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Open Economy Schumpeterian Growth

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CIES DISCUSSION PAPER 0317

Open Economy Schumpeterian Growth

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Abstract

This paper examines the Aghion and Howitt [1992] "creative destruction" endogenous growth model in an open economy setting. We consider four alternative trade regimes. The first two regimes allow the monopoly producer of the intermediate good to attain worldwide monopoly rents. In the first of the two, the countries engage in trade of only the imperfectly produced intermediate good. In the second, the two countries trade in both the intermediate good as well as in ideas. The last two regimes consider two countries which are identical before and after trade opens such that pro-competitive gains from trade are achieved. We again consider when only intermediaries may be traded and thereafter when both intermediaries and ideas may be traded. We find that the effects of trade on growth and welfare depend critically on the assumptions one imposes.

Keywords: Creative Destruction, Obsolescence, Endogenous Growth, International Trade, Imperfect Competition, Schumpeterian Growth

JEL classification: F12, F15, F43, O30

1. Introduction

The goal of new growth theory is to shed light on the nature of long run growth in per capita income. Irrespective of which model one chooses to employ as the framework for analysis of growth, the Ramsey (1928) model, it's more modern Lucas (1988) version, or the Diamond (1965) model, the underlying result is the same. When technological advances are assumed to be exogenous, long run per capita income growth can only result from increasing productivity of labor. In other words, GDP per capita can only grow in the long run as a result of continuous technological change. As a consequence of this theoretical regularity, several authors have considered the nature of technology and it's evolution.

Two influential papers in New Growth Theory are Romer (1990) and Aghion and Howitt (1992). They are similar in that they both consider technological change to be the result of researchers whose incentive it is to capture monopoly rents from their inventions. Research firms in Romer (1990) add to the level of technology through successive innovations. The firms combine human capital effort with the existing stock of knowledge to move technology forward one innovation at a time. The new innovation enters the production process through the incumbent firm who shifts its efforts from research to monopoly production of the newest intermediate input. Final goods production combines the latest intermediate good and work effort. The only input needed to produce the latest intermediate good is the one that immediately preceded it. Once a researcher comes up with an innovation, he owns monopoly rights over it's production for ever after. Furthermore, there always exists a market for every patent, however many generations back from the most current innovation it was introduced, since each successive innovation becomes an intermediate good whose production requires its predecessor. There ultimately develops a continuum of intermediate goods, each absolutely necessary to its successor, that lead up to final goods, which of course requires the latest intermediary.

Aghion and Howitt (1992) also consider patent exploitation as the incentive to conduct research. The fundamental difference in their model is that the production of each new improved intermediate good requires only work effort. Therefore, since final goods production still depends on the most current intermediate good, the latest intermediary replaces its predecessor. Hence, technological change is the result of continuous obsolescence or "creative destruction." Research firms compete to introduce the latest innovation at which time they cease researching and concentrate on production and consequently on profits. Unlike Romer (1990), the patents only last until the next innovation renders the current one obsolete. Although technological advances occur randomly, they do so with a discernable Poisson arrival rate. Thus on average, one may consider the likelihood of a technological advance within a given span of time.

Extensions of the above two seminal papers are numerous and cover many of the stylized facts that we observe in the world. Of particular interest here are the implications of international trade on technological change. Rivera-Batiz and Romer (1991) consider the open economy version of Romer (1990). Therein, they consider two economies that may trade in the imperfectly produced intermediate good as well as trade in ideas. Their incumbent innovator may capture monopoly rents in both the home and foreign markets. An interesting facet of their paper is that although they assume that the two countries are identical while in autarky, the countries cease to be so with integration. As a result, the two countries take turns innovating. This issue was first noted by Devereux and Lapham (1994). They find that if either country differs even slightly in size, relative research effort would favor the larger country. At the limit, the larger country through faster growth does all of the research for the whole world. In Barreto and Kobayashi (2001), we consider the implications of the two countries remaining identical even after integration. Our findings parallel the standard trade literature results of pro-competitive gains from trade between countries where one or more of the traded goods are imperfectly produced. Thus, we find that imperfect competition is a sufficient determinant of trade even between otherwise identical countries. Other papers that have considered various aspects of Schumpeterian growth in an open economy include Verspagan and Wakelin (1997), Dinoupoulos and Syropoulos (1997), and Dinoupoulos and Segerstrom (1999).

In the following paper, we consider both assumptions. Section 2 reviews the basic Aghion and Howitt (1992) model in a closed economy setting to serve as a benchmaark. Section 3 considers economic integration of two countries using their framework. Sub-sections 3.1 and 3.2 consider, as in Rivera-Batiz and Romer (1991), the availability of worldwide monopoly rents, first when only intermediaries may be traded and then when both intermediaries as well as ideas may be traded. Sections 3.3 and 3.4 consider, as in Barreto and Kobayashi (2001), the pro-competitive gains from trade that result from a duopoly after integration. Again, we consider first, if only intermediate goods may be traded and second, if intermediate goods as well as ideas may be traded. Section 4 compares the results across the four possible cases. Section 5 presents some conclusions.

2. Closed Economy

The following is a summary of the Schumpeterian approach to endogenous technological change introduced by Aghion and Howitt (1992). Throughout this section, we assume autarky within each country.

The economy consists of three sectors: a final goods sector, an intermediate goods sector, and a R&D sector, all of which behave to maximize the representative agent's utility function.

$$U(y) = \int_0^{\infty} e^{-r\tau} y_\tau d\tau \qquad (0.1)$$

Only the final good, y, can only be consumed and it is subject to the discount rate, r. It is produced using only the most recent version of the intermediate goods, x, according to the following production function.

$$y = Ax^\alpha \qquad (0.2)$$

This is the essence of the technological change resulting from obsolescence. Firms compete across time to produce an ever-improving intermediate good. When a firm develops a successful innovation, it is rewarded with monopoly profits derived from the sale of its version of x_t to the final goods producer of y_t.

The aggregate flow of labor supply, L, has two competing uses, intermediate goods production and research. Intermediate firms employ a simple one for one linear production function such that x is also the amount of labor used in producing intermediate goods. The development of new innovations is also a result of a simple linear technology such that n is the amount of labor used in research. Hence the labor-market clearing condition is

$$L = n + x \qquad (0.3)$$

The level of technology, A_t, increases through successive innovations, t, that make its initial level, A_0, ever more productive. Each new innovation raises productivity of A by a factor of γ such that

$$A_t = A_0\gamma^t \qquad \gamma > 1 \tag{0.4}$$

Innovations arrive randomly with a Poisson arrival rate of $\lambda \cdot \Phi(n)$, where $\Phi(n)$ is a constant returns to scale function of research effort, *n*, and $\lambda > 0$ is the productivity parameter of research technology.

$$\lambda\Phi(n) = \lambda n \tag{0.5}$$

The profit function associated with a new innovation is

$$\Pi_t^{RD} = \lambda n_t V_{t+1} - w_n n_t \tag{0.6}$$

where V_{t+1} is the discounted expected payoff to the $(t+1)^{th}$ innovation from research conducted in during period *t*.

$$V_{t+1} = \frac{\Pi_{t+1}^{x_{t+1}}}{r + \lambda n_{t+1}} \tag{0.7}$$

Therefore, the research firm's first order condition may then be expressed as a function of the expected payoff.

$$w*_n \geq \lambda V_{t+1} = \frac{\lambda \Pi_{t+1}^{x_{t+1}}}{r + \lambda n_{t+1}} \tag{0.8}$$

The profit function faced by final goods producers and its consequent first order condition are defined as follows.

$$\Pi_t^y = y_t - p_x x_t = A_t x_t^\alpha - p_x x_t \tag{0.9}$$

$$p_x = \alpha A_t x_t^{\alpha-1} \tag{0.10}$$

The profit function faced by an intermediary and its consequent first order condition are defined as follows.

$$\Pi_t^x = p_x x_t - w_x x_t = \alpha A_t x_t^\alpha - w_x x_t \tag{0.11}$$

$$w*_x \geq \alpha^2 A_t x_t^{\alpha-1} \tag{0.12}$$

Note that the wage paid by the intermediary may also be used to determine the demand for labor.

$$x*_t = \left(\frac{A_t \alpha^2}{w_x} \right)^{\frac{1}{1-\alpha}} \tag{0.13}$$

The inverse demand for the intermediate good may be expressed simply as a function of the wage.

$$p*_x = \alpha A_t \left(\frac{A_t \alpha^2}{w_x} \right)^{\frac{\alpha-1}{1-\alpha}} = \frac{w_x}{\alpha} \tag{0.14}$$

Therefore, the monopoly profits to the intermediary for the most recent innovation may be expressed as follows.

$$\Pi_t^x * = \left(\frac{1}{\alpha} - 1 \right) w_x x*_t \tag{0.15}$$

The labor market is competitive so that $w*_x = w*_n$ and the labor market clearing condition may then be expressed as

$$1 = \frac{\lambda \gamma \left(\frac{1-\alpha}{\alpha} \right) \left(L - n*_t \right)}{r + \lambda n*_{t+1}} \tag{0.16}$$

Accordingly, the research labor input, $n*$, which satisfies equation (0.16) may be expressed as

$$n^*_{AUT} = \frac{\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{AUT}}{\lambda + \lambda\gamma\left(\frac{1}{\alpha}-1\right)} \tag{0.17}$$

It is important to note that the interest rate, r, which is defined as the marginal product of intermediate goods in final goods production is, in the steady state equal to the discount rate.

$$r_{AUT} = \alpha A x^{\alpha-1} \tag{0.18}$$

Finally, we are only left to determine the real time growth rate in output, $\frac{\dot{y}_\tau}{y_\tau}$. In order to do so, consider first the flow of final output, y_t, between two successive innovations, t and $(t+1)$. The level of output, for any given innovation, is defined simply as

$$y_t = A_t x_t^\alpha = A_t\left(L - n_t\right)^\alpha \tag{0.19}$$

Technology changes at the fixed rate per innovation equal to γ. Therefore, the relationship of output between consecutive innovations is defined as

$$y_{t+1} = \gamma y_t \tag{0.20}$$

We may then interpret the log of equation (0.20) to imply that the real time output level, y_τ, increases by $(\ln\gamma)$ with each new innovation. The real time growth of output is determined by the number of innovations between period τ and $(\tau+1)$. Therefore

$$\ln y_{\tau+1} = (\ln\gamma)\varepsilon_\tau + \ln y_\tau \tag{0.21}$$

where ε_τ equals the number of innovations between period τ and $(\tau+1)$ and is distributed randomly with a Poisson arrival rate of λn_t. Simple substitution yields that the average growth rate of output is defined as follows.

$$g^*_{AUT} = \frac{\dot{y}_\tau}{y_\tau} = \lambda n^*_{AUT} \left(\ln \gamma\right) \tag{0.22}$$

3. Open Economy

In the closed economy, the intermediary solely owns and therefore exploits the leading-edge technology as a monopolist. However, once trade opens, the effects on the welfare and the growth rate of the economies in question depend critically upon the assumption that one adopts covering the nature of the two economies and their subsequent trade. One may either assume that trade allows each innovating firm to garner worldwide monopoly rents or that each country has its own imperfectly competitive intermediary that produces a perfect substitute for it foreign counterpart. Trade under the latter assumption results in cross border duopolistic competition and pro-competitive gains from trade.

