On The Mechanics of Trade-Induced Structural Transformation

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Abstract: Gains from trade come from a certain degree of specialization among trade partners. Specialization in the case of an agriculture-based developing country might be feared to imply a higher reliance than ever on low skill labor. Trade might thus be seen as a step away from the much awaited structural transformation of the economy, which can only come with increases in agricultural productivity. In this paper, we suggest that it needs not be the case. We show that trade openness can in fact trigger the structural transformation of such an agrarian society. It can induce a higher reliance on human capital accumulation and produce the necessary productivity gains for an economy to pick up. Our dynamic general equilibrium model provides a clear illustration of the mechanics behind such structural transformation.

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I Introduction

From the view-point of traditional trade theory, gains from trade come from specialization in goods for which a country has a comparative advantage. Thus for agriculture-based developing countries (Sub-Saharan African countries, in particular) specialization in agriculture is a source of gains from trade. Yet, industrial revolutions require a change in the skill-composition of the labor force, which - one may reasonably fear - do not naturally derive from specialization in agriculture —known to be intensive in the use of unskilled labor. "Globalization," as anti-trade activists typically call the gradual removal of trade barriers, may increase the divide between rich and poor countries if it implies that agriculture-based countries are pushed away from the necessary conditions for raising the share of economy-wide skilled labor— a process we refer to as structural transformation. Catching up with industrialized countries would then be still further from reach.

In this paper, we show that, unlike commonly believed, structural transformation can in fact be induced by a country's specialization in agriculture. Crucial to this process is the development of a sizable sector of agricultural research and extension services.[4] As a services provision sector, agricultural research and extension relies intensively on skilled labor —agronomists and agricultural technicians— for the design and transfer of organizational methods, new crop varieties, better management systems, with the purpose of improving farming practices so as to slow down deforestation, arrest erosion, and preserve or improve soil quality. The development of the research and extension services sector is therefore of prime importance for agriculture-based developing countries. Yet, in these countries, shortage of skill supply seriously limits the availability of quality research and extension services to farmers, which in turn limits on-farm productivity growth.[5]

Our theory of trade-induced structural transformation features a long run increase in the

[4]Agricultural extension encompasses a range of services aimed at expanding farmers' exposure to e ective organization and management skills, and to new technologies. It focuses on helping farmers master techniques and socioeconomic knowledge necessary to the improvement of the productivity of their farms.

[5]Back to the 1960ies, studies by Griliches (1963, 1964) covering many U.S. states over a decade found that education and expenditures on agricultural research and extension impact on agricultural output in a significant way.

share of economy-wide skilled labor without a corresponding change in the country's trade pattern. While a simple capital accumulation model could also push a liberalized economy out of an unskilled labor trap, as emphasized, for example, in early economic development theories (e.g., Lewis, 1954; Nurkse, 1953; Rosenstein-Rodan, 1943), this paper stresses that a country need not change its trade pattern in order to escape from an unskilled labor trap. The main features of our dynamic, intertemporal model of trade openness are the following.

There are two final goods (an agricultural good and a manufacturing good) all of which are tradable.[6]There are four factors of production (namely physical capital, unskilled labor, skilled labor, and an intermediate good), none of which is internationally traded. The input-output structure of the two tradable sectors (farming and manufacturing, respectively) is in the tradition of Ricardo-Viner's specific factor model: unskilled labor is specific to farming while skilled labor is specific to manufacturing. Only physical capital can be perfectly moved between farming and manufacturing. The input-output structure of the farming sector is, however, the more complex of the two. In particular, physical capital and unskilled labor are perfect substitutes in farming, and each of these two factors complements the intermediate good. More importantly, the farming sector exhibits a non-neutral process of technical change, whereby the availability of the intermediate good induces farmers to substitute physical capital for unskilled labor in the production process.[7] The structure of this process draws from a long tradition of technical change models. First, our modeling of the farming sector as characterized by increasing returns to scale draws from Griliches (1964). Second, the dynamic pattern of trade-induced re-allocation of production factors across sectors aligns with findings by Echevarria (1998) who reports that over time, Canadian agriculture became more capital intensive than manufacturing,

[6]This three-sector structure of the economy draws from Echevarria (1995).

[7]Observe that we could also allow the manufacturing sector (i.e., the import-competing sector under free trade) to be subject to technical change. This, however, would make structural transformation much easier to obtain for a small initially skill-scarce economy, as a change in trade patterns induced by technical change in manufacturing could act as another engine of structural transformation. We chose to bias the model as much as possible against the point we wanted to demonstrate.

even when accounting for land intensiveness. Third, increased capitalization of agriculture in the process of development is consistent with evidence of massive labor re-allocation away from agriculture (as in Clark 1940, Kuznets 1957, and Chenery 1960), and ultimate redeployment in services (as in Kongsamut et al. 2001). Fourth, our assumption that agricultural research and extension services (the intermediate good in our model) generate aggregate productivity gains draws from available evidence that these services were responsible for a substantial share of productivity growth in India over the last three decades (Evenson et al., 1999) and elsewhere (Evenson, 2001).[8] Finally, our model implicitly assumes the existence of a high level of financial development which allows for adequate farmers' response to incentive to use more improved agricultural inputs. This assumption is consistent with findings from a recent study by Claessens and Feijen (2006) over more than 50 countries between 1980 and 2003. They find that financial development increases overall agricultural productivity through fertilizer and tractor use, with 1 percent increase in private credit to GDP boosting value added per agricultural worker by 1.0 –1.7 percent.[9] Beck, Demirgüç-Kunt, and Levine (2005) also finds that financial development accelerates poverty reduction.

We use this model to demonstrate the effects of trade openness on the skill composition of the labor force of an initially skill-scarce small economy. In doing so, we follow the standard approach of assuming that countries differ in their relative endowments of the specific factors (in this case unskilled labor and skilled labor) used in tradables. Under this assumption, the specific-factor model is simply a variant of the Heckscher-Ohlin model;

[8]Estimates of the economic impact of agricultural research and extension services vary across regions and crops. Indeed, Evenson (2001) computed the median estimated internal rate of returns to be above 40% for extension services and between 40 and 60% for agricultural research. Griliches (1964) also found that an additional dollar of agricultural R&D expenditure per year would approximately generate 13 dollars of output, which implies a gross rate of return to the order of 1300 percent.

