# Does Agricultural Productivity Growth Promote a Dynamic Comparative Advantage in the Manufacturing Sector?

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# Does Agricultural Productivity Growth Promote a Dynamic Comparative Advantage in the Manufacturing Sector?*

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**Abstract**

This paper develops a dynamic Ricardian trade model with a supply of productive infrastructure in the manufacturing sector. We discuss the onset of trade liberalization when the home country has a (dynamic) comparative advantage in the manufacturing sector. Moreover, we compare over time the total welfare that adds welfare during autarkic periods (pre-industrialization periods) to that during specializing in manufacturing sector periods (industrialization periods) with one that exclusively specializes in the agricultural sector. From this setting, the following results are obtained: (1) an increase in agricultural productivity may hasten the onset of liberalization, (2) an improvement in labor efficiency in the public sector necessarily hastens the onset of the trade liberalization; and (3) the total welfare that adds the welfare during autarkic periods to that during specializing in manufacturing sector periods may be higher than that of the economy that exclusively specializes in the agricultural sector.

**Keyword**: Productive infrastructure, Industrialization, Timing of trade liberalization, Agricultural productivity.

**JEL classification**: F43, F10, O14

# 1 Introduction

The importance of agricultural productivity growth for industrialization has long been recognized by economists, for example, Nurkse (1953) stated that "[e]veryone knows that

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the spectacular industrial revolution would not have been possible without the agricultural revolution that preceded it," and Rostow (1960) argued that "revolutionary changes in agricultural productivity are an essential condition for successful take-off." However, in the classical Ricardian trade model, an increase in agricultural productivity promotes a comparative advantage in an agricultural sector, and hence, an increase in agricultural productivity does not promote a comparative advantage in the manufacturing sector. In light of this, are the above statements incorrect from a comparative advantage perspective?

There are many theoretical studies on economic development.[1)] In particular, Matsuyama (1992) is a renowned study that examines how agricultural productivity affects industrialization. It shows that an increase in agricultural productivity does not lead to industrialization in a small open economy because it promotes a comparative advantage in the agricultural sector at the expense of the manufacturing sector. In addition, Matsuyama shows that if a country with a small open economy has not industrialized, then the country specializes in the agricultural sector, and consequently, has a lowers growth rate. Matsuyama (1992) uses the Stone-Geary utility function of non-homothetic preferences, which implies that the income elasticity of demand for agricultural consumption is less than unity. Its engine of growth is driven by the learning-by-doing in the manufacturing sector.

Next, Redding (1999) investigates a comparative advantage in a dynamic environment with a similar setting as Matsuyama (1992). In his paper, the home country (a developing country) does not initially have a comparative advantage in the manufacturing sector. Therefore, if the home country has free trade at the beginning of study, then it cannot specialize in the manufacturing sector. However, Redding (1999) assumes that the learning potential, namely the efficiency of LBD in the manufacturing sector of the home country is higher than that of foreign country. Hence, if the home country continues to have an autarkic economy until it has a comparative advantage in the manufacturing sector, it will eventually be able to industrialize. This type of endogenous comparative advantage is called as "dynamic comparative advantage." Matsuyama (1992), does not however, directly address dynamic comparative advantage. Furthermore, his results imply that an increase in agricultural productivity would not promote a dynamic comparative advantage in the manufacturing sector because he assumes the Cobb-Douglas utility function in his model.

Redding (1999) shows that a country can have a dynamic comparative advantage in the manufacturing sector as long as the country has a greater learning potential. However, we believe that this is the case in only a small number of applicable countries. In the following, we examine the case of the firm Pohang Iron and Steel Company (POSCO) that has a dynamic comparative advantage in the Korean iron and steel industry but may have

1) There are numerous empirical studies that discuss whether free trade increases income and economic growth in developing countries. For example, Singh (2010) surveys relationships between international trade and economic growth. Several studies show that free trade fosters the economic growth of most countries in the world. On the other hand, in a recent empirical study, Kim (2011) shows that a greater degree of trade openness has positive (beneficial) effects on economic growth and standard of living in developed countries, but negative (wasteful) effects in developing countries. Further, government expenditure in developing countries has positive effects on its economic growth and the standard of living.

a low learning potential.