Trade in which the intermediate firm establishes a worldwide monopoly over its innovation is described in Rivera-Batiz and Romer (1991). Therein, they consider knowledge driven endogenous technological change, as is described in Romer (1990), where trade in intermediate goods without trade in ideas has no growth or welfare effects whatsoever. Their premise is intuitively simple. If the intermediate goods market is defined by imperfect competition, and the uniqueness of innovations extends worldwide, trade in a two-country model exactly doubles the size of the market faced by incumbent innovators. But since the incumbent innovator, whether home or foreign, faces twice the competition from both home and foreign R&D firms, the larger market is only available for half the time. One effect cancels the other such that trade in goods without trade in ideas has no net growth or welfare effects. Once trade in ideas is allowed, in addition to trade in intermediate goods, both positive welfare and growth effects result.

Alternatively, if one considers two identical countries in autarky and then maintains that they are still identical even after economic integration, trade in goods without trade in ideas results in pro-competitive gains. The result is intuitively similar to that which is found in the trade literature on imperfect competition as a determinant to trade between identical countries.[1] When two identical countries trade and the traded good is produced by local monopolies, the result is a duopoly where the two imperfect competitors share the worldwide market. This alternative, again using the Romer (1990) framework, is explored by Barreto and Kobayashi (2001). We find that trade in goods without trade in ideas has a negative growth effect but a positive welfare effect. Furthermore, once trade in ideas is also allowed, we show that the growth benefits of trade in ideas outweigh the negative growth effects of the pro-competitive gains from trade in intermediate goods.

There are analytic strengths as well as weaknesses to either lines of reasoning.[2] The main strength of Rivera-Batiz and Romer (1991) relates to the concept a worldwide monopoly as the incentive to innovate. The main weakness therein is the stepwise nature of trade where each country is forced to take turns innovating. The main strength of Barreto and Kobayashi (2001) is the pro-competitive gains result and its relation to the trade literature. The main weakness in our paper is that even without trade in ideas, each country comes up with identical competing innovations.

In the following analysis of economic integration in a Schumpeterian growth model, we consider both assumptions. Sections 3.1 and 3.2 consider trade in both intermediate goods and ideas under the same assumptions as Rivera-Batiz and Romer (1991). Sections

3.3 and 3.4 consider trade in both intermediate goods and ideas under the same assumptions as Barreto and Kobayashi (2001).

3.1 Trade in Intermediate goods $\left(x^H \neq x^F\right)$

Suppose that there are two monopolists, one per country, producing x_t at any given innovation, t. Let x^F be the foreign intermediate goods and x^H be the home intermediate good. Assume that the two countries are identical only until the time of integration. Once trade commences, the countries become differentiated such that $x^H \neq x^F$ and each incumbent intermediate good producer can garner monopoly rents across the entire world.[3]

Each country produces final goods according to the following production function.

$$y = f(x^H \text{ or } x^F) = Ax^{\alpha} \tag{1.1}$$

Thus output, at any given time, is a function of the most current innovation. That innovation may originate from home or abroad. As before, the interest rate and in the steady state, the discount rate, is the marginal product of intermediate goods used in final production.

$$r = \alpha A x^{\alpha-1} \tag{1.2}$$

The profit function faced by final goods producers and its consequent first order condition are the same as before.

$$\Pi_t^y = y_t - p_x x_t = A_t x_t^{\alpha} - p_x x_t \tag{1.3}$$

$$p_x = \alpha A_t x_t^{\alpha-1} \tag{1.4}$$

Note that p_x is the monopoly price of the latest innovation, x_t, as determined by the incumbent intermediate producer who may be foreign or domestic.

The monopolist intermediate goods producer, whether home or foreign, maximizes the following profit function and yields the subsequent first order conditions.

$$\Pi_t^x = p_x\left(2x_t\right) - w_x\left(2x_t\right) \tag{1.5}$$

$$w*_x = \alpha^2 A_t x_t^{\alpha-1} \tag{1.6}$$

$$x*_t = \left(\frac{\alpha^2 A_t}{w_x}\right)^{\frac{1}{1-\alpha}} \tag{1.7}$$

The monopoly profits can further be expressed as follows.

$$\Pi_t^x* = 2\left(\frac{1}{\alpha} - 1\right) w_x x*_t \tag{1.8}$$

The profit function faced by each R&D firm, whether home or foreign, is defined as

$$\Pi_t^{RD} = \lambda n_t V_{t+1} - w_n n_t \tag{1.9}$$

The effect of the larger market again enters the system analytically through the V_{t+1} term, which is defined as the discounted expected payoff to the $(t+1)^{th}$ innovation from research conducted in during period t.

$$\begin{gathered} r\left(2V_{t+1}\right) = \Pi_{t+1}^{x_{t+1}} - \lambda n_{t+1}\left(2V_{t+1}\right) \\ V_{t+1} = \frac{\Pi_{t+1}^{x_{t+1}}}{2r + 2\lambda n_{t+1}} \end{gathered} \tag{1.10}$$

Therefore, the research firm's first order condition may be expressed as

$$w*_n \geq \lambda V_{t+1} = \frac{\lambda \Pi_{t+1}^{x_{t+1}}}{2r + 2\lambda n_{t+1}} \tag{1.11}$$

The competitive labor market where $w*_x = w*_n$, yields the market clearing condition.

$$1 = \frac{2\lambda\gamma\left(\frac{1-\alpha}{\alpha}\right)\left(L - n*_t\right)}{2\left(r + \lambda n*_{t+1}\right)} \tag{1.12}$$

Accordingly, the labor input, $n*$, for R&D which satisfies this (1.12) may be expressed as follows.

$$n*_{3.1} = \frac{\lambda\gamma\left(\frac{1}{\alpha} - 1\right)L - r_{3.1}}{\lambda + \lambda\gamma\left(\frac{1}{\alpha} - 1\right)} \tag{1.13}$$

Notice that equation (1.13) is identical to equation (0.17). The optimal allocation of work effort toward research is the same under autarky as it is under trade in intermediate goods. Therefore, the consequent growth rates of output under the two regimes must also be equal.

$$g*_{3.1} = \frac{\dot{y}_\tau}{y_\tau} = \lambda n*_{3.1}\left(\ln\gamma\right) \tag{1.14}$$

3.2 Trade in Intermediate goods and Ideas $\left(x^H \neq x^F\right)$

Once again we assume, that both countries are not identical upon integration. Only now, in addition to trade in intermediate goods, the countries may also trade ideas. This concept is modeled by allowing the two countries to share in each others' research efforts such that for each country, $2n = n^F + n^H$.

As before, each country produces final goods using the most current innovation, irrespective of whether that innovation originates at home or abroad. Therefore, the final goods firm's profit function is identical to that found in section 3.1. Furthermore, the intermediary monopolist's profit function is also identical to that from the previous section. For the sake of continuity, those equations are reproduced here in summary.

$$\Pi_t^y = y_t - p_x x_t = A_t x_t^\alpha - p_x x_t \tag{2.1}$$

$$p_x = \alpha A_t x_t^{\alpha-1} \tag{2.2}$$

$$\Pi_t^x = p_x\left(2x_t\right) - w_x\left(2x_t\right) = 2\alpha A_t x_t^\alpha - 2w_x x_t \tag{2.3}$$

$$w*_x = \alpha^2 A_t x_t^{\alpha-1} \tag{2.4}$$

$$x*_t = \left(\frac{\alpha^2 A_t}{w_x}\right)^{\frac{1}{1-\alpha}} \tag{2.5}$$

$$\Pi_t^x * = 2\left(\frac{1}{\alpha} - 1\right) w_x x*_t \tag{2.6}$$

As mentioned earlier, trade in ideas takes the form of countries sharing their research effort with one another. Although each country's R&D firm benefits from the other's efforts, each need only pay its own employees. The profit function faced by R&D firm therefore takes the following form.

$$\Pi_t^{RD} = \lambda\left(n_t^H + n_t^F\right)V_{t+1} - w_n n_t \tag{2.7}$$

V_{t+1}, again defined as the discounted expected payoff to the $(t+1)^{th}$ innovation from research conducted in during period t, but is determined slightly differently than before.

$$\begin{gathered} r\left(2V_{t+1}\right) = \Pi_{t+1}^{x_{t+1}} - \lambda\left(n_{t+1}^H + n_{t+1}^F\right)\left(2V_{t+1}\right) \\ V_{t+1} = \frac{\Pi_{t+1}^{x_{t+1}}}{2r + 4\lambda n_{t+1}} \end{gathered} \tag{2.8}$$

The research firm's consequent first order condition may be expressed as follows.

$$w*_n \geq \lambda V_{t+1} = \frac{\lambda \Pi_{t+1}^{x_{t+1}}}{r + 2\lambda n_{t+1}} \tag{2.9}$$

The competitive labor market yields the market clearing condition, which may be expressed as

$$1=\frac{2\lambda\gamma\left(\frac{1-\alpha}{\alpha}\right)\left(L-n*_{t}\right)}{r+2\lambda n*_{t+1}} \tag{2.10}$$

Accordingly, the optimal labor input, $n*$, for R&D which satisfies this (2.10) may be expressed as follows.

$$n*_{3.2}=\frac{2\lambda\gamma\left(\frac{1}{\alpha}-1\right)L-r_{3.2}}{2\lambda+2\lambda\gamma\left(\frac{1}{\alpha}-1\right)} \tag{2.11}$$

Intuitively, once trade in ideas is introduced in addition to trade in intermediate goods, the period between innovations should be shorter. In other words, one would expect that through cooperation in research, one country's R&D firm can catch up and, using the foreign competitor's idea, improve upon the product in question. The analytic solution for the growth rate of income demonstrates this idea.

$$g*_{3.2}=\frac{\dot{y}_{\tau}}{y_{\tau}}=\lambda 2n*_{3.2}\left(\ln\gamma\right) \tag{2.12}$$

3.3 Trade in Intermediate goods $\left(x^{H}=x^{F}\right)$

In this section and the next, we consider the case where the two countries are absolutely identical in autarky as well as in trade. This mode of analysis parallels the standard trade literature's approach to imperfect competition as a determinant of trade. As in that line of research, imperfect competition in one or more traded goods leads to pro-competitive gains from trade between otherwise identical countries.