[9]Note that unlike consumers who may need collateralizable assets in order to borrow, farmers (even when individually lacking a sizable collateral for borrowing) can group in small cooperatives and benefit from group-lending as is well-documented in the microfinance literature. Because in the real-world, the main purpose of microfinance is to support participation in economic activities, we implicitly restricted this option to farmers only, leaving consumers collateral-constrained.

hence our main assumption that the initially skill-scarce, small economy has a comparative advantage in farming—the sector that uses unskilled labor as a specific factor. A well-known direct effect of trade openness, in that context, is a decline in the relative price of the manufacturing good. Since unskilled labor is a specific factor in farming, in the long run one may therefore expect, as an implication of Heckscher- Ohlin explanations of trade, a rise in the share of unskilled labor (and thus a decline in the share of skilled labor) in the economywide labor force. Yet, our theory predicts exactly the opposite: trade openness causes a rise in the relative share of skilled labor in the economy-wide labor force as well as a rise in the skill-premium in wage. While the rise in the skill-premium stands in sharp contrast with the standard Heckscher-Ohlin explanation of international trade (as summarized for instance in Harrigan and Zakrajsek, 2000), it is in fact consistent with empirical evidence that skill premia are effectively rising even in developing countries (e.g., China) whose comparative advantage lies in goods intensive in the use of unskilled labor (Robbins 1996; Arbache, Dickerson and Green, 2004).[10]

Why would trade openness enhance skill-premia and lead to an increase in the share of skilled labor in the economy-wide labor force of an initially skill-scarce small economy? The key mechanism behind this result is highlighted by the two direct effects trade openness introduces in the initially skill-scarce small open economy. First, trade openness lowers the relative price of the import-competing good. Second, it raises the demand for production factors used in farming. We show in this paper that these two direct effects of trade openness combine to produce the following wave of indirect effects:

(1) the manufacturing sector contracts due to import competition;

(2) the farming sector expands;

(3) the price of the intermediate good used intensively in farming rises;

(4) this in turn causes the intermediate good sector to expand.

The contraction of the manufacturing sector might be feared to imply a decline in the price of the specific factor used in manufacturing (i.e., skilled labor)—which is a standard prediction of the Ricardo-Viner model. However, because skilled labor is also used inten-

[10]We thank the referee of this journal for pointing this out to us.

sively in the non-tradable (intermediate good) sector, the expansion of the latter following trade liberalization overturns this standard prediction. More importantly, the expansion of the intermediate good sector combined with the non-neutral effect of technical change in farming represents the driving-force of the increase in both the skill-premium in wage and the return to education following trade liberalization. Because this mechanistic process is unleashed by the economy's exposure to international competition, we argue that trade openness can indeed pool an initially skill-scarce economy out of the unskilled labor trap without altering its pattern of trade.

To sum up, with respect to the literature on trade and development, we make three important contributions. First, trade openness can trigger the development of a skilled labor force in an initially skill-scarce country, contrary to the prediction of the existing literature that trade openness will cause this scarcity to persist in the long run (as in Findlay and Kierzkowski 1983, Matsuyama 1992, and Stokey 1996). Second, the development of this skilled labor force drives agricultural development under trade openness, contrary to the findings of the existing literature where such development benefits exclusively the non-farming sector (as in Cartiglia 1997, Eichers 1999, and Ranjan 2001). Third, a rise in the skill premium in wage is the driving force behind the liberalizing economy's ability to escape the unskilled-labor trap, contrary to findings from the existing literature that a decline in the skill premium in wage is necessary for an initially skill-scarce economy to escape this trap (e.g., Cartiglia 1997 and Ranjan 2001). Unlike this literature, therefore, we obtain a positive association between trade openness and the share of skilled labor in the economywide labor force that is consistent with empirical evidence.

Our paper is also linked to the economic growth literature in which substantial ground has been gained on the understanding of the process of structural transformations (see, e.g. Laitner, 2000; Gollin, Parente, Rogerson, 2002), and the potential role of human capital (see, e.g. Temple and Voth, 1998). In particular, our analysis fits well into the sectoral approach of this strand of the literature and adds to Kongsamut et al. (2001), Echevarria (2007), and Ngai and Pissarides (2007) contributions in a significant number of ways. Of all these models, only Echevarria (2007) studies structural transformation under trade openness. Indeed, our model can be viewed as extending Echevarria (2007) to include the empirically-relevant feature of substitutability between unskilled labor and physical capital in farming,[11] as well as accounting for the agricultural research and extension services sector as a non-tradable sector. As a result, unlike Echevarria's, our model implies the persistence in the long run of the country's initial trade pattern, even as its economy makes its way out of the unskilled-labor trap.

Finally, as a by-product of our model, trade openness has a negative effect on the supply of child labor as more young agents relinquish unskilled jobs to seek an education. This indirectly links our paper to the literature on the effects of trade on child labor. In the next section, we describe the model, which we analyze in depth in Section 3. We conclude in Section 4. All Propositions along with the theorem are proved in the Appendix section.

II The model

We build an overlapping-generations, three-sector economy in which economic activities extend over an infinite number of periods. It operates in discrete time t. There are two final goods: a commercial crop (good a) which we take as the numeraire, and an import-competing good (m). Both final goods are tradable. In addition, there is an intermediate good (x), which is used as an input into the production of good a. This intermediate good is nontradable. The nontradable good sector is the research and extension services sector, which provides technology-based solutions for relaxing on-farm yield constraints.

At the beginning of every period, a new generation of two period-lived heterogeneous agents is born. This new generation coexists with a generation of old agents. There is no population growth. Each generation has total population size normalized at unity.

Young agents are endowed with a level of physical capital, k, which they rent out to firms in the beginning of the first period of their life, at a market price r. They differ in their respective endowment of physical capital, and are distributed across capital levels according to a cumulative function, Ψ, with strictly positive p.d.f., ψ, over the bounded

[11] For a survey of the empirical findings, see Hamermesh, 1993.

support, $\left[0, \bar{k}\right]$, $0 < \bar{k} < \infty$. The difference in capital endowment is the only source of inequality in this environment. Capital fully depreciates within a period.[12]

In their first period of life, all agents must decide whether to invest in skill accumulation or to supply unskilled labor to firms from that period on. In their second and last period, agents supply labor to firms in exchange for a wage, ω_i, which depends on their skill status i ($i = s$ if skilled, u if unskilled).

Let e be a binary variable taking value 1 if a young individual decides to invest in skill acquisition, and 0 if he elects to supply unskilled labor to firms. A young agent who chooses $e = 0$, supplements his capital income with an unskilled labor income in the first period, and remains an unskilled worker throughout his entire lifetime. In contrast, an agent who elects for $e = 1$ will forgo income from unskilled labor in the first period, in order to receive a skill-enhancing education, and so becomes a skilled worker in his second and last period of life. All education costs are pure opportunity costs.[13]

Let $y_{\tau t}(e, k)$ denote the income at time t of an agent of age $\tau \in \{1, 2\}$ having made decision e when his endowment of capital was k:

$$y_{\tau t}(e, k) = \begin{cases} r_t k + (1 - e)\,\omega_{ut} & \text{for } \tau = 1 \\ e\omega_{st} + (1 - e)\,\omega_{ut} & \text{for } \tau = 2 \end{cases}$$

Let p_j denote the relative price of good j ($j = m, x$). We use the small country assumption, i.e. the prices of exported/imported goods are exogenously determined by the international market. We also assume that the international market is stable so that these prices are constant over time.