Over fifty years ago, the Korean iron and steel industry was stagnant and probably lacked a comparative advantage in the sector. However, in 1973, POSCO was founded by the Korean government. The Korean government assisted POSCO in an array of ways: investment in facilities, infrastructure supply, and transfers of the latest technology. This assistance played a central role in the dramatic reduction of its production cost (Amsden, 1989). In 1985, POSCO became one of the firms with the lowest production cost in the iron and steel industry in the world, thus gaining a comparative advantage in the industry. This demonstrates that infrastructure provided by the government is a major contributing factor to obtaining the comparative advantage in a manufacturing sector.[2)]

Based on the example of POSCO, if the government provides infrastructure that reinforces learning potential, then a country with an initial relatively low learning potential may have a dynamic comparative advantage in the manufacturing sector by using the infrastructure. However, infrastructure support from the government may increase tax and labor in the public sector. Namely, a supply of infrastructure by the government may increase future welfare, but reduce present welfare. Therefore, the total welfare that adds the welfare during autarkic periods (pre-industrialization periods) to that during specializing in manufacturing sector periods (industrialization periods) may be lower than that obtained by specializing in the agricultural sector over time. Then, from the welfare perspective, even if a country has a dynamic comparative advantage in the manufacturing sector, the country should not have a dynamic comparative advantage in the sector during autarkic periods with infrastructure support. We believe that this point should be further analyzed.

Note that Redding (1999) models states where an increase in agricultural productivity promotes a comparative advantage in the agricultural sector, similar to the classical Ricardian trade model. This result differs from the above statements by Nurkse and Rostow. Chang et al. (2006) show that an increase in agricultural productivity may promote a comparative advantage in the manufacturing sector. This could be due to provision of infrastructure by the government that wishes to increase manufacturing productivity as mentioned by Matsuyama (1992). Chang et al. (2006) conclude that an increase in agricultural productivity promotes a transition in labor from the agricultural sector to the manufacturing sector, because their model assumes the Stone-Geary utility function. In their model, if a developing country (home country) would be able to obtain a comparative advantage in the manufacturing sector through substantial investment in infrastructure by the government, then the government will follow this policy. However, the following three problems exist in their model: first, their model assumes that infrastructure costs are only financed by the tax revenue of the government, that is the production of the infrastructure does not use labor. However, this assumption is not realistic. Second, their model does not analyze a case in which the government continues to supply infrastructure using labor from the public sector. Hence, we do not know whether an increase in agricultural productivity

2) Some theoretical approaches show that infrastructure supply strongly affects productivity and the real GDP (Barro, 1990, Jones, 1998). This type of infrastructure is called “productive infrastructures” (Chang et al., 2006).

hastens trade liberalization because they do not analyze the onset of trade liberalization in their model. Third, their welfare analysis is not explicitly explained.[3)]

In the present paper, to solve the above problems, we construct a dynamic Ricardian trade model with a continuous infrastructure supply provided by the government that reinforces the learning potential. The model has two sectors: a manufacturing sector and an agricultural sector. The manufacturing sector is the only sector driving economic growth. It does so through the learning-by-doing and the infrastructure provided by the government, which maximizes the growth rate of manufacturing productivity in the home country. The infrastructure is produced by labor provided by the government.

Our paper shows that an increase in agricultural productivity may hasten the onset of trade liberalization. In addition, we compare total welfare in an economy specializing in the agricultural sector with an economy with a dynamic comparative advantage in the manufacturing sector during autarkic periods and that has infrastructure provided by the government. In our paper, we assume that specializing in the manufacturing sector is defined as industrialization in a small open economy.

The following main three main results are obtained: (1) an increase in agricultural productivity may hasten the onset of trade liberalization; it promotes a dynamic comparative advantage in the manufacturing sector during autarkic periods with the government investment in infrastructure, (2) a rise in the efficiency of public employees also hastens trade liberalization, and (3) the total welfare that adds the welfare during autarkic periods to that during specializing in manufacturing sector periods may not be higher than welfare obtained through specializing in the agricultural sector over time.

The rest of this paper is organized as follows: Section 2 explains a basic model under autarky. Section 3 discusses an economy with a small open economy. Section 4 discusses a optimal tax rates and optimal supply of infrastructure that maximize the growth rate of manufacturing productivity in the home country. Section 5 compares the total welfare that adds the welfare during autarkic periods to that during specializing in manufacturing sector periods with welfare obtained through specializing in the agricultural sector over time.