Suppose again that there are two monopolists, one per country, producing x_t at any given innovation, t. Since they are completely identical, each monopolist produces a version of the most current innovation. The two versions are perfect substitute for one another. Once trade in intermediate goods is allowed, the final goods producer in each country effectively faces a duopoly. Just as in the trade literature, it is the ability of the final goods producer to buy from abroad that changes the market structure of intermediate goods from monopoly to duopoly. Actual trade in intermediate goods does not occur since there is no need. The firm's production function therefore takes the following form.

$$y = A\left(x^H + x^F\right)^{\alpha} \tag{3.1}$$

As a result of the new market structure, the interest rate, defined as the marginal product of intermediate goods in final production, takes the following form.

$$r = 2\alpha A\left(2x\right)^{\alpha-1} \tag{3.2}$$

The final goods producer's profit function and its consequent first order condition are then defined as

$$\Pi_t^y = y_t - p_x\left(x_t^H + x_t^F\right) = A_t\left(2x_t\right)^{\alpha} - p_x\left(2x_t\right) \tag{3.3}$$

$$p_x = \alpha A_t\left(2x_t\right)^{\alpha-1} \tag{3.4}$$

The profit function faced by duopolist is analytically similar to autarky but the consequent first order conditions change to reflect the Cournot price.

$$\Pi_t^x = p_x x_t - w_x x_t = 2^{\alpha-1}\alpha A_t x_t^{\alpha} - w_x x_t \tag{3.5}$$

$$w^*_x = \alpha^2 A_t\left(2x_t\right)^{\alpha-1} \tag{3.6}$$

$$x^*_t = \frac{1}{2}\left(\frac{\alpha^2 A_t}{w_x}\right)^{\frac{1}{1-\alpha}} \tag{3.7}$$

The profits to the duopolist can therefore be expressed as

$$\Pi_t^x * = \left(\frac{1}{\alpha} - 1\right) w_x x*_t \tag{3.8}$$

As in section 3.1, the profit function faced by R&D sector is defined as follows.

$$\Pi_t^{RD} = \lambda n_t V_{t+1} - w_n n_t \tag{3.9}$$

where V_{t+1} is the discounted expected payoff to the $(t+1)^{th}$ innovation from research conducted in during period t which is determined from the following.

$$\begin{gathered} rV_{t+1} = \Pi_{t+1}^{x_{t+1}} - \lambda n_{t+1} V_{t+1} \\ V_{t+1} = \frac{\Pi_{t+1}^{x_{t+1}}}{r + \lambda n_{t+1}} \end{gathered} \tag{3.10}$$

Therefore, the research firm's first order condition may be expressed as

$$w*_n \geq \lambda V_{t+1} = \frac{\lambda \Pi_{t+1}^{x_{t+1}}}{r + \lambda n_{t+1}} \tag{3.11}$$

The competitive labor market clearing condition may be expressed as

$$1 = \frac{\lambda \gamma \left(\frac{1-\alpha}{\alpha}\right)\left(L - n*_t\right)}{r + \lambda n*_{t+1}} \tag{3.12}$$

Accordingly, the labor input in research, $n*$, which satisfies this (3.12) may be expressed as follows.

$$n*_{3.3} = \frac{\lambda \gamma \left(\frac{1}{\alpha} - 1\right) L - r_{3.3}}{\lambda + \lambda \gamma \left(\frac{1}{\alpha} - 1\right)} \tag{3.13}$$

Notice that the analytic solution to the optimal research effort, equation (3.13), is similar in construction to that from autarky, equation (0.17). But, it is important to note they are indeed different because of the interest rate under duopoly, equation (3.2), is not the same as the interest rate under autarky, equation (0.18). As a result, although analytically similar to autarky, the average growth rate of income also differs with trade.

$$g*_{3.3} = \frac{\dot{y}_\tau}{y_\tau} = \lambda n*_{3.3}\left(\ln \gamma\right) \tag{3.14}$$

3.4 Trade in Intermediate goods and Ideas $\left(x^H = x^F\right)$

We again assume that both countries are absolutely identical before and after integration. Similar to the changes from sections 3.1 to 3.2, here we modify section 3.3 to allow trade in ideas in addition to trade in intermediate goods. Again, this concept is modeled by allowing both countries R&D firms to share in each other's research effort such that $2n = n^F + n^H$.

The final good producer's profit function, the intermediary's producer's profit functions and consequent first order conditions are the same as in section 3.3. We reproduce them here to maintain the paper's continuity.

$$y = A\left(x^H + x^F\right)^\alpha \tag{4.1}$$

$$r = 2\alpha A\left(2x\right)^{\alpha-1} \tag{4.2}$$

$$\Pi_t^y = y_t - p_x\left(x_t^H + x_t^F\right) = A_t\left(2x_t\right)^\alpha - p_x\left(2x_t\right) \tag{4.3}$$

$$p_x = \alpha A_t\left(2x_t\right)^{\alpha-1} \tag{4.4}$$

$$\Pi_t^x = p_x x_t - w_x x_t = 2^{\alpha-1}\alpha A_t x_t^\alpha - w_x x_t \tag{4.5}$$

$$w*_x = \alpha^2 A_t\left(2x_t\right)^{\alpha-1} \tag{4.6}$$

$$x*_t = \frac{1}{2}\left(\frac{\alpha^2 A_t}{w_x}\right)^{\frac{1}{1-\alpha}} \tag{4.7}$$

$$\Pi_t^x * = \left(\frac{1}{\alpha} - 1\right) w_x x*_t \tag{4.8}$$

The R&D firm in each country now faces a profit function that must account for the benefits of the added research productivity.

$$\Pi_t^{RD} = \lambda\left(n_t^H + n_t^F\right)V_{t+1} - w_n n_t \tag{4.9}$$

where V_{t+1} is determined as follows.

$$\begin{aligned} rV_{t+1} &= \Pi_{t+1}^{x_{t+1}} - \lambda\left(n_{t+1}^H + n_{t+1}^F\right)V_{t+1} \\ V_{t+1} &= \frac{\Pi_{t+1}^{x_{t+1}}}{r + 2\lambda n_{t+1}} \end{aligned} \tag{4.10}$$

Therefore, the research firm's first order condition may be expressed as

$$w*_n \geq 2\lambda V_{t+1} = \frac{2\lambda \Pi_{t+1}^{x_{t+1}}}{r + 2\lambda n_{t+1}} \tag{4.11}$$

The competitive labor market results in the following market clearing condition.

$$1 = \frac{2\lambda\gamma\left(\frac{1-\alpha}{\alpha}\right)\left(L - n*_t\right)}{r + 2\lambda n*_{t+1}} \tag{4.12}$$

Accordingly, the analytic solution for the optimal labor input to the R&D firm which satisfies equation (4.12) may be expressed as follows.

$$n*_{3.4} = \frac{2\lambda\gamma\left(\frac{1}{\alpha} - 1\right)L - r_{3.4}}{2\lambda + 2\lambda\gamma\left(\frac{1}{\alpha} - 1\right)} \tag{4.13}$$

And the average growth rate of income is defined as

$$g*_{3.4} = \frac{\dot{y}_\tau}{y_\tau} = \lambda 2n*_{3.4}\left(\ln\gamma\right) \qquad (4.14)$$

Little can be said from simple inspection of the analytic solution for $n*$ or $g*$. Fortunately though, careful analysis conducted in the next section, reveals that all four cases are comparable such that firm conclusions may be drawn about the effects of trade in goods and in ideas on growth and welfare when endogenous technological change is defined by creative destruction.

4. Comparisons

The following analysis considers the effects of free trade on growth rates and welfare. We compare the results of section (3.1) through (3.4). Table 1 summarizes the results from autarky and the four cases. Note that case (3.1) is exactly the same as the autarky. As mentioned before, the intuition behind this result is simple. The intermediary monopolist in the case (3.1) produces twice as much x as the intermediary monopolist in autarky but for a half the time. Thus trade in intermediate goods without trade in ideas has no growth or welfare effects whatsoever. Henceforth, we will not mention case (3.1) but instead consider only autarky as the benchmark.

To determine trade's effect on average growth rates of output, we need to compare not only the labor efforts across cases, but also all of the various components that directly and indirectly determine the average growth rate. The following presents mostly intuitive explanations for the relationships across the cases. Appendix 2 contains the analytic proofs that coincide with the following results.

First, compare the optimal relative research efforts in each of the four cases. The results may be summarized as follows.

$$n*_{3.2} > n*_{3.4} > n*_{AUT} > n*_{3.3}$$

When trade in ideas allowed, as in cases (3.2) and (3.4), the efficiency of research labor effectively doubles in both countries. With higher marginal products of research effort, both $n*_{3.2}$ and $n*_{3.4}$ are higher than autarky research effort, $n*_{AUT}$. Since the monopolist in the case (3.2) enjoys higher profits than the duopolist in the case (3.4), the incumbent researcher in case (3.2) has that more to gain from being the next innovator. The greater incentive is reflected by more research effort, thus $n*_{3.2} > n*_{3.4}$. The R&D firm in case (3.3) has the least to gain as a duopolist without the benefit of shared research. His research is the least productive of all and consequently he has the lowest relative research effort.

Second, consider the relative employment by the intermediaries. Recall that since the labor markets are competitive, i.e. $L = n + x$, the following results must mirror those from the employment by the research firms.

$$x*_{3.2} < x*_{3.4} < x*_{AUT} < x*_{3.3}$$

$x*_{3.2} < x*_{3.4}$ and $x*_{AUT} < x*_{3.3}$ are easily justified as the pro-competitive gains from trade results. As the market structure shifts from monopoly to duopoly, output of x increases. The fact that $x*_{3.4} < x*_{AUT}$ implies that the positive wealth effect in terms of research from trade in ideas is relatively greater than the negative substitution effect from trade in intermediate goods.

Third, compare the intermediate good prices that are set by the various imperfect competitors.

$$p_{3.2} > p_{AUT} > p_{3.4} > p_{3.3}$$

Diagrams 1 through 8 compare the various price and quantities set by the imperfect competitors under the differing regimes. In Diagram 5, the international monopolist which also enjoys the benefits of trade in ideas, sets his price, $p_{3.2}$, higher and his quantity lower than the autarky monopolist. Thus the productivity benefits of trade in ideas, reflected in the marginal cost to the monopolist, outweigh the effects of reduced demand for intermediate goods. In Diagram 2, which compares the duopolist that enjoys the benefits of trade in ideas to autarky, the opposite is the case. Although the researchers in cases (3.4) gain productivity from shared ideas, those benefits are outweighed by the fall in demand for intermediate goods such that $p_{AUT} > p_{3.4}$ and $x_{AUT} > x_{3.4}$. Diagram 3 compares the two duopoly cases (3.3) and (3.4). Since the pro-competitive gains from trade affect both regimes equivalently, the net difference between the two is the trade in ideas in case (3.4). Thus $p_{3.4} > p_{3.3}$ and $x_{3.4} < x_{3.3}$. Diagram 8 summarizes all of the results. Notice that cases (3.2) and (3.4) share the same demand curve. This is because the only difference is the market structure faced by the imperfect competitor, which is reflected by movement along the curve. The same can be said of case (3.1) versus autarky.