[12]Clearly, not allowing for capital accumulation is a simplifying assumption. Since it biases the results against structural transformations implying increases in the proportion of skilled workers, it is made without loss of generality. We will show that even absent capital accumulation, trade may lead to such structural transformations in an initially skill-scarce, agriculture-based economy. We thus take the strongest case against our claim.

[13]We abstract from education fees. One could argue that education fees are a function of education supply and demand as well as public expenditures on education. As a country opens up to trade, an increase in the demand for education may initially increase school fees, but as the supply of skilled labor increases, so should the supply of teachers and tax receipts. As a result the speed of structural transformation may be somewhat lower in early stages in a model with school fees. But our qualitative results would not change.

In each period, a typical individual divides his income between the consumption of good a (denoted as C_a) and of good m (denoted as C_m). The lifetime utility of an agent born in period t is given by:

$$\mathbf{U}(c_{1t}, c_{2t+1}) = \ln c_{1t} + \ln c_{2t+1} \tag{1}$$

where $c_{\tau t} = (C_{a\tau t})^{\mu} (C_{m\tau t})^{1-\mu}$, $\mu \in (0, 1)$. Agents choose their occupational strategy (e) by anticipating the consequences this choice will have on their lifetime utility which in turn depends on how much they consume in every period. By backward induction, forward-looking agents first determine their optimal lifetime utility given their occupational choice, then select the occupational option that yields the highest lifetime utility. As discounting is not central in the question we address, we assume no discounting to simplify the notation.

An agent's periodic budget constraint implies: $C_{a\tau t} + p_m C_{m\tau t} \leq y_{\tau t}(e, k)$.[14] Given the utility function specified in (1), we can derive the following demand equations:

$$\begin{aligned} C_{a\tau t} &= \mu y_{\tau t}(e, k) & (2) \\ C_{m\tau t} &= (1-\mu)\frac{y_{\tau t}(e, k)}{p_m}. & (3) \end{aligned}$$

The above demand schedules will prove useful when characterizing skilled and unskilled labor supplies.

A Agents' occupational choices

At any date t, the supply of skilled labor is given by the total proportion, η_{st}, of skilled individuals. This figure equals the total proportion of adult agents who chose to invest in skill acquisition when young. Since all young agents are forward-looking, in choosing their occupation, they balance the future benefits against present education costs.

[14]This budget constraint implies that given his income as determined by $y_{\tau t}(e, k)$, a consumer can neither borrow nor lend. Since agents are homogenous in terms of learning ability, and education is the only mechanism for human capital accumulation in this economy, a borrowing constraint for utility-maximizing agents is sufficient to obtain the observed coexistence of unskilled labor and skilled labor in the economywide labor force of modern societies.

Let $V(e, k, m_t)$ denote the indirect lifetime utility of a young agent who makes occupational choice, e, in the first period, when he is endowed with a level of physical capital, k, and prices are given by the vector $m_t = (r_t, \omega_{ut}, \omega_{st+1}, \omega_{ut+1}, p_m)$. From (1), substituting in (2) and (3), yields:

$$\begin{aligned} V(e, k, m_t) &= \ln[r_t k + (1-e)\omega_{ut}] + \ln[e\omega_{st+1} + (1-e)\omega_{ut+1}] \\ &\quad - (1-\mu)\ln p_m + Z, \end{aligned} \tag{4}$$

with Z, a constant, residual term. Thus, a young agent will choose to invest in skill-enhancing education if his endowment, k, of physical capital satisfies:

$$V(1, k, m_t) \geq V(0, k, m_t) \ .$$

He will take employment as an unskilled worker otherwise.

Let $\vartheta(k, \theta_t, \pi_{t+1}) = V(1, k, m_t) - V(0, k, m_t)$ represent the net gain an agent derives from investing in skill acquisition in the first half of his life, when he is endowed with a level of physical capital k, and faces an opportunity cost of education, $\theta_t = \omega_{ut}/r_t$, and a future skill-premium, $\pi_{t+1} = \omega_{st+1}/\omega_{ut+1}$. Using (4), it can be established that:

$$\vartheta(k, \theta_t, \pi_{t+1}) = \ln\left[\frac{k}{k+\theta_t}\right] + \ln \pi_{t+1} \ . \tag{5}$$

As can be inferred from (5), *ceteris paribus*, the net gain from investing in skill rises with the agent's physical capital endowment, k, or with the future level of the skill-premium, π_{t+1}, while it drops with a rise in the opportunity cost of this investment. Therefore, a young agent will choose to forgo income from unskilled labor in order to invest in skill-enhancing formal education if and only if his endowment of physical capital, k, satisfies the inequality $\vartheta(k, \theta_t, \pi_{t+1}) > 0$. He will elect to remain unskilled for the rest of his active life if and only if his endowment satisfies $\vartheta(k, \theta_t, \pi_{t+1}) < 0$. Since the function ϑ is increasing in k, young agents who benefit from investing in skill acquisition are necessarily those endowed with a level of physical capital higher than a threshold, k_t^*, which characterizes an indifferent agent. This threshold solves the equation $\vartheta(k, \theta_t, \pi_{t+1}) = 0$. Using (5), we find k_t^* to be:

$$k_t^* = \frac{\theta_t}{(\pi_{t+1}) - 1}. \tag{6}$$

Equation (6) implies that in absence of a skill premium (i.e., $\omega_{st+1} = \omega_{ut+1}$), there does not exist a level of endowment such that education is worthwhile since $k_t^* \longrightarrow +\infty$. As long as this skill premium exists (as is the case in many countries), the number of young agents who choose to work as unskilled workers is given by $\Psi(k_t^*) < 1$, while that of young agents who will invest in skill-acquisition and thus become skilled individuals in their second period of life is simply:

$$n_t = 1 - \Psi(k_t^*) \ , \tag{7}$$

all $t = 0, 1, ...$ Given the properties of the function, Ψ, it follows from (6) that any exogenous factor that raises the opportunity cost of education (respectively, the skill premium) hinders (respectively, fosters) skill accumulation through formal schooling.

In period t, the total supply of skilled labor is the proportion of agents who chose to invest in skill-acquisition in period $t-1$. In contrast, the total supply of unskilled labor in period t, is composed of two different generations of agents: old agents who did not attend school in period $t-1$ (in total number $1-n_{t-1}$), and young agents who elect to work from period t on (in total number $1-n_t$). Therefore, letting η_{it} denote the total supply of labor of quality i $(i = s, u)$ in period t, we have:

$$\eta_{st} = n_{t-1} \tag{8}$$

$$\eta_{ut} = 2 - n_t - n_{t-1}, \tag{9}$$

$t = 0, 1, ...$

A structural transformation in this economy can thus be captured by the law of motion for η_{it}. To clearly characterize the dynamics of skilled labor supply, we now explicitly model the supply side of the economy.