# 2 Model

## 2.1 Production

In this economy, there are two goods (sectors): agriculture ($a$) and manufacture ($m$). Labor is the only production factor and total labor endowment is normalized to unity, $L(=1)$. Assume that we neglect population growth and migration. In addition, we suppose that labor is perfectly mobile between the two sectors and wage $w_t$ is identical across the two

3) Ortiz (2006) also introduces Matsuyama (1992) to Barro type infrastructure (1992). This paper does not consider the onset of trade liberalization.

sectors. We specify the production technology as follows:

$$X_{mt} = M_t L_{mt}, \tag{1}$$
$$X_{at} = A L_{at}. \tag{2}$$

where $X_{it}$ denotes the total output in sector $i(= a, m)$ at time $t$, $A$ is the agricultural productivity and is a constant parameter, and $M_t$ is the manufacturing productivity at time $t$.[4)]

Through learning-by-doing and investment in infrastructure, manufacturing productivity $M_t$ increases. In the paper, $G_t$ is considered as the quantity of the infrastructure provided by the government. Furthermore, the government must employ labor to supply infrastructure. The growth rate of manufacturing productivity, which is based on Boldrin and Scheinkman(1988) and Chang et al. (2006), is as follows:

$$\dot{M}_t = G_t X_{mt} \Rightarrow \frac{\dot{M}_t}{M_t} = G_t L_{mt}. \tag{3}$$

The infrastructure production function is defined as follows[5)]:

$$G_t = \phi L_g, \tag{4}$$

where, $\phi$ is the efficiency parameter of labor in the public sector and $L_g$ is the number of workers in the public sector.

We assume that the government imposes the same production tax rate $\tau(> 0)$ on both sectors. The setting of the production tax rate follows Ortiz (2004) and Chang et al. (2006). Thus, the revenue of the government is

$$\tau(P_t X_{mt} + X_{at}) = \tau w_t, \tag{5}$$

where $P_t$ is a relative manufacturing price in terms of the agricultural price at $t$. Furthermore, from equation (5), the government uses the tax revenue to pay public sector wages as follows:

$$L_g = \tau. \tag{6}$$

Hence, from equations (4) and (6) we derive $G = \phi\tau$.

The labor market clearing condition in home country is as follows:

$$L_{at} + L_{mt} + L_g = 1. \tag{7}$$

4) The linear production function in (1) and (2) is different than the that in Matsuyama (1992). The setting does not affect this study's results.

5) The infrastructure production function is a linear function for simplification.

The profits in each sector are defined as follows:

$$\pi_{mt} = P_t(1-\tau)X_{mt} - w_t L_{mt}, \tag{8}$$
$$\pi_{at} = (1-\tau)X_{at} - w_t L_{at}. \tag{9}$$

From equations (8) and (9), we derive the profit maximization conditions and rewrite them as follows:

$$P_t = \frac{w_t}{(1-\tau)M_t}, \tag{10}$$
$$1 = \frac{w_t}{(1-\tau)A}. \tag{11}$$

From equations (10) and (11), the relative price is $P_t = \frac{A}{M_t}$. Thus, if manufacturing productivity increases, then the relative price decreases.

## 2.2 Consumer behavior

We define consumer behavior in this section. Let us assume that consumers obtain utility from the consumption of manufacturing and agricultural goods. All consumers in the economy share identical preferences. We adopt the Stone-Geary utility function of a non-homothetic preference.[6] The utility maximization problem is given by

$$\max W = \int_0^\infty u_t e^{-\rho t} dt \text{ where } u_t = \beta \log(c_{at} - \gamma) + \log(c_{mt}), \tag{12}$$
$$\text{s.t. } c_{at} + P_t c_{mt} = w_t, \tag{13}$$

where $\gamma > 0$ denotes the subsistence level of agricultural consumption, $\rho > 0$, constant discount rate, and $c_{at}$ and $c_{mt}$ are the agricultural consumption per capita manufacturing consumption per capita, respectively, at $t$. In addition, $c_{at}$ must satisfy the condition $c_{at} - \gamma > 0$.