The interest rate, r, is defined as the marginal product of intermediate goods, x, in the production of final goods.

$$r_{3.4} > \{r_{3.2}, r_{3.3}\} > r_{AUT}$$

Trade in intermediate goods, a staple in all four cases, leads to an increase in the demand for those goods, therefore the autarky marginal product of x and consequently the interest rate, r_{AUT}, must be less than all of the others. The addition of trade in ideas will increase the productivity of labor and accordingly the marginal product of intermediate goods, thus $r_{3.4} > r_{3.3}$. Furthermore, the marginal product of x is greater under duopoly than under monopoly, thus $r_{3.4} > r_{3.2}$. Intuitively, consider one firm that takes care of a large market versus two firms that share that same market. The lower relative production of the individual duopolist implies a higher marginal product than the high relative production and low marginal product of the monopolist. It is not clear which is higher, $r_{3.2}$ or $r_{3.3}$.[4]

The results for the growth rates of per capita income are summarized as follows.

$$g^*_{3.2} > g^*_{3.4} > g^*_{AUT} > g^*_{3.3}$$

Growth rates ultimately reflect labor effort in research which in turn ultimately reflects incentives. Case (3.2) provides R&D firms the greatest incentive and consequently results in the highest growth rate. Case (3.3) provides the least incentive and growth suffers accordingly. Purely as a result of pro-competitive gains from trade, $g^*_{AUT} > g^*_{3.3}$. In other words, trade in imperfectly produced intermediate goods without trade in ideas between two identical countries results in less research effort due to the reduced incentives under duopoly versus under monopoly. Whereas, $g^*_{3.2} > g^*_{3.4} > g^*_{AUT}$ because the countries devote more effort toward research as the R&D sector becomes more competitive as well as more effective. Therefore, the greater are the incentives to the research firm, i.e. monopoly versus duopoly, the more creative destruction takes place, and the higher is the rate of technological advance which ultimately drives the long run growth in per capita income.

A final point to consider is the levels of welfare of the home and foreign representative agents at any given time across the four cases. This is a difficult comparison to make because in the long run, the economy with the highest growth rate must eventually be the best off. At best, one can comment loosely about the transition from autarky to trade given each scenario. For example, assuming the same initial conditions, at the point at which trade opens, agents are better off in case (3.4) than (3.2) because the initial effect on welfare would have to be greater since $x_{3.4} > x_{3.2}$ and $p_{3.4} < p_{3.2}$. But given enough time, whatever discreet pro-competitive gain from trade in welfare were accrued from agents under case (3.4) would eventually be insignificant given the higher growth rate of technology in case (3.2).

5. Conclusions

The growth rate of income per capita is positively correlated with the incentives available to the respective R&D firms. There is no way to escape this simple fact. Irrespective of what drives technological change, whether it is knowledge driven as suggested by Romer (1990) or obsolescence driven as suggested by Aghion and Howitt (1992), or which methodology one assumes that trade is based upon, international monopolies as suggested by Rivera-Batiz and Romer (1991) or international oligopolies as suggested by Barreto Kobayashi (2001), the greater is the return to research, the more of it is conducted, and the faster technology will develop.

The cursory result of this therefore suggests that in the long run, monopolies are superior to competition due to the incentive to conduct research is greater. This may well be true in the long run, although it is not necessarily true for any time interval less than the long run. Herein we have presented the theoretical results of trade given a certain set of rules for its evolution. We have in no way quantified the results. Therefore, it is possible that the pro-competitive gains from trade may be so great that the short to medium term welfare benefits as well as the distributional elements of greater competition may outweigh the long run growth considerations associated purely with incentives.

As a to the new growth literature, we add significantly. First, we develop a more simple and elegant way to consider trade between countries when growth is defined by "creative destruction." Second, we show that irrespective of how technology evolves, it is the incentive structure to the R&D firm that has the crucial impact on growth rates. Third, we add to the trade literature by comprehensively comparing the effects of two distinct incentive structures in the context of endogenous growth and economic integration.

The possible extensions of this paper are numerous. Any change in the incentive available to the research firm will affect growth. An obvious extension is to consider barriers to trade. Another extension along public choice lines is to consider the imposition of taxes. One could consider an income tax on final production versus a value added tax on intermediaries as well as final production. And lastly, an interesting exercise given the framework presented here would be to consider differentiated countries, whether in size, market organization, base technological level.

Appendix 1 – Welfare analysis of laissez-faire versus social optimum levels of research

To understand the implications on welfare of trade when obsolescence motivates technological change, consider a social planner's problem when she attempts to maximize the expected present value of consumption, y_τ.

The social planner's problem under autarky, which exactly the same as case (3.1), is to maximize the following expected welfare.

$$U = \int_0^\infty e^{-r\tau} y_\tau d\tau = \int_0^\infty e^{-r\tau} \left(\sum_{t=0}^\infty \Pi(t,\tau) A_t x^\alpha \right) d\tau \tag{5.1}$$

where $\Pi(t,\tau)$ is the probability of t innovations up to time τ. The innovations process is Poisson with an arrival rate of λn, therefore

$$\Pi(t,\tau) = \frac{(\lambda n \tau)^t}{t!} e^{-\lambda n \tau} \tag{5.2}$$

The social planner must consider both technological change and the labor market equilibrium.

$$A_t = A_0 \gamma^t \qquad \gamma > 1 \tag{5.3}$$

$$L = n + x \tag{5.4}$$

The utility function can therefore be rewritten as

$$U(n) = \frac{A_0 (L-n)^\alpha}{r - \lambda n (\gamma - 1)} \tag{5.5}$$

The socially optimal level of research, n_{AUT}^S, which satisfies the first-order-condition, $U'\left(n_{AUT}^S\right) = 0$, may be expressed as follows.

$$1 = \frac{\lambda(\gamma-1)\left(\frac{1}{\alpha}\right)\left(L - n_{AUT}^S\right)}{r - \lambda n_{AUT}^S (\gamma - 1)} \tag{5.6}$$

Hence, the socially optimal level of research, n_2^S, is

$$n_{AUT}^S = \frac{\lambda(\gamma-1)\left(\frac{1}{\alpha}\right)L - r_{AUT}}{\lambda(\gamma-1)\left(\frac{1}{\alpha} - 1\right)} \tag{5.7}$$

In case (3.2), expected welfare is

$$U = \int_0^\infty e^{-r\tau} y(\tau) d\tau = \int_0^\infty e^{-r\tau} \left(\sum_{t=0}^\infty \Pi(t,\tau) A_t x^\alpha \right) d\tau \tag{5.8}$$

where $\Pi(t,\tau)$ is modified as follows.

$$\Pi(t,\tau) = \frac{\left(\lambda\left(n + n^F\right)\tau\right)^t}{t!} e^{-\lambda\left(n+n^F\right)\tau} \tag{5.9}$$

Therefore the utility function can be rewritten as

$$U(n)=\frac{A_0(L-n)^{\alpha}}{r-2\lambda n(\gamma-1)} \tag{5.10}$$

And the socially optimal level of research, $n_{3.2}^S$, is

$$n_{3.2}^S=\frac{2\lambda(\gamma-1)\left(\frac{1}{\alpha}\right)L-r_{3.2}}{2\lambda(\gamma-1)\left(\frac{1}{\alpha}-1\right)} \tag{5.11}$$

In case (3.3), expected welfare function is changed to

$$U=\int_0^{\infty}e^{-r\tau}y(\tau)\,d\tau=\int_0^{\infty}e^{-r\tau}\left(\sum_{t=0}^{\infty}\Pi(t,\tau)A_t\left(x+x^F\right)^{\alpha}\right)d\tau \tag{5.12}$$

where $\Pi(t,\tau)$ is again defined as it was under autarky.

$$\Pi(t,\tau)=\frac{(\lambda n\tau)^t}{t!}e^{-\lambda n\tau} \tag{5.13}$$

The utility function and its consequent social optimal level of research, $n_{3.3}^S$, can be expressed as follows.

$$U(n)=\frac{2^{\alpha}A_0(L-n)^{\alpha}}{r-\lambda n(\gamma-1)} \tag{5.14}$$

$$n_{3.3}^S=\frac{\lambda(\gamma-1)\left(\frac{1}{\alpha}\right)L-r_{3.3}}{\lambda(\gamma-1)\left(\frac{1}{\alpha}-1\right)} \tag{5.15}$$

Lastly, in the case (3.4), expected welfare is

$$U=\int_0^{\infty}e^{-r\tau}y(\tau)\,d\tau=\int_0^{\infty}e^{-r\tau}\left(\sum_{t=0}^{\infty}\Pi(t,\tau)A_t\left(x+x^F\right)^{\alpha}\right)d\tau \tag{5.16}$$

where $\Pi(t,\tau)$ is defined as follows.

$$\Pi(t,\tau)=\frac{\left(\lambda\left(n+n^F\right)\tau\right)^t}{t!}e^{-\lambda\left(n+n^F\right)\tau} \tag{5.17}$$

and the utility function and its consequent social optimal level of research, $n_{3.4}^S$, are

$$U(n)=\frac{2^{\alpha}A_0(L-n)^{\alpha}}{r-2\lambda n(\gamma-1)} \tag{5.18}$$

$$n_{3.4}^S=\frac{2\lambda(\gamma-1)\left(\frac{1}{\alpha}\right)L-r_{3.4}}{2\lambda(\gamma-1)\left(\frac{1}{\alpha}-1\right)} \tag{5.19}$$

The parallels between the competitive optimum levels of work effort and their corresponding social optimum levels make the comparisons across the four cases straight forward. The three effects of obsolescence, appropriability, business stealing, and intertemporal spillovers, that differentiate the social optimum from the laissez faire equilibrium depend solely on the parameters. For example, the business stealing effect is result of the relative size of innovations, γ. The larger the innovations, the more incentive for firms to research and the greater will be the laissez-faire growth rate. The appropriability effect depends on α, where the closer α is to one, the less the monopolist can appropriate the whole output flow and resulting less research than is socially optimal. Irrespective, since the parameters are the same across cases, the results are as well. If the social optimum level of research is greater than the laissez faire-level, then it will be greater in the open economy setting as well.