B Production and factor prices

In this subsection, we describe the production technologies for all goods produced in this economy. For convenience we temporarily drop the time subscript, except when absolutely necessary.

B.1 Production of the import-competing good

Production of the import-competing good m requires physical capital (K_m) and skilled labor (S_m). Output in this sector is described by a standard Cobb Douglas technology:

$$Y_m = (K_m)^{\alpha} (S_m)^{1-\alpha}, \qquad \alpha \in (0,1)$$

Profit-maximization by perfectly competitive firms leads to the following factor demand schedules:

$$\omega_{sm} = (1-\alpha) p_m \left(\frac{K_m}{S_m}\right)^{\alpha} \tag{10}$$

$$r_m = \alpha p_m \left(\frac{K_m}{S_m}\right)^{\alpha-1}. \tag{11}$$

B.2 The research and extension services sector

This sector produces research and extension services, using skilled labor only.[15] Workers in this sector are agronomists and/or agricultural technicians. They do research and technically assist farmers in raising on-farm productivity. The representative firm's output, Y_x, is given by:

$$Y_x = (S_x)^{1-\alpha}. \tag{12}$$

Profit maximization in this nontradable sector leads to the following wage:

$$\omega_{sx} = (1-\alpha) p_x (S_x)^{-\alpha}, \tag{13}$$

[15] In our model, agricultural research and extension services are assumed to be privately provided. In areas dominated by commercial farming, private sector involvement in the provision of extension services seems to be a natural mechanism for addressing farmers' needs in ever-changing agro-ecological environments (World Bank, 1997). With the increased commercialization of agriculture in many developing countries, it seems therefore appropriate to assume a private provision of research and extension services. In practice, many developing countries, often with the help of The World Bank, have created competitive private-sector networks of extension consultants to deliver inputs and technology to private farmers (Schultz et al., 1996). Umali-Deininger (1996) also documents the involvement of private consulting firms in the provision of extension services in countries such as Argentina, Brazil, Colombia, Mexico, Uruguay, Korea, and Taiwan.

where p_x denotes the relative price of extension services. Assuming skills are perfectly transferable across sectors, the economy faces the following resource constraint in the skilled labor market: $S_m + S_x \leq \eta_s$.

B.3 The farming sector

Research and extension services have been an important input for agricultural development in most developing countries (Evenson and Mwabu, 1998; Evenson, Pray and Rosegrant, 1999; Evenson, 2001; Owens *et al.* 2003), along with capital, land and labor. To keep the focus on the importance of research and extension services, we abstract away from land as an input into farming. Farming in our model essentially requires the use of agricultural research and extension services, X, physical capital, K_a, and unskilled labor, U. Adding land to such model would make the analysis more complex without qualitatively affecting the results.

The production function we use is CES in capital and unskilled labor and Cobb Douglas in research and extension services. This production function captures two important features of agricultural production: the easy substitutability of physical capital and unskilled labor and their complementarity with agricultural research and extension services.[16] Production functions of this type are now commonly used in multifactor models in which the elasticities of substitution may vary between pairs of factors. Fallon and Layard (1975) use a double CES form whereas Stokey (1996), Greenwood and Seshadri (2002), Krusell, Ohanian, Ríos-Rull and Violante (2000) and Maoz and Moav (2004) use a form closer to ours. Agricultural output in our model is given by:[17]

$$Y_a = X^{1-\alpha} \left[\phi\left(\bar{X}\right) K_a + U\right]^{\alpha}, \tag{14}$$

where $\bar{X}$ denotes the total supply of extension services, and $\phi\left(\bar{X}\right)$ measures the technical

[16] The assumption of a strong substitutability of unskilled labor and capital is supported by a large body of empirical evidence surveyed in Hamermesh (1993). Evidence of a complementarity between skills and capital in farming can also be found in Hamermesh (1993). In manufacturing, the capital-skill complementarity has been extensively documented since Griliches (1969).

[17] Note that labor shares are identical for all sectors. We make this assumption simply to ensure the existence of a closed form solution, in line with Acemoglu (2003) and Cartiglia (1997).

progress on the productivity of physical capital brought about by overall agricultural research and extension services. The assumption of a capital augmenting technical progress in the sense of Solow is a simplifying assumption to keep the analysis tractable. For simplicity also, we set:

$$\phi\left(\bar{X}\right) = \bar{X}^{\varepsilon}, \qquad 0 < \varepsilon < 1 \tag{15}$$

In equilibrium, demand equals supply: $X = \bar{X}$. Since good X is nontradable, domestic market-clearing implies that:

$$X = Y_x. \tag{16}$$

Under perfect competition, profit-maximization leads to the following factor demand schedules:

$$p_x = (1-\alpha)\left[\frac{\phi(X) K_a + U}{X}\right]^{\alpha} \tag{17}$$

$$\omega_u = \alpha\left[\frac{\phi(X) K_a + U}{X}\right]^{\alpha-1}, \tag{18}$$

$$r_a = \alpha\phi(X)\left[\frac{\phi(X) K_a + U}{X}\right]^{\alpha-1}. \tag{19}$$

Denoting by K the aggregate stock of physical capital, we can write the resource constraint in the capital market as follows:

$$K_a + K_m \leq K, \quad \text{with } K = \int_0^1 kdk\ .$$

Since $\varepsilon \in (0,1)$, it is straightforward to show using (18) and (19) that growth in agricultural research and extension services will raise the marginal productivity of both physical capital and unskilled labor, but the magnitude of this increase will be higher for physical capital, thus initiating the process of capital-augmenting technical change in agriculture.

III Equilibrium effects

In this section, we analyze the effects of trade openness on the skill composition of the labor force of an initially skill-scarce small economy (our main result), and also analyze its implications for (i) the opportunity cost of education, (ii) the skill-premium in wage; (iii) the (gross) return to education; and (iv) the price of the non-tradeable good. We begin by defining an equilibrium in the context of a small open economy with exogenously determined prices for tradables and internationally immobile factor inputs.

