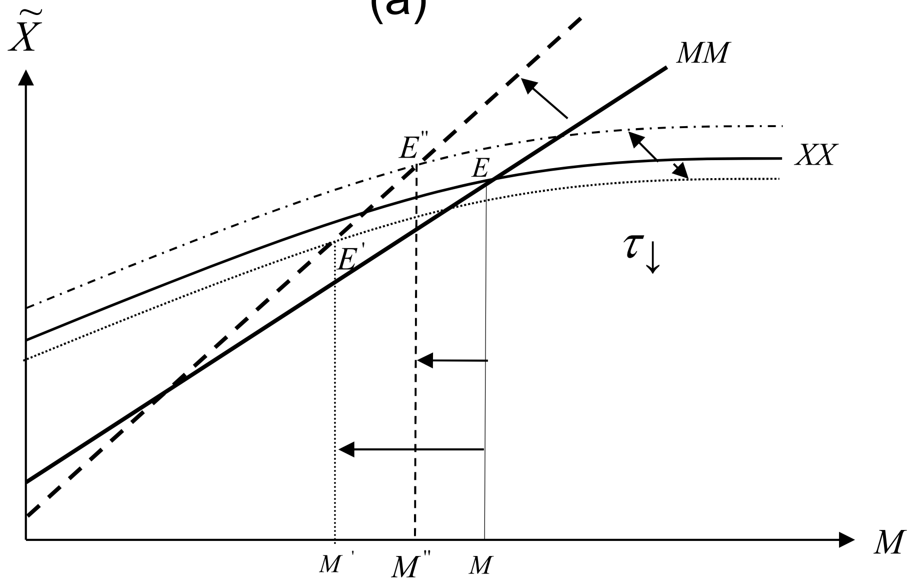


Figure 3. Determination of Length of Production Line

(a)



(b)