We obtain the aggregated utility maximizing condition as follows:

$$C_{at} = \gamma + \beta P_t C_{mt}, \tag{14}$$

where $C_{at}$ and $C_{mt}$ denote the aggregation of consumption per capita of agricultural goods and manufacturing goods, respectively.

From equation (14) and the budget constraint, we derive the demand functions at $t$ as

6) The Stone-Geary utility function is adapted by Matsuyama (1992), Spilimbergo (2000), and Kongsamut et al. (2001).

follows:

$$C_{mt} = \frac{w - \gamma}{P_t(1+\beta)}, \tag{15}$$

$$C_{at} = \frac{\beta w + \gamma}{1+\beta}. \tag{16}$$

Hence, the indirect utility function at $t$, $\tilde{u}_t$, is

$$\tilde{u}_t = J + (1+\beta)\log(w_t - \gamma) - \log P_t, \tag{17}$$

where $J = \beta \log \beta - (1+\beta)\log(1+\beta)$. A decrease in the relative price increases the real income, and hence improves welfare.

## 2.3 Autarky

Consider the equilibrium in the case of autarky. In the paper, it should be noted that industrialization is defined as the transition of labor from the agricultural sector to the manufacturing sector. This definition is in common with those in Matsuyama (1992) and Chang et al. (2006). Hence, an extreme case of industrialization is an economy that exclusively specializes in the manufacturing sector because, logically, all the labor in the economy is in the manufacturing sector.

Market clearing conditions are as follows:

$$C_{at} = (1-\tau)X_{at}, \tag{18}$$

$$P_t C_{mt} = (1-\tau)P_t X_{mt}. \tag{19}$$

We rewrite equations (18) and (19) as follows:

$$C_{at} = (1-\tau)X_{at}, \tag{20}$$

$$C_{mt} = (1-\tau)X_{mt}. \tag{21}$$

Hence, from equations (20) and (21), labor demands in each sector are derived as follows:

$$L_A = \left[\frac{\beta(1-\tau)A + \gamma}{A(1+\beta)}\right], \tag{22}$$

$$L_m = \left[\frac{(1-\tau)A - \gamma}{A(1+\beta)}\right], \tag{23}$$

$$L_g = \tau. \tag{24}$$

From equations (22) and (23), an increase in $\tau$ decreases the number of workers in both sectors.[7)]

7) We partially differentiate equations (22) and (23) with respect to $\tau$. We obtain $\partial L_A/\partial\tau = -\beta/1+\beta < 0$ and $\partial L_m/\partial\tau = -1/1+\beta < 0$.

As obtained from equations (10), (11), and (17), the indirect utility function in closed-economy case $\tilde{u}_t^C$ is as follows:

$$\tilde{u}_t^C = J + (1+\beta)\log[(1-\tau)A - \gamma)] - \log A + \log M_t. \tag{25}$$

The above equation (25) shows that an increase in agricultural productivity increases the indirect utility in autarky.

# 3 Small open economy

In this section, we consider the case of a small open economy. Namely, we consider a case where the home country is a small country and trades with the rest of the world. Worldwide variables are distinguished from variables by adding an "$*$" for the latter. It takes the world price $P^*$ as given, which is exogenously determined by the rest of the world as autarky. For simplicity, we assume that infrastructure supply does not exist in the rest of the world. Here, the manufacturing productivity of the rest of the world at time $t$, $M_t^*$, is determined by $\dot{M}_t^* = \delta^* X_{mt}^*$ where $\delta^* > 0$. In addition, we assume that the relationship of the initial comparative advantage between the home country and the rest of the world is $M_0^*/A^* > M_0/A$.

From the assumption of the Ricardian production functions, the home country specializes in the sector that has a comparative advantage when it starts to trade with the rest of world. There are three possible of specializing patterns in the home country: (1) if $M_t^*/A^* > M_t/A$, the home country specializes in the agricultural sector; (2) if $M_t^*/A^* < M_t/A$, then it specializes in the manufacturing sector; and (3) if $M_t^*/A^* = M_t/A$, then it has an incomplete specialization.