Definition 1 (Equilibrium) *An intertemporal general equilibrium for this initially skill-scarce, agricultural-based, open economy is a sequence of prices, $\{p_{xt}, r_{at}, r_{mt}, \omega_{ut}, \omega_{sxt}, \omega_{smt}\}_{t=0}^{\infty}$, a sequence of threshold physical capital endowments, $\{k_t^*\}_{t=0}^{\infty}$, a sequence of school-goers, $\{n_t\}_{t=0}^{\infty}$, a sequence of intersectoral allocation of inputs, $\{K_{at}, K_{mt}, S_{xt}, S_{mt}, U_t, X_t\}_{t=0}^{\infty}$, and a sequence of relative supply of skilled and unskilled labor $\{\eta_{st}, \eta_{ut}\}_{t=0}^{\infty}$, such that, for all t:*
(i) given $(p_m, p_{xt}, \eta_{st}, \eta_{ut}, \eta_{st+1}, \eta_{ut+1}, \omega_{sxt}, \omega_{smt}, \omega_{ut}, K)$, $X_t = (S_{xt})^{1-\alpha}$, S_{xt} satisfies (13), S_{mt} satisfies (10), K_{at} satisfies (19), K_{mt} satisfies (11), and U_t satisfies (18);
(ii) $\omega_{sxt} = \omega_{smt} = \omega_{st}$ and $r_{at} = r_{mt} = r_t$;
(iii) given (K_{at}, U_t, X_t), p_{xt} satisfies (17);
(iv) given k_t^*, n_t^* satisfies

$$n_t = 1 - \Psi\left(k_t^*\right)\ ; \tag{20}$$

(vi) given $(p_m, \eta_{st}, \eta_{ut}, \eta_{st+1}, \eta_{ut+1}, K)$, k_t^* satisfies (6);
(vii) η_{st} and η_{ut} , satisfy

$$\begin{aligned} \eta_{st} &= n_{t-1} \\ \eta_{ut} &= 2 - n_t - n_{t-1}; \end{aligned}$$

(viii) all markets clear and p_{xt} adjusts accordingly.

In a model like ours, the picture of the general equilibrium effects of trade openness can be quite blurry. To clarify this picture, we restrict attention to long run effects by emphasizing the economy's behavior along the steady state.

Definition 2 *A steady state equilibrium for this small open economy is a general equilibrium in which the capital-output ratio in the import-competing sector, K_{mt}/Y_{mt}, remains constant overtime.*

Using the production technology in the import-competing sector, we re-write the capital-output ratio as follows:

$$\frac{K_{mt}}{Y_{mt}} = (\rho_t)^{1-\alpha},$$

where $\rho_t = K_{mt}/S_{mt}$ all t. Therefore, the capital-output ratio in the import-competing sector is constant along the steady-state of the small open economy if and only if $\rho_t = \rho$, all t.

Theorem. *Suppose the set, $[\rho_{\min}, \rho_{\max}]$, of feasible capital-skilled labor ratios satisfies*

$$(p_m)^{\bar{\sigma}} / B^{\varepsilon}\bar{\alpha} < \rho_{\min} < \rho_{\max} < 2\,(p_m)^{\bar{\sigma}} / B^{\varepsilon}. \tag{21}$$

Then, there exists a unique steady state equilibrium for this small open economy.

With this theorem in hand, we can now proceed to study the properties of the steady state equilibrium of this small open economy. We begin with the following result:

Proposition 1 *Under condition (21), trade openness causes the capital-output ratio in the import-competing sector to rise.*

The validity of Proposition depends on condition (21) being met. Observe that since $B \in (0, 1)$ by construction, α and ε can always be appropriately chosen, and p_m appropriately scaled such that the set, $[\rho_{\min}, \rho_{\max}]$, of all feasible values for ρ, and whose end-points satisfy condition (21) is always non-empty. We are now ready to state the main result of this paper:

Proposition 2 *Under condition (21), trade openness raises the supply of skilled labor in the small open economy.*

Why may trade openness cause the skilled labor supply to rise in the long run in this initially skill-scarce agrarian small economy? To understand the importance of this question, it must first be recalled that this small agrarian economy has a comparative advantage in the export of a good that does not require skilled labor directly. Instead, the good uses a non-tradable input that is intensive in the use of skilled labor. Explaining the mechanistic process behind this surprising result about the long run effects of trade openness on the structure of the labor force of this initially skill-scarce economy is crucial if one is to amply inform the existing debate on policies aimed at pooling agrarian economies out of unskilled labor traps. We begin our explanation with the following Proposition:

Proposition 3 *Under condition (21), trade openness raises the price, p_x, of the intermediate good.*

Along with the fall in the relative price, p_m, of the manufacturing good, the rise in the relative price, p_x, of the intermediate good is a direct effect of trade openness. These two effects combine to create the following indirect effects:

Proposition 4 *Under condition (21), trade openness causes a contraction of the manufacturing sector, and the expansion of both the farming and the intermediate good sectors.*

That trade openness causes a contraction of the import-competing manufacturing sector, and an expansion of the farming sector is a standard implication of trade openness under Hecksher-Ohlin's or Ricardo-Viner's explanations of free trade. As trade openness causes a decline in the relative price of the manufacturing good, both physical capital and skilled labor pool out of the import-competiting sector, thus causing its contraction. In contrast, the farming sector expands because the decline in the relative price of the import-competing good corresponds to a rise in the relative price of the agricultural good. Thus profits in that sector will rise so that in the long run, more firms are attracted into the farming sector, resulting in an increase in agricultural output. However, since the intermediate good is used intensively in farming the expansion of the farming sector induces a rise in the price of the intermediate good (Proposition 3 above). This, in turn, raises profits in the intermediate good sector, thus attracting more firms and causing output to rise in the long run. In what follows, we show how this mixed sequence of contraction and expansion effects of trade openness induces a rise in the return to education.

Define a real-valued function $R : M \to M$ by $\forall p_m \in M$, $R(p_m) = \Pi(p_m)/\Theta(p_m)$, where $R(p_m)$ denotes the steady-state level of the (gross) rate of return to education.

Proposition 5 *If condition (37) holds, then, in the long run, trade openness raises the return to education.*

The above result reflects the effects on the incentive to invest in skill-imparting education, of two conflicting forces unleashed by trade openness. First, trade openness, by inducing a contraction of the manufacturing sector and an expansion of the farming sector, causes the unskilled labor wage to rise more than proportionately to a rise in the return to capital. This is because unskilled labor is a specific factor in farming, while capital is mobile between the two sectors. The result is a rise in the opportunity cost of education, which tends to discourage investment in education. Second, trade openness, by inducing an expansion of the intermediate good sector, causes a rise in the skilled labor wage, because production of the intermediate good is intensive in skilled labor. Furthermore, as technical change in farming causes farmers to substitute capital for unskilled labor as more of the intermediate good becomes available, the skilled labor wage rises more than proportionately to the increase in the unskilled labor wage, thus causing a rise in the skill-premium in wage, which in turn tends to encourage investment in education. Whether or not, in the long run, trade openness causes more agents to invest in education in this initially skill-scarce small economy depends on which one of these two conflicting effects is the strongest. The above Proposition therefore states that the skill-premium effect offsets the adverse effect of the opportunity cost of education. Compared to findings in the existing literature (e.g., Cartiglia 1997; Ranjan 2001), the distinguishing feature of our main result is that a trade-induced decline in the (opportunity) cost of education is not necessary to enhance skill accumulation. Indeed, when trade openness does cause this cost to rise (as argued in this paper), all that is needed for a trade-liberalizing small economy to escape the unskilled labor trap is that the skill premium in wage increases more than the opportunity cost of education.