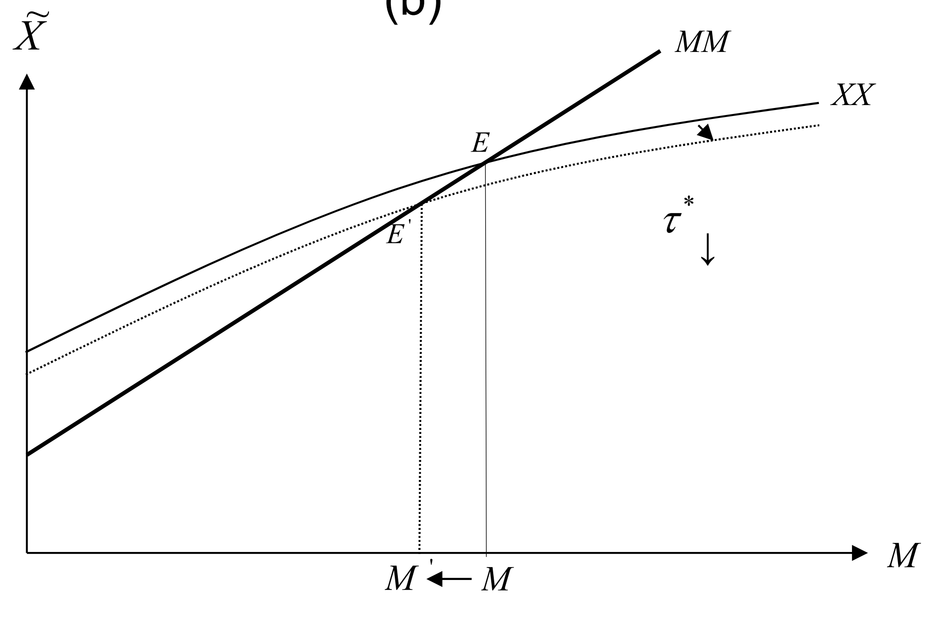


Figure 4. Technology Choice and Trade in Intermediate Goods

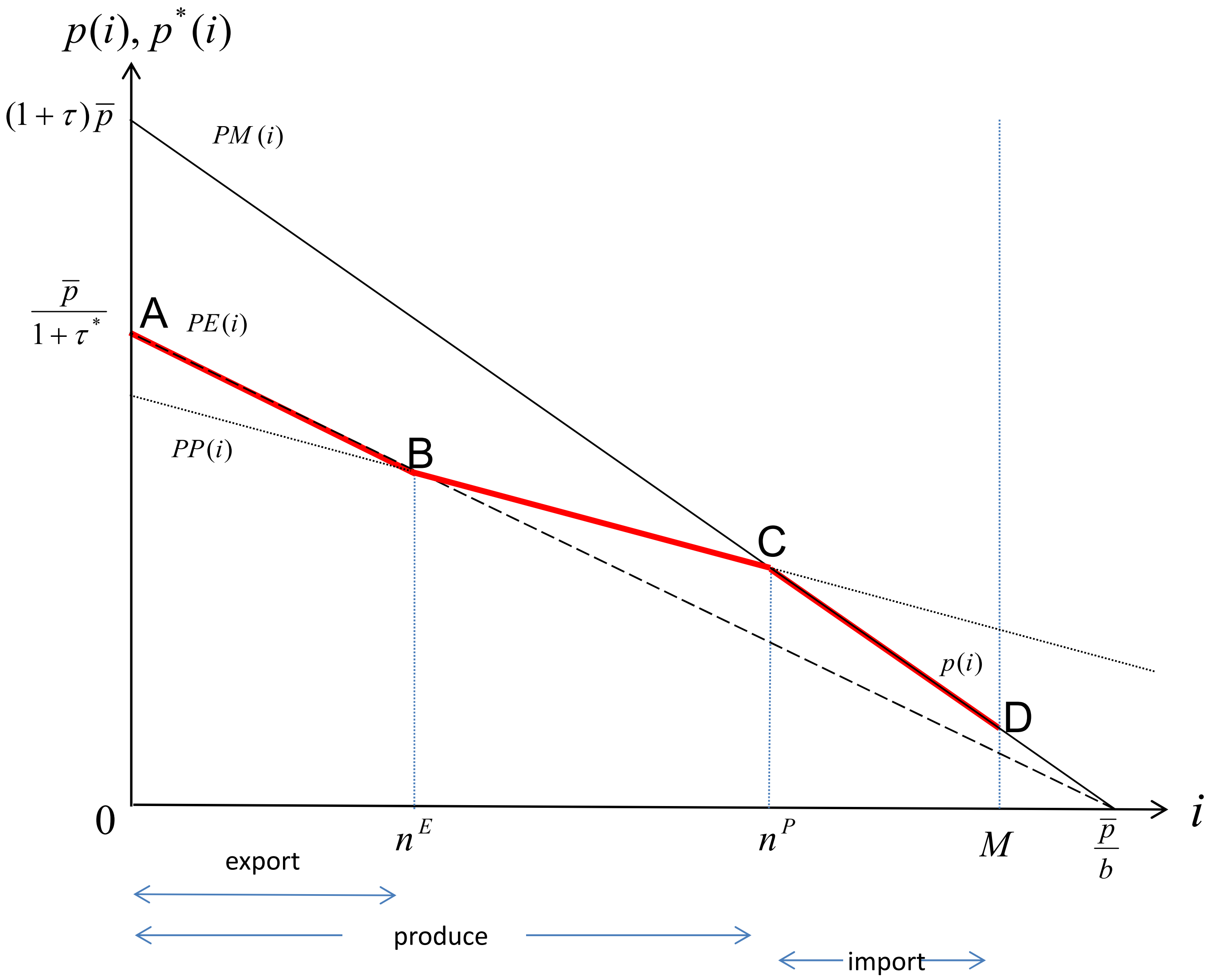
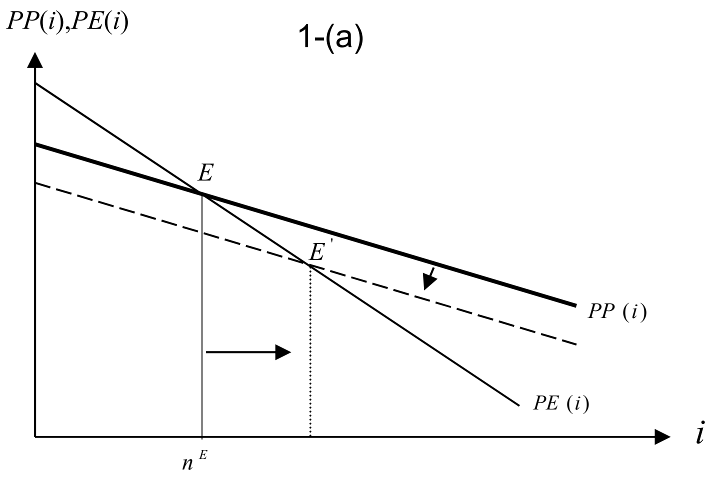


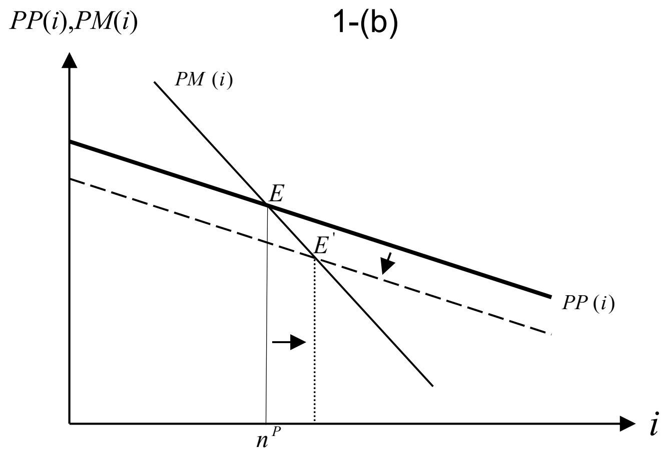
Figure 5. Determination of Technology and Trade Pattern