Appendix 2 – Technical Summary of Comparisons of Laissez Faire Analytic Equilibriums

Summary Results of Comparisons

$$n*_{AUT} < n*_{3.2}, \quad n*_{AUT} > n*_{3.3}, \quad n*_{AUT} < n*_{3.4}, \quad n*_{3.2} > n*_{3.3}, \quad n*_{3.2} > n*_{3.4}, \quad n*_{3.3} < n*_{3.4}$$

$$\Rightarrow \; n*_{3.2} > n*_{3.4} > n*_{AUT} > n*_{3.3}$$

$$x*_{AUT} > x*_{3.2}, \quad x*_{AUT} < x*_{3.3}, \quad x*_{AUT} > x*_{3.4}, \quad x*_{3.2} < x*_{3.3}, \quad x*_{3.2} < x*_{3.4}, \quad x*_{3.3} > x*_{3.4}$$

$$\Rightarrow \; x*_{3.3} > x*_{AUT} > x*_{3.4} > x*_{3.2}$$

$$w_{AUT} < w_{3.2}, \quad w_{AUT} > w_{3.3}, \quad w_{AUT} > w_{3.4}, \quad w_{3.2} > w_{3.3}, \quad w_{3.2} > w_{3.4}, \quad w_{3.3} < w_{3.4}$$

$$\Rightarrow \; w_{3.2} > w_{AUT} > w_{3.4} > w_{3.3}$$

$$p_{AUT} < p_{3.2}, \quad p_{AUT} > p_{3.3}, \quad p_{AUT} > p_{3.4}, \quad p_{3.2} > p_{3.3}, \quad p_{3.2} > p_{3.4}, \quad p_{3.3} < p_{3.4}$$

$$\Rightarrow \; p_{3.2} > p_{AUT} > p_{3.4} > p_{3.3}$$

$$r_{AUT} < r_{3.2}, \quad r_{AUT} < r_{3.3}, \quad r_{3.2} < r_{3.4}, \quad r_{3.3} < r_{3.4}$$

$$\Rightarrow \; r_{3.4} > \{r_{3.2}, r_{3.3}\} > r_{AUT}$$

$$n*_{3.2} > n*_{3.4} > n*_{AUT} > n*_{3.3}$$

$$\Rightarrow \; g*_{3.2} > g*_{3.4} > g*_{AUT} > g*_{3.3}$$

<u>**AUT versus 3.2**</u>

$$n^*_{AUT} = \frac{\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{AUT}}{\lambda+\lambda\gamma\left(\frac{1}{\alpha}-1\right)} \qquad \text{vs.} \qquad n^*_{3.2} = \frac{2\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{3.2}}{2\lambda+2\lambda\gamma\left(\frac{1}{\alpha}-1\right)}$$

where $n^*_{AUT} > n^*_{3.2}$ if $2r_{AUT} < r_{3.2}$

$$2r_{AUT} = 2\alpha A x_{AUT}^{\alpha-1} < \alpha A x_{3.2}^{\alpha-1} = r_{3.2}$$
$$2x_{AUT}^{\alpha-1} < x_{3.2}^{\alpha-1}$$
$$2^{\frac{1}{\alpha-1}} x_{AUT} > x_{3.2}$$

and since $0 < 2^{\frac{1}{\alpha-1}} < 1 \quad \forall \quad 0 < \alpha < 1$, then $x_{AUT} > x_{3.2}$ ➔ ⊗

therefore $n^*_{AUT} < n^*_{3.2}$ implying $2r_{AUT} > r_{3.2}$

$$2r_{AUT} = 2\alpha A x_{AUT}^{\alpha-1} > \alpha A x_{3.2}^{\alpha-1} = r_{3.2}$$
$$2x_{AUT}^{\alpha-1} > x_{3.2}^{\alpha-1}$$
$$2^{\frac{1}{\alpha-1}} x_{AUT} < x_{3.2}$$

and if $n^*_{AUT} < n^*_{3.2}$, then $x^*_{AUT} > x^*_{3.2}$ which implies $r_{AUT} < r_{3.2}$

$$x^*_{AUT} = \left(\frac{w_{xAUT}}{\alpha^2 A}\right)^{\frac{1}{\alpha-1}} > \left(\frac{w_{x3.3}}{\alpha^2 A}\right)^{\frac{1}{\alpha-1}} = x^*_{3.2}$$
$$w_{xAUT} < w_{x3.2}$$

recall that: $p^*_x = \frac{w_x}{\alpha}$ ➔ $\therefore p_{xAUT} < p_{x3.2}$

if $n^*_{AUT} < n^*_{3.2}$, then $\lambda n^*_{AUT}(\ln\gamma) < \lambda 2 n^*_{3.2}(\ln\gamma)$ ➔ $g^*_{AUT} < g^*_{3.2}$

$\therefore$ Therefore, $n^*_{AUT} < n^*_{3.2}$, $x^*_{AUT} > x^*_{3.2}$, $r_{AUT} < r_{3.2}$, $w_{AUT} < w_{3.2}$, $p_{AUT} < p_{3.2}$, and $g^*_{AUT} < g^*_{3.2}$

AUT versus 3.3

$$n*_{AUT} = \frac{\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{AUT}}{\lambda + \lambda\gamma\left(\frac{1}{\alpha}-1\right)} \qquad \text{vs.} \qquad n*_{3.3} = \frac{\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{3.3}}{\lambda + \lambda\gamma\left(\frac{1}{\alpha}-1\right)}$$

where $n*_{AUT} < n*_{3.3}$ if $r_{AUT} > r_{3.3}$

$$r_{AUT} = \alpha A x_{AUT}^{\alpha-1} > 2\alpha A x_{3.3}^{\alpha-1} = r_{3.3}$$
$$x_{AUT}^{\alpha-1} > 2x_{3.3}^{\alpha-1}$$
$$x_{AUT} < 2^{\frac{1}{\alpha-1}} x_{3.3}$$

and since $0 < 2^{\frac{1}{\alpha-1}} < 1 \quad \forall \quad 0 < \alpha < 1$, then $x_{AUT} < x_{3.3}$ ➔ ⊗

therefore $n*_{AUT} > n*_{3.3}$ which implies $r_{AUT} < r_{3.3}$

$$r_{AUT} = \alpha A x_{AUT}^{\alpha-1} < 2\alpha A x_{3.3}^{\alpha-1} = r_{3.3}$$
$$x_{AUT}^{\alpha-1} < 2x_{3.3}^{\alpha-1}$$
$$x_{AUT} > 2^{\frac{1}{\alpha-1}} x_{3.3}$$

and if $n*_{AUT} > n*_{3.3}$, then $x*_{AUT} < x*_{3.3}$

recall that $w*_x = \frac{\Pi_t^x *}{\left(\frac{1}{\alpha}-1\right)x*_t}$, and since $\Pi*_{AUT} > \Pi*_{3.3}$, therefore

$$w*_{AUT} = \frac{\Pi_{AUT}^x *}{\left(\frac{1}{\alpha}-1\right)x*_{AUT}} > \frac{\Pi_{3.3}^x *}{\left(\frac{1}{\alpha}-1\right)x*_{3.3}} = w*_{3.3}$$
$$\therefore w_{xAUT} > w_{x3.3}$$

recall that: $p*_x = \frac{w_x}{\alpha}$ ➔ $\therefore p_{xAUT} > p_{x3.3}$

if $n*_{AUT} > n*_{3.3}$, then $\lambda n*_{AUT}(\ln\gamma) > \lambda n*_{3.3}(\ln\gamma)$ ➔ $g*_{AUT} > g*_{3.3}$

$\therefore$ Therefore, $n*_{AUT} > n*_{3.3}$, $x*_{AUT} < x*_{3.3}$, $r_{AUT} < r_{3.3}$, $w_{AUT} > w_{3.3}$, $p_{AUT} > p_{3.3}$ and $g*_{AUT} > g*_{3.3}$

AUT versus 3.4

$$n^*_{AUT} = \frac{\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{AUT}}{\lambda+\lambda\gamma\left(\frac{1}{\alpha}-1\right)} \qquad \text{vs.} \qquad n^*_{3.4} = \frac{2\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{3.4}}{2\lambda+2\lambda\gamma\left(\frac{1}{\alpha}-1\right)}$$

where $n^*_{AUT} > n^*_{3.4}$ if $2r_{AUT} < r_{3.4}$

$$2r_{AUT} = 2\alpha A x_{AUT}^{\alpha-1} < 2\alpha A x_{3.4}^{\alpha-1} = r_{3.4}$$
$$x_{AUT}^{\alpha-1} < x_{3.4}^{\alpha-1}$$
$$x_{AUT} > x_{3.4} \quad \Rightarrow \quad \otimes$$

therefore $n^*_{AUT} < n^*_{3.4}$ which implies $2r_{AUT} > r_{3.4}$

$$2r_{AUT} = 2\alpha A x_{AUT}^{\alpha-1} > 2\alpha A\left(2x_{3.4}\right)^{\alpha-1} = r_{3.4}$$
$$x_{AUT}^{\alpha-1} > \left(2x_{3.4}\right)^{\alpha-1}$$
$$x_{AUT} < 2x_{3.4}$$

and if $n^*_{AUT} < n^*_{3.4}$ then $x^*_{AUT} > x^*_{3.4}$

$$x^*_{AUT} = \left(\frac{w_{xAUT}}{\alpha^2 A}\right)^{\frac{1}{\alpha-1}} > \frac{1}{2}\left(\frac{w_{x3.4}}{\alpha^2 A}\right)^{\frac{1}{\alpha-1}} = x^*_{3.4}$$
$$w_{xAUT}^{\frac{1}{\alpha-1}} < \frac{1}{2} w_{x3.4}^{\frac{1}{\alpha-1}}$$
$$w_{xAUT} > 2^{1-\alpha} w_{x3.4}$$
$$\therefore w_{xAUT} > w_{x3.4}$$

recall that: $p^*_x = \dfrac{w_x}{\alpha}$ $\Rightarrow$ $p_{x\,AUT} > p_{x3.4}$

if $n^*_{AUT} < n^*_{3.4}$, then $\lambda n^*_{AUT}\left(\ln\gamma\right) < \lambda 2n^*_{3.4}\left(\ln\gamma\right)$ $\Rightarrow$ $g^*_{AUT} < g^*_{3.4}$

$\therefore$ Therefore, $n^*_{AUT} < n^*_{3.4}$, $x^*_{AUT} > x^*_{3.4}$, $w_{AUT} > w_{3.4}$, $p_{AUT} > p_{3.4}$
and $g^*_{AUT} < g^*_{3.4}$