IV Concluding remarks

This paper examines the forces underlying the structural transformation of a small economy with initially a comparative advantage in the production of agricultural commodities. To explore the nature of these forces, we use a three-sector intertemporal general equilibrium model, with two final goods and one intermediate, nontradable good. Our model identifies three main ingredients for a successful process of structural transformation. The First is the substitutability of physical capital for unskilled labor in farming. The second is a capital-augmenting process of technical change in farming induced by a greater availability of agricultural research and extension services. The third is trade openness itself, which, in the long run, leads to an increase in the relative supply of skilled labor. Previous studies imply that this increase in the relative proportion of skilled individuals fails to benefit the export sector, which they model as unskilled-labor intensive (e.g. Cartiglia 1997). Our model reverses this prediction by modeling the farming sector explicitly and accounting for the complementarity between capital and research and extension services (intensive in skills). This ensures that the export sector (i.e., the farming sector) directly benefits from the trade-induced increase in the supply of skilled labor. The latter strengthens its international competitiveness.

Our message to policy makers is two-fold. First, specialization in agriculture can be an engine of structural change if the barriers to quality education are not too big. In this paper, we have assumed that the cost of education is the opportunity cost for a young agent of not working. A trade-induced structural transformation will be all the more powerful if the government makes education one of its most important policies. The availability of affordable quality education is essential for the mechanics we have highlighted in this paper to work. Second, trade may lead to a serious shrinking of the import competing sector. Our analysis suggests that protecting this noncompetitive sector against all odds may not be an effective way to stimulate the accumulation of human capital.

Our message to anti-trade activists is simple. Relax! Trade and the specialization it implies do not wipe out the hopes for poor countries to move away from poverty. On the contrary, trade can be an important engine of structural revolution.

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Appendix

Proof of the Theorem.

The proof consists of 5 claims:

Claim 1. *Given p_m, the output of the non-tradable is constant along the steady state of the small open economy*

Proof. The output of the non-tradable good is given by $Y_{xt} = (S_{xt})^{1-\alpha}$, all t. We thus need to show that S_{xt} is time-invariant, given p_m. First, using factors price equations, we can characterize the real wage for skilled labor in terms of the non-tradable good as follows:

$$\frac{\omega_{st}}{p_{xt}} = p_m \left[\frac{\frac{K_{mt}}{S_{mt}}}{\frac{\phi(X_t)K_{at}+U_t}{X_t}} \right]^{\alpha}. \tag{22}$$

Second, perfect mobility of capital between the farming sector and the import-competing sector implies equal capital return in both sectors: $r_{mt} = r_{at}$. This equality in turn can be shown to lead to:

$$\frac{\frac{K_{mt}}{S_{mt}}}{\frac{\phi(X_t)K_{at}+U_t}{X_t}} = \left[\frac{p_m}{\phi\left(X_t\right)} \right]^{1/(1-\alpha)}. \tag{23}$$

Combining (22) and (23) by way of substitution yields the real wage for skilled labor in terms of the non-tradable good as follows:

$$\frac{\omega_{smt}}{p_{xt}} = \left[\frac{p_m}{\left(X_t\right)^{\varepsilon\alpha}} \right]^{1/1-\alpha}, \tag{24}$$

where (24) makes use of the fact that $\phi\left(X_t\right) = X_t^{\varepsilon}$, by definition. Next, solving the factor price equation in the non-tradable sector for S_{xt} yields

$$S_{xt} = (1-\alpha)^{1/\alpha} \left(\frac{\omega_{sxt}}{p_{xt}} \right)^{-1/\alpha}. \tag{25}$$

Furthermore, from the market-clearing condition for the non-tradable good, we obtain the following equation:

$$X_t = Y_{xt} = (S_{xt})^{1-\alpha},$$

all t. Again solving for S_{xt} yields

$$S_{xt} = (X_t)^{1/1-\alpha}. \tag{26}$$

Combining (24), (25), and (26) using the equal-wage condition, $\omega_{smt} = \omega_{sxt}$, and rearranging terms yields

$$Y_t = X_t = (p_m)^{-\sigma} B \tag{27}$$

all t, where

$$\begin{aligned} \sigma &= \frac{1}{\alpha(1-\varepsilon)}, \\ B &= (1-\alpha)^{(1-\alpha)/\alpha(1-\varepsilon)}. \end{aligned}$$

Equation (27) thus establishes our claim· ■

Claim 2. *Given p_m, the opportunity cost of education is constant along the steady state of the small open economy*

Proof. The opportunity cost of education is given by

$$\theta_t = \frac{\omega_{ut}}{r_t},$$

where $r_t = r_{mt} = r_{at}$ due to the perfect mobility of capital between the farming sector and the import-competing sector, and

$$\omega_{ut} = (1-\alpha)\left[\frac{\phi(X_t) K_{at} + U_t}{X_t}\right]^{\alpha},$$

all t. Combining the above equation with the fact that $r_t = r_{at}$, it therefore follows by way of substitution that

$$\theta_t = \frac{1}{\phi(X_t)}.$$

And from **Claim 1**, it follows that $\theta_t = \Theta(p_m)$, all t, where

$$\Theta(p_m) = \delta(p_m)^{\bar{\sigma}}, \tag{28}$$

$\delta = B^{-\varepsilon}$, and $\bar{\sigma} = \varepsilon\sigma$. Equation (28) thus proves our claim· ■

Claim 3. *Given* p_m and ρ, *the skill premium is constant along the steady state of the small open economy.*

Proof. The skill premium is measured by the ratio $\pi_t = \omega_{st}/\omega_{ut}$. By way of substitution, this ratio in turn can be shown to be equal to

$$\pi_t = \frac{(1-\alpha)}{\alpha} \frac{1}{\Theta(p_m)} \frac{\omega_{st}}{r_t}.$$

We can the show that $\pi_t = \Pi(p_m, \rho)$, as an implication of perfect intersectoral mobility of physical capital and skilled labor, where

$$\Pi(p_m, \rho) = \frac{\bar{\alpha}\rho}{\Theta(p_m)}, \tag{29}$$

$\bar{\alpha} = (1-\alpha)/\alpha$, and $\rho = K_{mt}/S_{mt}$, all t. Equation (29) establishes our claim· ■

Equation (29) implies that the minimum stock of physical capital endowment, k_t^*, above which investing in education is optimal also remains unchanged along the steady state as a result of the capital-output ratio in the import-competing sector being constant in the steady state: $k_t^* = \kappa(p_m, \rho)$, all t, where[18]

$$\kappa(p_m, \rho) = \frac{(p_m)^{2\bar{\sigma}} \delta^2}{\bar{\alpha}\rho - \delta (p_m)^{\bar{\sigma}}}. \tag{30}$$

Therefore, we can characterize the steady state proportion, $n = N(p_m, \rho)$, of young agents who invest in education as follows:

$$N(p_m, \rho) = 1 - \Psi[\kappa(p_m, \rho)]. \tag{31}$$

This implies that, by construction, the supply of skilled labor and unskilled labor respectively are both constant along the steady state:

$$\eta_s = N(p_m, \rho) \tag{32}$$

$$\eta_u = 2[1 - N(p_m, \rho)] \tag{33}$$

We can now state and prove the following claim.