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

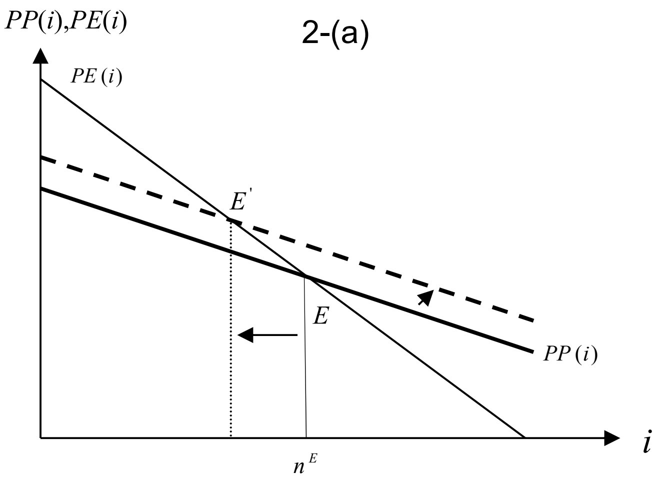
◎ Direct effect : $PP(i) \downarrow \Rightarrow n^E \uparrow$

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



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

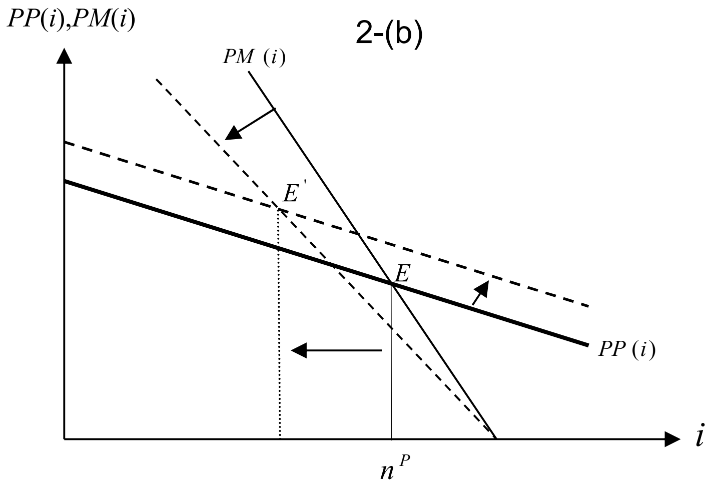
$\Delta n^E \rightarrow \Delta n^P$



τ↓

◎ $PE(i)$ no change

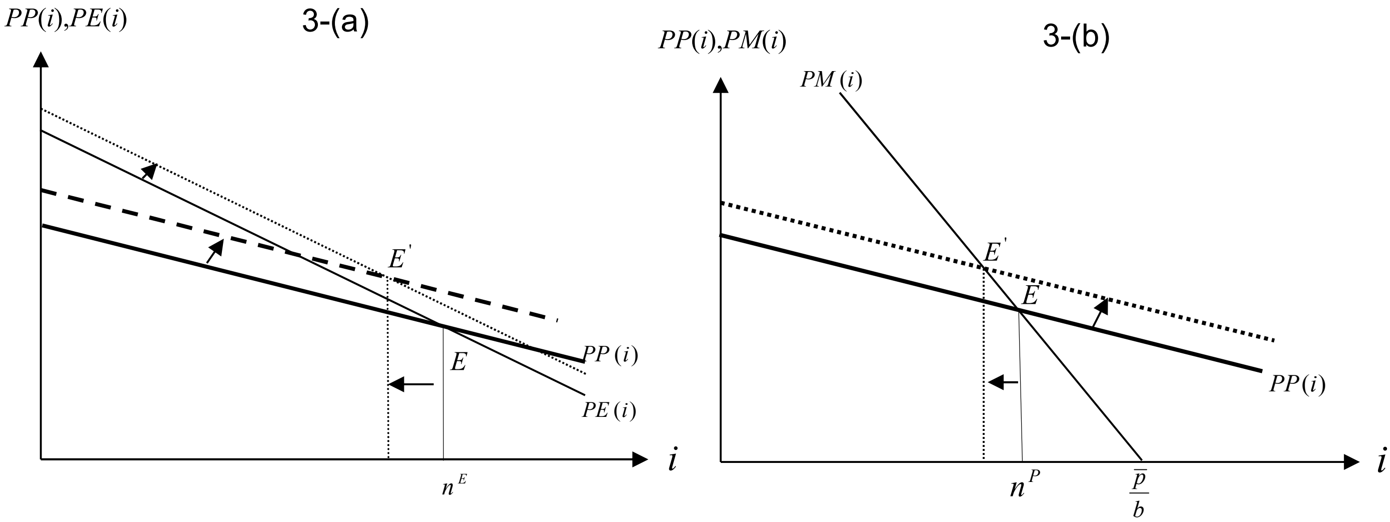
◎ $\tilde{X} \downarrow \Rightarrow MPL(i) \downarrow \Rightarrow PP(i) \uparrow$