3.2 versus 3.3

$$n*_{3.2} = \frac{2\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{3.2}}{2\lambda + 2\lambda\gamma\left(\frac{1}{\alpha}-1\right)} \qquad \text{vs.} \qquad n*_{3.3} = \frac{\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{3.3}}{\lambda + \lambda\gamma\left(\frac{1}{\alpha}-1\right)}$$

where $n*_{3.2} < n*_{3.3}$ if $r_{3.2} > 2r_{3.3}$

$$r_{3.2} = \alpha A x_{3.2}^{\alpha-1} > 4\alpha A\left(2x_{3.3}\right)^{\alpha-1} = 2r_{3.3}$$
$$x_{3.2}^{\alpha-1} < 4\left(2x_{3.3}\right)^{\alpha-1}$$
$$x_{3.2} < 2^{\frac{\alpha+1}{\alpha-1}} x_{3.3}$$

and since $0 < 2^{\frac{\alpha+1}{\alpha-1}} < 1 \quad \forall \quad 0 < \alpha < 1$, then $x_{3.2} < x_{3.3}$ ➔ $\otimes$

therefore $n*_{3.2} > n*_{3.3}$ which implies $r_{3.2} < 2r_{3.3}$

$$r_{3.2} = \alpha A x_{3.2}^{\alpha-1} > 4\alpha A\left(2x_{3.3}\right)^{\alpha-1} = 2r_{3.3}$$
$$x_{3.2}^{\alpha-1} < 4\left(2x_{3.3}\right)^{\alpha-1}$$
$$x_{3.2} < 2^{\frac{\alpha+1}{\alpha-1}} x_{3.3}$$

and if $n*_{3.2} > n*_{3.3}$ then $x*_{3.2} < x*_{3.3}$

$$x*_{3.2} = \left(\frac{w_{x3.2}}{\alpha^2 A}\right)^{\frac{1}{\alpha-1}} < \frac{1}{2}\left(\frac{w_{x3.3}}{\alpha^2 A}\right)^{\frac{1}{\alpha-1}} = x*_{3.3}$$
$$w_{x3.2}^{\frac{1}{\alpha-1}} < \frac{1}{2} w_{x3.3}^{\frac{1}{\alpha-1}}$$
$$w_{x3.2} > 2^{1-\alpha} w_{x3.3}$$
$$\therefore w_{x3.2} > w_{x3.3}$$

recall that: $p*_x = \frac{w_x}{\alpha}$ ➔ $\therefore p_{x3.2} > p_{x3.3}$

if $n*_{3.2} > n*_{3.3}$, then $\lambda 2n*_{3.2}\left(\ln\gamma\right) > \lambda n*_{3.3}\left(\ln\gamma\right)$ ➔ $g*_{3.2} > g*_{3.3}$

$\therefore$Therefore $n*_{3.2} > n*_{3.3}$, $x*_{3.2} < x*_{3.3}$, $w_{3.2} > w_{3.3}$, $p_{3.2} > p_{3.3}$, and $g*_{3.2} > g*_{3.3}$

Note : It is not clear which is higher, $r_{3.2}$ or $r_{3.3}$.

if $r_{3.2} > r_{3.3}$ $$r_{3.2} = \alpha A x_{3.2}^{\alpha-1} > 2\alpha A\left(2x_{3.3}\right)^{\alpha-1} = r_{3.3}$$
$$x_{3.2}^{\alpha-1} > 2^{\alpha} x_{3.3}^{\alpha-1}$$
$$x_{3.2} < 2^{\frac{\alpha}{\alpha-1}} x_{3.3}$$

since $0 < 2^{\frac{\alpha}{\alpha-1}} < 1$, then $x_{3.2} < x_{3.3}$ ➔ OK

if $r_{3.2} < r_{3.3}$ $$r_{3.2} = \alpha A x_{3.2}^{\alpha-1} < 2\alpha A\left(2x_{3.3}\right)^{\alpha-1} = r_{3.3}$$
$$x_{3.2}^{\alpha-1} < 2^{\alpha} x_{3.3}^{\alpha-1}$$
$$x_{3.2} > 2^{\frac{\alpha}{\alpha-1}} x_{3.3}$$

since $0 < 2^{\frac{\alpha}{\alpha-1}} < 1$, then $x_{3.2}$ could be more or less than $x_{3.3}$.

$\therefore$ Therefore three cases, $r_{3.2} > r_{3.3}$, $r_{3.2} < r_{3.3}$, and $r_{3.2} = r_{3.3}$, must all be considered.

3.2 versus 3.4

$$n*_{3.2} = \frac{2\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{3.2}}{2\lambda + 2\lambda\gamma\left(\frac{1}{\alpha}-1\right)}\lambda \qquad \text{vs.} \qquad n*_{3.4} = \frac{2\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{3.4}}{2\left[\lambda + \lambda\gamma\left(\frac{1}{\alpha}-1\right)\right]}$$

where $n*_{3.2} < n*_{3.4}$ if $r_{3.2} > r_{3.4}$

$$r_{3.2} = \alpha A x_{3.2}^{\alpha-1} > 2\alpha A\left(2x_{3.4}\right)^{\alpha-1} = r_{3.4}$$
$$x_{3.2}^{\alpha-1} > 2^{\alpha} x_{3.4}^{\alpha-1}$$
$$x_{3.2} < 2^{\frac{\alpha}{\alpha-1}} x_{3.4}$$

and since $0 < 2^{\frac{\alpha}{\alpha-1}} < 1 \quad \forall \quad 0 < \alpha < 1$, then $x_{3.2} < x_{3.4}$ ➔ $\otimes$

therefore $n*_{3.2} > n*_{3.4}$ which implies $r_{3.2} < r_{3.4}$

$$r_{3.2} = \alpha A x_{3.2}^{\alpha-1} < 2\alpha A\left(2x_{3.4}\right)^{\alpha-1} = r_{3.4}$$
$$x_{3.2}^{\alpha-1} < 2^{\alpha} x_{3.4}^{\alpha-1}$$
$$x_{3.2} > 2^{\alpha} x_{3.4}^{\alpha-1}$$

and if $n*_{3.2} > n*_{3.4}$ then $x*_{3.2} < x*_{3.4}$

$$x*_{3.2} = \left(\frac{w_{x3.2}}{\alpha^2 A}\right)^{\frac{1}{\alpha-1}} > \frac{1}{2}\left(\frac{w_{x3.4}}{\alpha^2 A}\right)^{\frac{1}{\alpha-1}} = x*_{3.4}$$
$$w_{x3.2}^{\frac{1}{\alpha-1}} < \frac{1}{2} w_{x3.4}^{\frac{1}{\alpha-1}}$$
$$w_{x3.2} > 2^{1-\alpha} w_{x3.4}$$
$$\therefore w_{x3.2} > w_{x3.4}$$

recall that: $p*_x = \frac{w_x}{\alpha}$ ➔ $p_{x3.2} > p_{x3.4}$

if $n*_{3.2} > n*_{3.4}$, then $\lambda 2n*_{3.2}(\ln\gamma) > \lambda 2n*_{3.4}(\ln\gamma)$ ➔ $g*_{3.2} > g*_{3.4}$

$\therefore$Therefore, $n*_{3.2} > n*_{3.4}$, $x*_{3.2} < x*_{3.4}$, $r_{3.2} < r_{3.4}$, $w_{3.2} > w_{3.4}$, $p_{3.2} > p_{3.4}$, and $g*_{3.2} > g*_{3.4}$

3.3 versus 3.4

$$n*_{3.3} = \frac{\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{3.3}}{\lambda + \lambda\gamma\left(\frac{1}{\alpha}-1\right)} \qquad \text{vs.} \qquad n*_{3.4} = \frac{2\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{3.4}}{2\lambda + 2\lambda\gamma\left(\frac{1}{\alpha}-1\right)}$$

where $n*_{3.3} > n*_{3.4}$ if $2r_{3.3} < r_{3.4}$

$$2r_{3.3} = 4\alpha A\left(2x_{3.3}\right)^{\alpha-1} < 2\alpha A\left(2x_{3.4}\right)^{\alpha-1} = r_{3.4}$$
$$2\left(2x_{3.3}\right)^{\alpha-1} < \left(2x_{3.4}\right)^{\alpha-1}$$
$$2^{\alpha} x_{3.3}^{\alpha-1} < 2^{\alpha-1} x_{3.4}^{\alpha-1}$$
$$2^{\frac{1}{\alpha-1}} x_{3.3} > x_{3.4}$$

and since $0 < 2^{\frac{1}{\alpha-1}} < 1 \;\; \forall \;\; 0 < \alpha < 1$, then $x_{3.3} > x_{3.4}$ ➔ ⊗

therefore $n*_{3.3} < n*_{3.4}$ implying $2r_{3.3} > r_{3.4}$

$$2r_{3.3} = 4\alpha A\left(2x_{3.3}\right)^{\alpha-1} > 2\alpha A\left(2x_{3.4}\right)^{\alpha-1} = r_{3.4}$$
$$2\left(2x_{3.3}\right)^{\alpha-1} > \left(2x_{3.4}\right)^{\alpha-1}$$
$$2^{\alpha} x_{3.3}^{\alpha-1} > 2^{\alpha-1} x_{3.4}^{\alpha-1}$$
$$\therefore 2^{\frac{1}{\alpha-1}} x_{3.3} < x_{3.4}$$

and if $n*_{3.3} < n*_{3.4}$ then $x*_{3.3} > x*_{3.4}$ which implies $r_{3.3} < r_{3.4}$

$$x*_{3.3} = \frac{1}{2}\left(\frac{w_{x3.3}}{\alpha^2 A}\right)^{\frac{1}{\alpha-1}} > \frac{1}{2}\left(\frac{w_{x3.4}}{\alpha^2 A}\right)^{\frac{1}{\alpha-1}} = x*_{3.4}$$
$$w_{x3.3}^{\frac{1}{\alpha-1}} > w_{x3.4}^{\frac{1}{\alpha-1}}$$
$$\therefore w_{x3.3} < w_{x3.4}$$

recall that: $p*_{x} = \frac{w_x}{\alpha}$ ➔ $\therefore p_{x3.3} < p_{x3.4}$

If $n*_{3.3} < n*_{3.4}$, then $\lambda n*_{3.3}\left(\ln\gamma\right) < \lambda 2n*_{3.4}\left(\ln\gamma\right)$ ➔ $g*_{3.3} < g*_{3.4}$

$\therefore$Therefore $n*_{3.3} < n*_{3.4}$, $x*_{3.3} > x*_{3.4}$, $r_{3.3} < r_{3.4}$, $w_{3.3} < w_{3.4}$, $p_{3.3} < p_{3.4}$, and $g*_{3.3} < g*_{3.4}$