[18]Note that a positive threshold level of k_t^* clearly requires

$$\rho_{\min} > (p_m)^{\bar{\sigma}} \delta/\bar{\alpha}.$$

Claim 4. *Given* p_m and ρ, *the demand for physical capital in the farming sector remains unchanged along the steady state.*

Proof. Recall that due to perfect intersectoral mobility of physical capital, we have that: $r_m = r_a$. Using the previous claims, as well as the market-clearing condition for unskilled labor use, and solving the above equation for K_{at} yields the steady state demand for capital in the farming sector as follows:

$$K_{at} = \rho B^{\frac{1-\alpha(1-\varepsilon)}{1-\alpha}} (p_m)^{-\sigma/(1-\alpha)} - \frac{2\left[1 - N(p_m, \rho)\right]}{(p_m)^{-\bar{\sigma}} B^{\varepsilon}}, \tag{34}$$

which is constant and finite, as long as ρ is also constant and finite. This completes the proof of the claim· ■

Therefore, a steady state exists if and only if the capital-output ratio in the import-competing sector is constant overtime, implying that ρ is constant. Recall that

$$\rho = \frac{K_{mt}}{S_{mt}}, \qquad \text{all } t.$$

From the resource constraints respectively for skilled labor, and physical capital use, market-clearing implies that

$$\rho = \frac{K - K_{at}}{\eta_s - S_{xt}},$$

all t. Substituting in (26), (27), (31), (33) and (34), rearranging terms yields

$$\rho = f(\rho, p_m) \tag{35}$$

where $f : [\rho_{\min}, \rho_{\max}] \times M \to [\rho_{\min}, \rho_{\max}]$ denotes a real-valued function defined explicitly by

$$f(\rho, p_m) = \frac{K - \rho B^{1+\varepsilon\alpha/(1-\alpha)} (p_m)^{-\sigma/(1-\alpha)} - 2\left[1 - N(p_m, \rho)\right] (p_m)^{\varepsilon\sigma} B^{-\varepsilon}}{N(p_m, \rho) - (p_m)^{-\sigma/1-\alpha} B^{1/1-\alpha}} \tag{36}$$

where $M \subset \Re_+$. It therefore suffices to show that the function f is monotonically decreasing in ρ. Hence our final claim:

Claim 5. Suppose the set, $[\rho_{\min}, \rho_{\max}]$, of feasible capital-skilled labor ratios satisfies

$$(p_m)^{\bar{\sigma}} / B^{\varepsilon}\bar{\alpha} < \rho_{\min} < \rho_{\max} < 2 (p_m)^{\bar{\sigma}} / B^{\varepsilon}. \tag{37}$$

Then, equation (35) admits a unique solution.

Proof. We need to show that the graph representing the function g defined by $g(\rho) = \rho$, and the graph representing the function $f(., p_m)$ intersect only once, for a given level of p_m. Clearly the graph of g corresponds to the 45 degree line. To show that f is monotonically decreasing in ρ, it suffices to establish that $f_\rho < 0$. From (36), differentiating with respect to ρ, re-arranging terms yields

$$f_\rho = \left[\left(2 (p_m)^{\bar{\sigma}} B^{-\varepsilon} - \rho \right) N_\rho - B^{1+\varepsilon\alpha/(1-\alpha)} (p_m)^{-\sigma/(1-\alpha)} \right] S_m^{-1} \tag{38}$$

where $N_\rho < 0$. If $f_\rho < 0$, then the graph representing $f(., p_m)$ cut the 45^o line just once. Observe from (38) that $N_\rho < 0$. Since $\rho \in [\rho_{\min}, \rho_{\max}]$, condition (37) which ensures that $2 (p_m)^{\bar{\sigma}} B^{-\varepsilon} - \rho > 0$, also guarantees that $f_p > 0$. This completes the proof of the theorem$\cdot$ ■

Proof of Proposition 1.

Consider equation (35). Define a function $\Gamma : [\rho_{\min}, \rho_{\max}] \times M \to \Re$, by $\forall (\rho, p_m) \in M \times M$, where $M \subset \Re_+$,

$$\Gamma(\rho, p_m) \equiv f(\rho, p_m) - \rho. \tag{39}$$

To prove this Proposition, it therefore suffices to show that $\exists \varphi : M \to [\rho_{\min}, \rho_{\max}]$, defined implicitly by $\forall p_m \in M$,

$$\Gamma[\varphi(p_m), p_m] \equiv 0. \tag{40}$$

For that purpose, we first differentiate (39) with respect to ρ to obtain:

$$\Gamma_\rho = f_\rho - 1 < 0.$$

Next, differentiate (39) with respect to p_m to get:

$$\Gamma_{p_m} = \left[2 (p_m)^{\bar{\sigma}} B^{-\varepsilon} - \rho \right] (S_m)^{-1} N_{p_m} - (p_m)^{\bar{\sigma}-1} (S_m)^{-1} \bar{\sigma} \eta_u^* B^{-\varepsilon} + (p_m)^{\frac{-(1+\sigma)}{1-\alpha}} (S_m)^{-1} \rho\lambda, \tag{41}$$

where

$$\lambda = \frac{1}{\alpha(1-\varepsilon)}(1-\alpha)^{\frac{1-\alpha(1-\varepsilon)}{\alpha(1-\varepsilon)}}\left[B^{\frac{-\alpha(1-\varepsilon)}{1-\alpha}}-1\right],$$

$$N_{p_m} = -(p_m)^{2\bar{\sigma}-1}\bar{\sigma}\delta^2\frac{\left[2+\delta(p_m)^{\bar{\sigma}}\right]}{\left[\bar{\alpha}\rho-\delta(p_m)^{\bar{\sigma}}\right]^2}\psi\left[\kappa(p_m,\rho)\right]<0,$$

$$\eta_u = 2\left[1-N(p_m,\rho)\right]>0.$$

For an appropriate choice of α and ε, $\lambda \longrightarrow 0$, so that the fourth terms in (41) can be neglected without loss of generality, thus leading to:

$$f_{p_m} = \left[2(p_m)^{\bar{\sigma}}B^{-\varepsilon}-\rho\right](S_m)^{-1}N_{p_m}-(p_m)^{\bar{\sigma}-1}(S_m)^{-1}\bar{\sigma}\eta_u^*B^{-\varepsilon}.$$

Under condition (21), it is then clear that $\Gamma_p < 0$, so that the *Implicit Function Theorem* applies, thus establishing the existence of a real-valued function $\varphi : M \rightarrow [\rho_{\min}, \rho_{\max}]$, defined implicitly by (40), and such that $\varphi' < 0$, where

$$\varphi' = -\frac{\Gamma_{p_m}}{\Gamma_\rho}.$$

This completes the proof·

Proof of Proposition 2.