In addition, we assume that the tax rule is as follows:

**Assumption 1.** *When the home country specializes in the agricultural production at $t = 0$, then the home government does not impose production tax. In other words, the infrastructure expenditure is zero: $G = 0$. When the home country intends to specialize in the manufacturing production, then the home country imposes a production tax $\tau > 0$. In other words, the public expenditure of infrastructure is positive, $G > 0$.*

We explain the above assumption. If the home country specializes in the agricultural sector, then infrastructure supply does not promote industrialization in a small open economy because the number of workers in the agricultural sector is zero, and hence the home government does not need to impose tax on the both sectors to increase the welfare in the home country. If the home country intends to specialize in the manufacturing sector, then the manufacturing productivity must be sufficient to obtain a comparative advantage in autarky, and thus the government imposes tax on both sectors to supply the infrastructure.

We now consider the following two cases. The first case is an economy that specializes in the agricultural sector from $t = 0$. The second case is composed of the following two-stage economy: the home country is autarkic until $t_1$ when it obtains a comparative advantage in the manufacturing sector and it specializes in the manufacturing sector thereafter. Hence, we assume that the home country is autarkic from $t = 0$ until $t_1$, when it obtains a comparative advantage in the manufacturing sector, and begins to trade with the rest of the world from $t_1$ to infinity. We define $t_1$ as the onset of trade liberalization. In this paper, a comparative advantage is endogenously changed over time, which is called a dynamic comparative advantage (Redding, 1999). In other words, the second case is considered as the case where the home country develops a dynamic comparative advantage in the manufacturing sector by using infrastructure in autarky at $t_1$.

## 3.1 The case of specializing in the agricultural sector

We consider the case of a small open economy from $t = 0$ to infinity. The home country continuously specializes in agricultural production over time, with the assumption $\frac{M_0^*}{A^*} > \frac{M_0}{A}$. Hence, profit maximization is realized in the home country as follows:

$$1 = \frac{w_t}{A} \Leftrightarrow A = w_t \tag{26}$$

From equation (26), we derive the welfare in the home country specializing in agricultural sector at $t$, $u_{At}^F$, as follows:

$$\tilde{u}_{At}^F = J + (1+\beta)\log[A-\gamma] - \ln A^* + \ln M_t^*. \tag{27}$$

Note that the productivity growth rate in the foreign manufacturing sector $\dot{M}_t^*/M_t^*$ is positive and hence, continuously improves indirect welfare in the home country. In addition, we find from equation (27) that the supply of infrastructure is useless for manufacturing productivity growth.

## 3.2 The case of specializing in the manufacturing sector

The home country specializes in the agricultural sector at $t = 0$ because the home country has a comparative advantage in the agricultural sector at $t = 0$. Hence, the home country must have a comparative advantage in the manufacturing production at $t_1 \in (0, \infty)$ to industrialize. Hence, in this paper, the industrialization of a small open economy implies that the home country specializes in the manufacturing sector at $t_1$ and thus, also signifies that the home country obtains a dynamic comparative advantage in the manufacturing sector at $t_1$. Hence, the condition of industrialization in small open economy $t > t_1$ is as follows:

$$\frac{M_t}{A} > \frac{M_t^*}{A^*} \text{ for any } t \text{ such that } t_1 \leq t \tag{28}$$

Therefore, we make the following assumption so the home country obtains a comparative advantage in the manufacturing sector.

**Assumption 2.** *If the home country intends to specialize in the manufacturing sector, then the home country is in autarky until $t_1$.*

In addition, we assume that the home country continues to have a comparative advantage in the manufacturing sector after $t_1$. Then the growth rate of the home country's manufacturing productivity is higher than that in the rest of the world. Hence, we assume the following condition:

**Assumption 3.** *The labor productivity growth of the manufacturing sector in the home country is higher than that in the rest of the world at $t > t_1$:*

$$\frac{\dot{M}_t}{M_t} \geq \frac{\dot{M}_t^*}{M_t^*}. \tag{29}$$

If Assumption 3 is satisfied, then the home country continues to have a comparative advantage in the manufacturing sector after $t_1$.