Diagram 1

AUT vs. 3.3

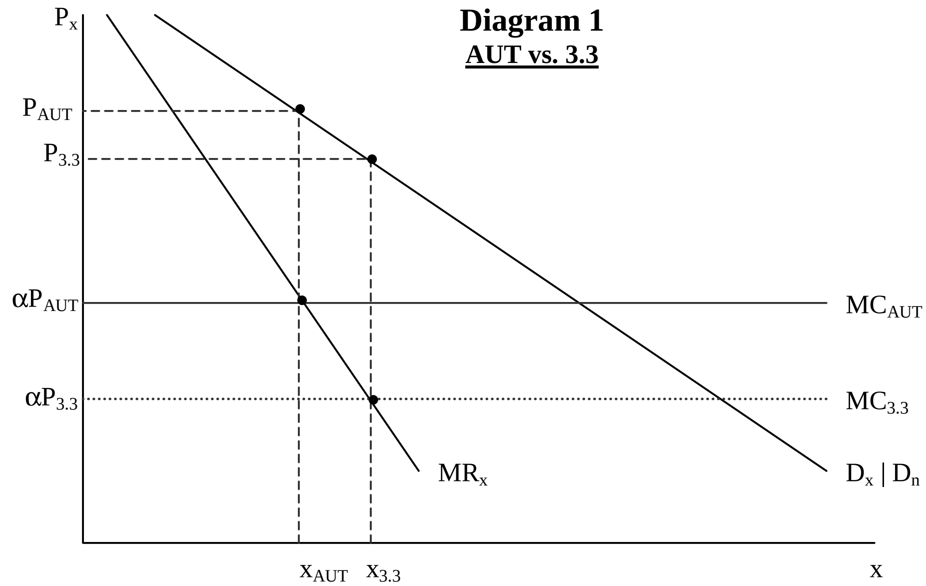
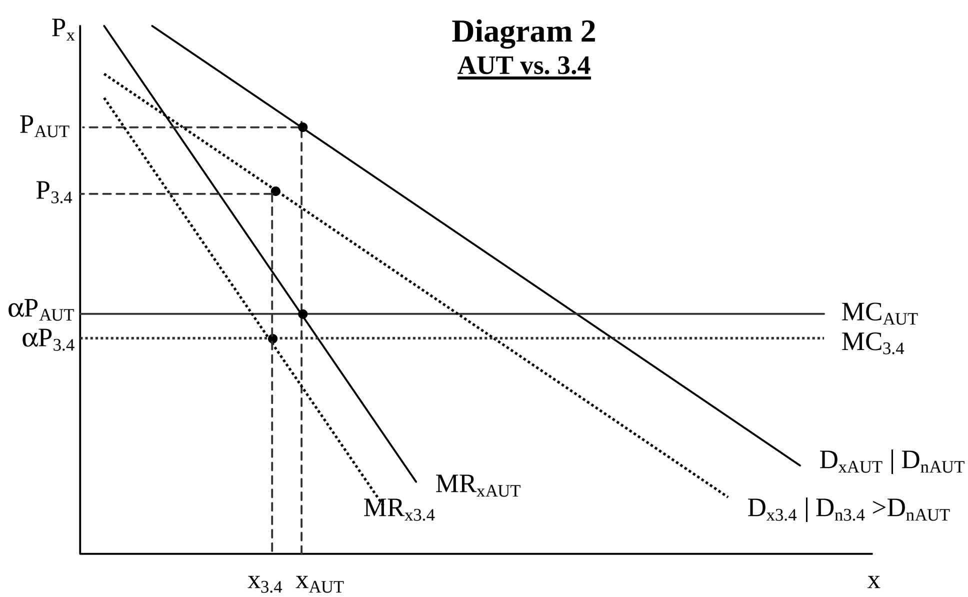


Diagram 2

AUT vs. 3.4



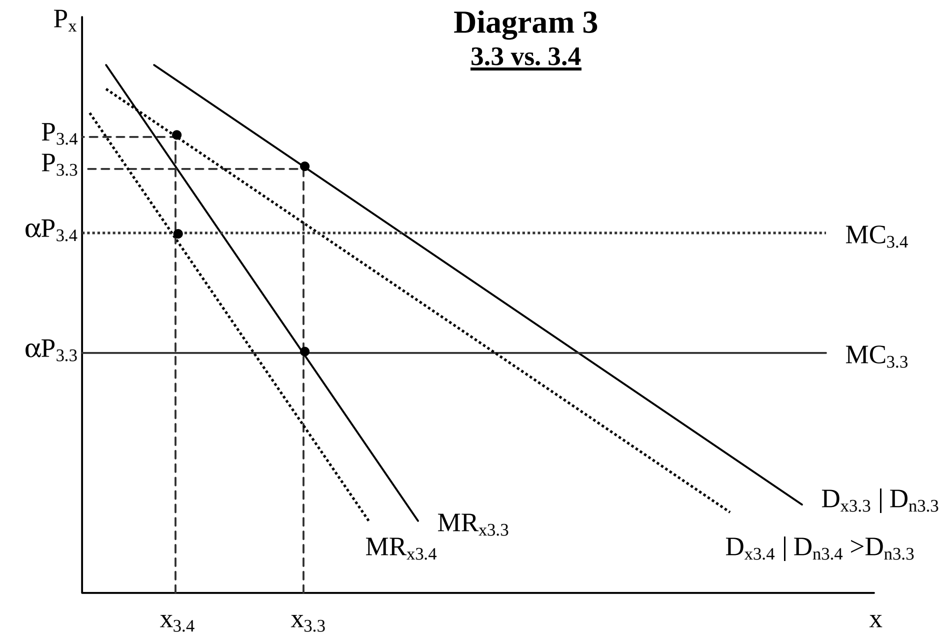


Diagram 3
3.3 vs. 3.4
P_x
P_3.4
P_3.3
αP_3.4
αP_3.3
MC_3.4
MC_3.3
D_x3.3 | D_n3.3
D_x3.4 | D_n3.4 >D_n3.3
MR_x3.3
MR_x3.4
x_3.4
x_3.3
x

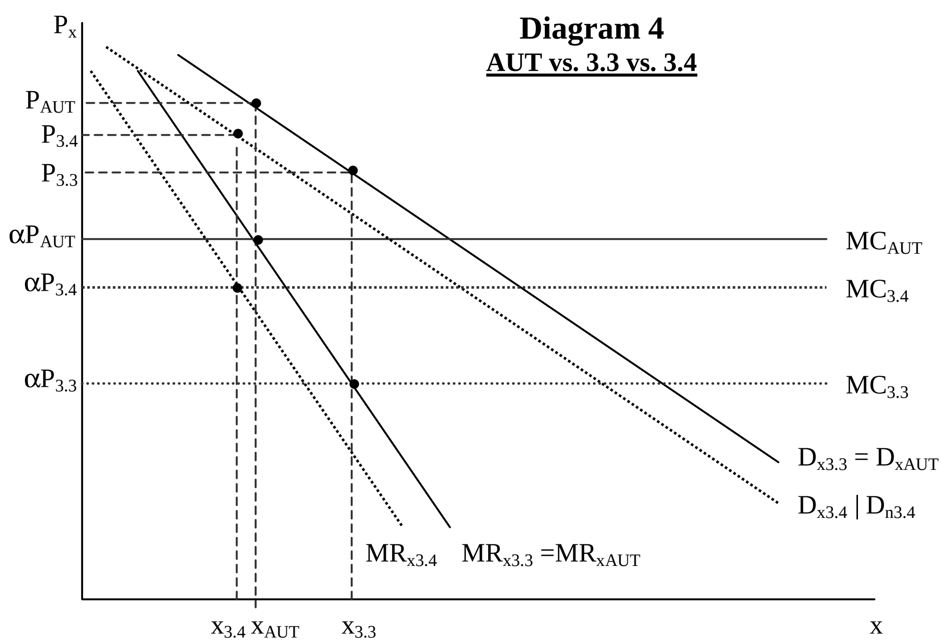


Diagram 4
AUT vs. 3.3 vs. 3.4
P_x
P_AUT
P_3.4
P_3.3
αP_AUT
αP_3.4
αP_3.3
MC_AUT
MC_3.4
MC_3.3
D_x3.3 = D_xAUT
D_x3.4 | D_n3.4
MR_x3.4
MR_x3.3 =MR_xAUT
x_3.4 x_AUT
x_3.3
x

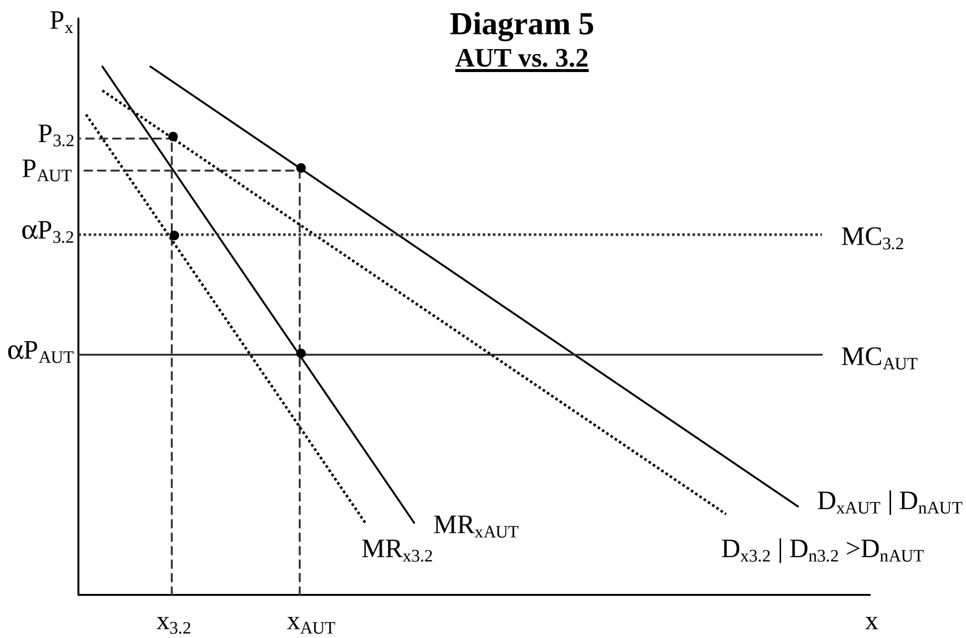


Diagram 5
AUT vs. 3.2
P_x
$P_{3.2}$
P_{AUT}
$\alpha P_{3.2}$
αP_{AUT}
$MC_{3.2}$
MC_{AUT}
D_{xAUT} | D_{nAUT}
MR_{xAUT}
$MR_{x3.2}$
$D_{x3.2}$ | $D_{n3.2}$ >D_{nAUT}
$x_{3.2}$
x_{AUT}
x

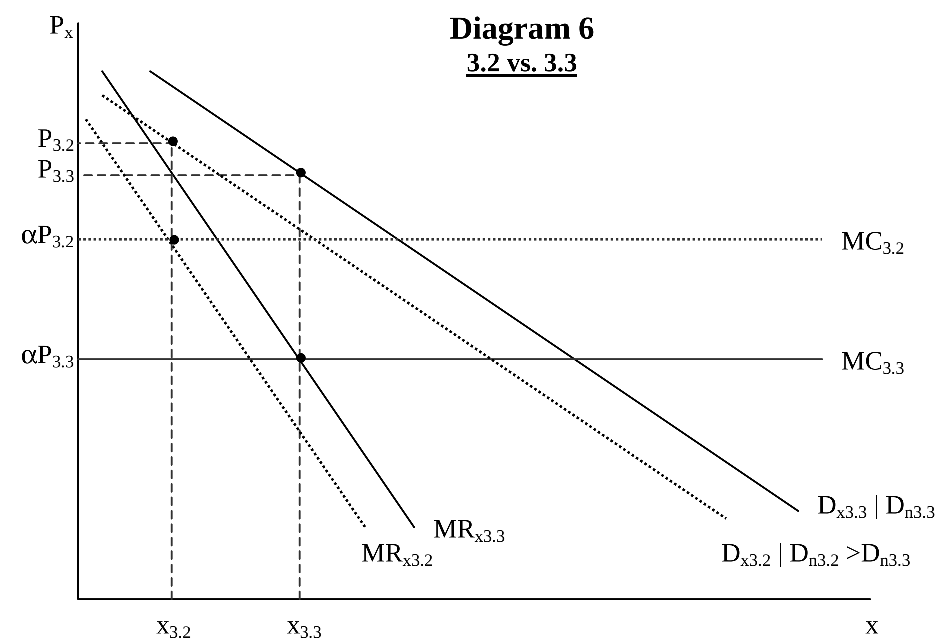


Diagram 6
3.2 vs. 3.3
P_x
$P_{3.2}$
$P_{3.3}$
$\alpha P_{3.2}$
$\alpha P_{3.3}$
$MC_{3.2}$
$MC_{3.3}$
$D_{x3.3}$ | $D_{n3.3}$
$MR_{x3.3}$
$MR_{x3.2}$
$D_{x3.2}$ | $D_{n3.2}$ >$D_{n3.3}$
$x_{3.2}$
$x_{3.3}$
x