First combine (28), (30) and (31), using $\rho = \varphi(p_m)$ to define a real-valued function $N^* : M \rightarrow [0,1]$ such that $\forall p_m \in M$, $N^*(p_m) \equiv N[p_m, \varphi(p_m)]$, where

$$N[p_m,\varphi(p_m)] = 1-\Psi\left[\frac{(p_m)^{2\bar{\sigma}}\delta^2}{\bar{\alpha}\varphi(p_m)-(p_m)^{\bar{\sigma}}\delta}\right] \tag{42}$$

denotes the steady-state economywide supply of skilled labor. We need to show that $N^*(.)$ is a decreasing function of p_m: $N^{*\prime} < 0$. Differentiating (42) with respect to p_m yields

$$N^{*\prime}(p_m) = -\frac{(p_m)^{2\bar{\sigma}-1}\delta^2 2\bar{\sigma}\psi(k^*)}{\left[\bar{\alpha}\varphi(p_m)-(p_m)^{\bar{\sigma}}\delta\right]}-\frac{\left[\bar{\sigma}\delta(p_m)^{\bar{\sigma}-1}-\bar{\alpha}\varphi'(p_m)\right]}{\left[\bar{\alpha}\varphi(p_m)-\delta(p_m)^{\bar{\sigma}}\right]^2}(p_m)^{2\bar{\sigma}}\delta^2\psi(k^*)$$

which is negative by the above theorem, under condition (21) which guarantees that the term

$$\frac{(p_m)^{2\bar{\sigma}}\delta^2}{\left[\bar{\alpha}\varphi(p_m)-(p_m)^{\bar{\sigma}}\delta\right]}$$

is strictly positive. This completes the proof·

Proof of Proposition 3.

The price, p_x^*, of the intermediate good is determined in (17) . However, as an implication of perfect intersectoral mobility of capital, and by substituting in (27) one can re-write the steady state value of this price as follows:

$$p_x^* = [\varphi(p_m)]^{\alpha} (p_m)^{-\frac{(1+\bar{\sigma})\alpha}{1-\alpha}} \gamma,$$

where

$$\gamma = (1-\alpha) B^{\varepsilon\alpha/(1-\alpha)}.$$

It then suffices to show that $dp_x^*/dp_m < 0$. Clearly, the result follows from Proposition 1. This completes the proof·

Proof of Proposition 4.

The proof consists of three claims:

Claim 1. *trade openness causes a contraction of the import competing sector.*

Proof. We need to show that $dY_m^*/dp_m > 0$. First, substitute $\rho^* = \varphi(p_m)$ and $N^*(p_m) \equiv N[p_m, \varphi(p_m)]$ back into (34) to obtain an expression for the stock of capital used in farming, $\kappa_a^*(p_m) \equiv K_a^*[N^*(p_m), \varphi(p_m)]$:

$$\kappa_a^*(p_m) = \varphi(p_m) B^{\frac{1-\alpha(1-\varepsilon)}{1-\alpha}} (p_m)^{-\sigma/(1-\alpha)} - \frac{2(1-N^*[p_m, \varphi(p_m)])}{(p_m)^{-\bar{\sigma}} B^{\varepsilon}}.$$

Differentiating the above with respect to p_m using $\varphi'(p_m) < 0$ and $N^{*\prime} < 0$ reveals that $\kappa_a^{*\prime} < 0$.

Next, observe that by construction,

$$Y_m^*(p_m) = (K_m^*)^{\alpha} (S_m^*)^{1-\alpha} = [\varphi(p_m)]^{\alpha-1} K_m^*.$$

The result then follows by way of differentiation using the market clearing condition for capital along with the fact that $\varphi' < 0$. This establishes the claim·

Claim 2. *trade openness causes an expansion of the intermediate good sector.*

Proof. We need to show that $dY_x^*/dp_m < 0$. Combining (26) and (27) first yields that

$$S_x^*(p_m) = (p_m)^{-\sigma/1-\alpha} B^{1/1-\alpha}.$$

Since $Y_x^* = (S_x^*)^{1-\alpha}$, the result then follows by way of differentiation using the fact that $\sigma > 0$ and $B > 0$. This establishes the claim·

Claim 3. *trade openness causes an expansion of the farming sector.*

Proof. We need to show that $dY_a^*/dp_m < 0$. First observe that by construction,

$$Y_a^* = X^{*1-\alpha} \left[\phi\left(\bar{X}^*\right) K_a^* + U^*\right]^\alpha = \left[\frac{\phi\left(\bar{X}^*\right) K_a^* + U^*}{X^*}\right]^\alpha X^*$$

Using the equal return to capital condition implied by perfect mobility of capital between the import-competing sector and the export sector yields the following:

$$Y_a^* = (\rho)^\alpha (X^*)^{\frac{1-\alpha-\varepsilon}{1-\alpha}} (p_m)^{\frac{1}{1-\alpha}}.$$

Since $X^* = (p_m)^{-\sigma} B$, using (27), we then obtain that

$$Y_a^* = (p_m)^{-\mu} \rho^\alpha \bar{B},$$

where

$$\bar{B} = B^{\frac{1-\alpha(1-\varepsilon)}{1-\alpha}}$$
$$\mu = \frac{\alpha + \sigma\left[1 - \alpha(1-\varepsilon)\right]}{1-\alpha} > 0.$$

Therefore, that $dY_a^*/dp_m < 0$, simply follows from Proposition 1. This completes the proof of Proposition 4·

Proof of Proposition 5.

To prove this result, we first substitute (28) and (**??**) back into $R(p_m) = \Pi(p_m)/\Theta(p_m)$ to obtain the following:

$$R(p_m) = \frac{\bar{\delta}}{(p_m)^{2\bar{\sigma}}} \varphi(p_m),$$

where $\bar{\delta} = \bar{\alpha}\delta^{-2}$. Differentiating the above with respect to p_m then yields

$$R' = \frac{\bar{\delta}}{(p_m)^{2\bar{\sigma}}} \left[\varphi'(p_m) - 2\bar{\sigma}\varphi(p_m)(p_m)^{-1}\right],$$

which is negative, since $\varphi' < 0$ by Proposition 1. This completes the proof·