τ↓

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

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



$\tau^* \downarrow$

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

(if the direct effect is dominant)

$\tau^* \downarrow$

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

Figure A1. Determination of aggregate intermediate good usage under exogenous M

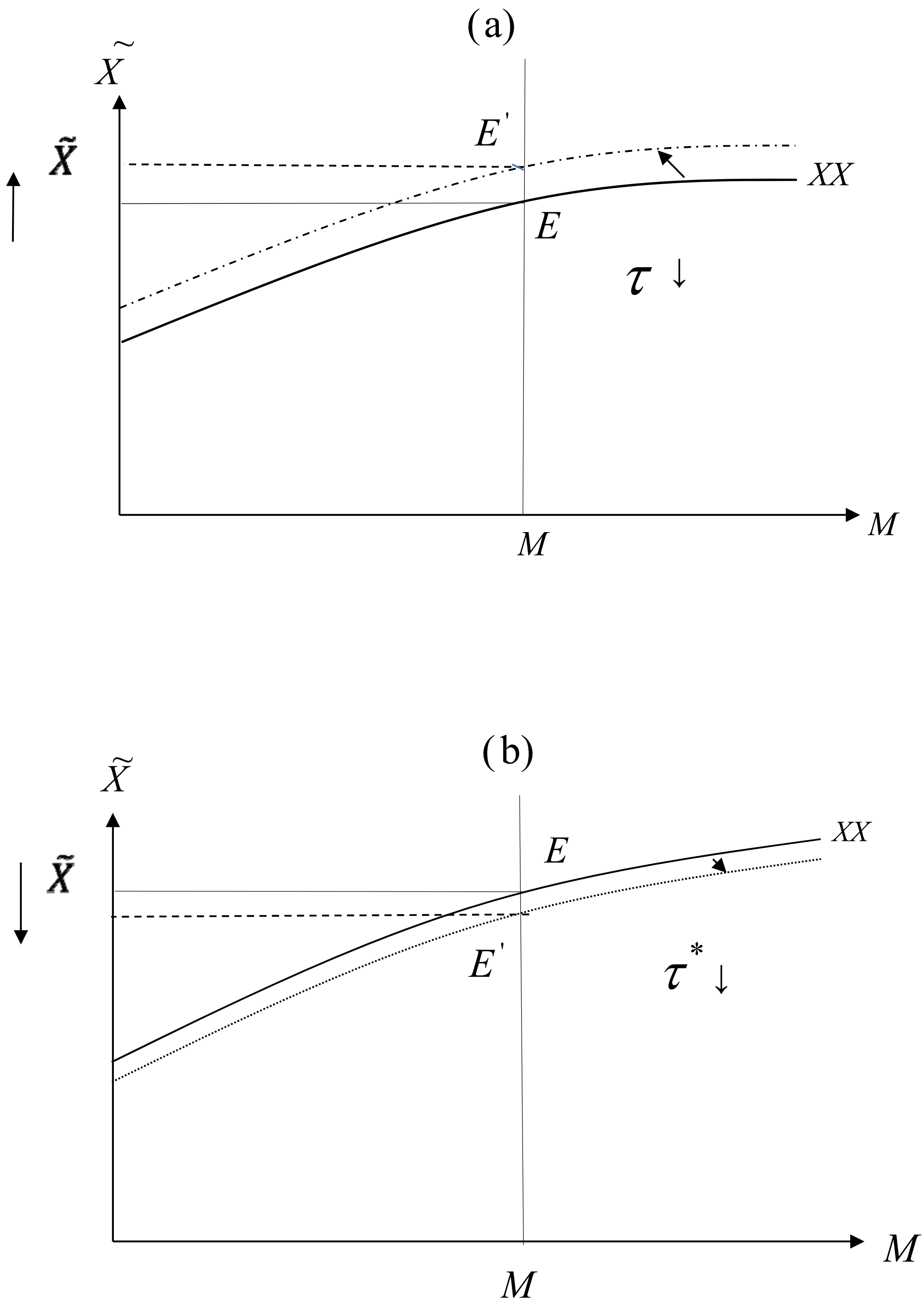


Figure A2. Technology Choice and Trade in Intermediate Goods under exogenous M