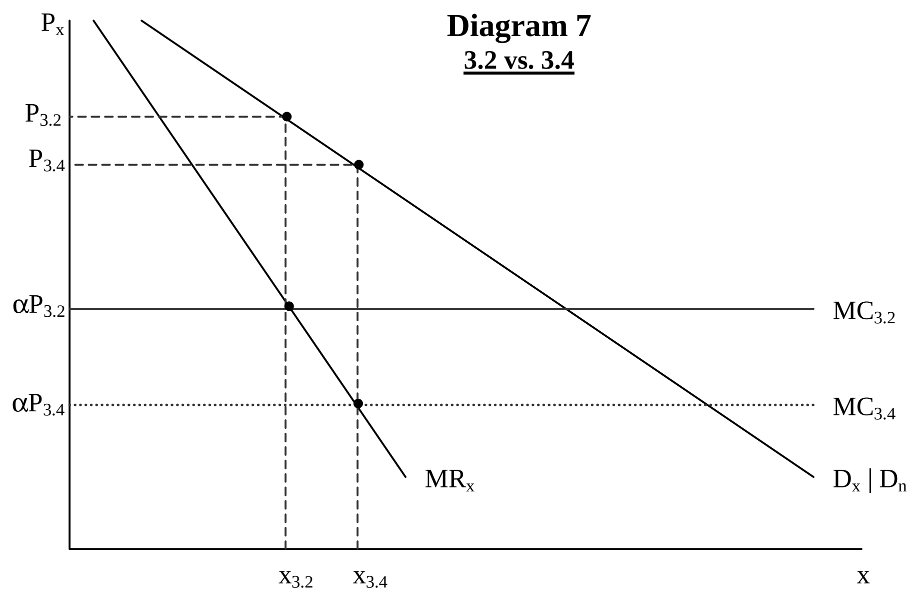


Diagram 7
3.2 vs. 3.4
Px
P3.2
P3.4
αP3.2
αP3.4
MC3.2
MC3.4
MRx
Dx | Dn
x3.2
x3.4
x

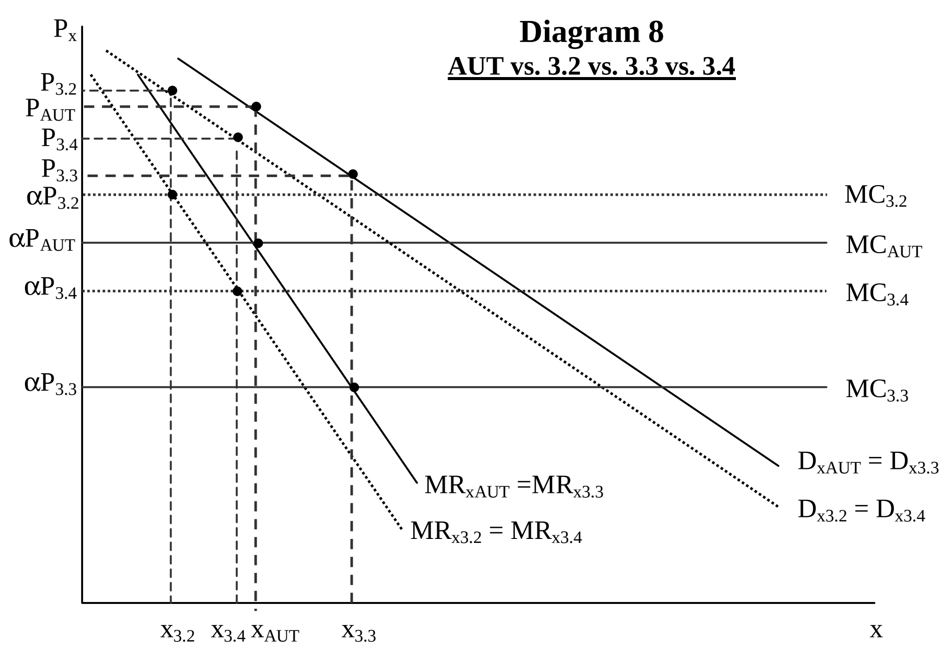


Diagram 8
AUT vs. 3.2 vs. 3.3 vs. 3.4
Px
P3.2
PAUT
P3.4
P3.3
αP3.2
αPAUT
αP3.4
αP3.3
MC3.2
MCAUT
MC3.4
MC3.3
DxAUT = Dx3.3
Dx3.2 = Dx3.4
MRxAUT =MRx3.3
MRx3.2 = MRx3.4
x3.2
x3.4
xAUT
x3.3
x

Table 1

<u>Autarky</u>

$$n^*_{AUT} = \frac{\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{AUT}}{\lambda+\lambda\gamma\left(\frac{1}{\alpha}-1\right)}$$

$$p_{AUT} = \alpha A_t x_t^{\alpha-1}$$

$$w_{AUT} = \alpha^2 A_t x_t^{\alpha-1}$$

$$x^*_{AUT} = \left(\frac{w_x}{\alpha^2 A_t}\right)^{\frac{1}{\alpha-1}}$$

$$r_{AUT} = \alpha A x^{\alpha-1}$$

$$n^S_{AUT} = \frac{\lambda(\gamma-1)\left(\frac{1}{\alpha}\right)L - r_{AUT}}{\lambda(\gamma-1)\left(\frac{1}{\alpha}-1\right)}$$

$$g^*_{AUT} = \lambda n^*_{AUT}(\ln\gamma)$$

<u>3.1 Trade in Intermediaries</u> $(x^H \neq x^F)$

$$n^*_{3.1} = \frac{\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{3.1}}{\lambda+\lambda\gamma\left(\frac{1}{\alpha}-1\right)}$$

$$p_{3.1} = \alpha A_t x_t^{\alpha-1}$$

$$w_{3.1} = \alpha^2 A_t x_t^{\alpha-1}$$

$$x^*_{3.1} = \left(\frac{w_x}{\alpha^2 A_t}\right)^{\frac{1}{\alpha-1}}$$

$$r_{3.1} = \alpha A x^{\alpha-1}$$

$$n^S_{3.1} = \frac{\lambda(\gamma-1)\left(\frac{1}{\alpha}\right)L - r_{3.1}}{\lambda(\gamma-1)\left(\frac{1}{\alpha}-1\right)}$$

$$g^*_{3.1} = \lambda n^*_{3.1}(\ln\gamma)$$

<u>3.2 Trade in Intermediaries + Ideas</u> $(x^H \neq x^F)$

$$n^*_{3.2} = \frac{2\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{3.2}}{2\lambda+2\lambda\gamma\left(\frac{1}{\alpha}-1\right)}$$

$$p_{3.2} = \alpha A_t x_t^{\alpha-1}$$

$$w_{3.2} = \alpha^2 A_t x_t^{\alpha-1}$$

$$x^*_{3.2} = \left(\frac{w_x}{\alpha^2 A_t}\right)^{\frac{1}{\alpha-1}}$$

$$r_{3.2} = \alpha A x^{\alpha-1}$$

$$n^S_{3.2} = \frac{2\lambda(\gamma-1)\left(\frac{1}{\alpha}\right)L - r_{3.2}}{2\lambda(\gamma-1)\left(\frac{1}{\alpha}-1\right)}$$

$$g^*_{3.2} = \lambda 2 n^*_{3.2}(\ln\gamma)$$

<u>3.3 Trade in Intermediaries</u> $(x^H = x^F)$

$$n^*_{3.3} = \frac{\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{3.3}}{\lambda+\lambda\gamma\left(\frac{1}{\alpha}-1\right)}$$

$$p_{3.3} = \alpha A_t (2x_t)^{\alpha-1}$$

$$w_{3.3} = \alpha^2 A_t (2x_t)^{\alpha-1}$$

$$x^*_{3.3} = \frac{1}{2}\left(\frac{w_x}{\alpha^2 A_t}\right)^{\frac{1}{\alpha-1}}$$

$$r_{3.3} = 2\alpha A(2x)^{\alpha-1}$$

$$n^S_{3.3} = \frac{\lambda(\gamma-1)\left(\frac{1}{\alpha}\right)L - r_{3.3}}{\lambda(\gamma-1)\left(\frac{1}{\alpha}-1\right)}$$

$$g^*_{3.3} = \lambda n^*_{3.3}(\ln\gamma)$$

<u>3.4 Trade in Intermediaries + Ideas</u> $(x^H = x^F)$

$$n^*_{3.4} = \frac{2\lambda\gamma\left(\frac{1}{\alpha}-1\right)L - r_{3.4}}{2\lambda+2\lambda\gamma\left(\frac{1}{\alpha}-1\right)}$$

$$p_{3.4} = \alpha A_t (2x_t)^{\alpha-1}$$

$$w_{3.4} = \alpha^2 A_t (2x_t)^{\alpha-1}$$

$$x^*_{3.4} = \frac{1}{2}\left(\frac{w_x}{\alpha^2 A_t}\right)^{\frac{1}{\alpha-1}}$$

$$r_{3.4} = 2\alpha A(2x)^{\alpha-1}$$

$$n^S_{3.4} = \frac{2\lambda(\gamma-1)\left(\frac{1}{\alpha}\right)L - r_{3.4}}{2\lambda(\gamma-1)\left(\frac{1}{\alpha}-1\right)}$$

$$g^*_{3.4} = \lambda 2 n^*_{3.4}(\ln\gamma)$$

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ENDNOTES

[1]For example, see Markusen, et.al. (1995), chapter 11 or any other intermediate to graduate level international trade textbook for a complete description imperfect competition as a determinant of trade between identical countries.

[2] See Barreto and Kobayashi (2001) for a complete discussion of the pros and cons.

[3] See Rivera-Batiz and Romer (1991) for a thorough discussion of this assumption.

[44] See appendix 2 for details.

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