The relative world price of the manufactured goods determines $w_t$: $P_t^* = \frac{w_t}{M_t}$. Then the indirect utility function at $t > t_1$ is as follows:

$$\tilde{u}_{Mt}^F = J + (1+\beta)\ln\left[(1-\tau)A^*\frac{M_t}{M_t^*} - \gamma\right] - \ln A^* + \ln M_t^*. \tag{30}$$

We examine the intuition of equation (30). The effect of $M_t^*$ is decomposed into the following two effects. A rise in $M_t^*$ decreases the relative world price in the manufacturing sector, and hence, welfare in the home country improves. On the other hand, a rise in $M_t^*$ reduces the comparative advantage in the manufacturing sector in the home country. Hence, the indirect welfare in the home country declines.

The change in the manufacturing productivity growth rate in the home country during autarkic periods $t^A \in [0, t_1]$ and during open economy periods $t^F \in (t_1, \infty)$ is depicted in Figure 1.

[Insert here Figure 1.]

# 4 Manufacturing productivity growth rate and the infrastructure

In this section, we consider how to determine the productivity growth rate of the manufacturing sector.

## 4.1 Infrastructure supply needed to maximize the manufacturing productivity growth rate

In the section, we discuss the optimal tax rate and optimal infrastructure supply.

We assume that the home government prefers to pursue a policy that maximizes their manufacturing productivity growth rate. In other words, an optimal supply of the infrastructure maximizes the manufacturing productivity growth rate. This implies that the policy maximizes the production possibility frontier in the home country in the next period $t + dt$. Hence, let us assume that the home government imposes the following tax rule.

**Assumption 4.** *The home government supplies productive infrastructure to maximize the manufacturing productivity growth rate in the home country, $G^*$, and it imposes a tax that finances the cost of $G^*$, $\tau^*(> 0)$.*[8)]

We describe $\tau^*$ as the optimal tax rate. The government in the home country solves the following problem:

$$\max_{\tau} \frac{\dot{M}_t}{M_t}. \tag{31}$$

Hence, the home government supplies optimal infrastructure to maximize equation (31) from Assumption 4.

We describe a tax rate under autarky as $\tau^C$. From equation (31), we obtain the following proposition:

**Proposition 1.** *The optimal tax rate in autarky, $\tau^{C*}$, is as follows:*

$$\tau^{C*} = \frac{1}{2}\left(1 - \frac{\gamma}{A}\right) \tag{32}$$

**Proof of proposition 1.** *The manufacturing productivity growth rate in autarky is as follows:*

$$\frac{\dot{M}_t^C}{M_t^C} = \phi\tau^C \left[\frac{(1-\tau^C)A - \gamma}{A(1+\beta)}\right], \tag{33}$$

*where $M_t^C$ is the manufacturing productivity growth rate at $t$ in autarky.*

*From equation (33), the optimal tax in autarky $\tau^{C*}$ is derived as follows:*

$$\frac{\partial \frac{\dot{M}_t^C}{M_t^C}}{\partial \tau^C} = 0 \iff \tau^{C*} = \frac{1}{2}\left(1 - \frac{\gamma}{A}\right). \tag{34}$$

■

8) The most preferable policy may maximize real GDP growth in the home country. However, there is no qualitative difference between the results of a policy that maximizes real GDP growth and those of the policy in Assumption 4. Hence, for simplification, we employ the policy described in Assumption 4.

Next we consider the tax rate in a small open economy $\tau^F$ and define the optimal tax rate as $\tau^{F*}$. If the home country specializes in the manufacturing sector, then the labor demand in the manufacturing sector is $L_m^F = (1-\tau^F)$ and that in the public sector is $L_g = \tau^F$ at $t > t_1$. Hence $\dot{M}_t/M_t = (1-\tau^F)\tau^F$. We obtain the following proposition for a small open economy:

**Proposition 2.** *The optimal tax rate in a small open economy, $\tau^{F*}$, is*

$$\tau^{F*} = \frac{1}{2}. \tag{35}$$

**Proof of proposition 2.** *The manufacturing productivity growth rate in a small open economy is as follows:*

$$\frac{\dot{M}_t^F}{M_t^F} = \phi\tau^F(1-\tau^F), \tag{36}$$

*where $M_t^F$ is the manufacturing productivity growth rate at $t(> t_1)$ in a small open economy.*

*From equation (36), the optimal tax in autarky $\tau^{F*}$ is derived as follows:*

$$\frac{\partial\frac{\dot{M}_t^F}{M_t^F}}{\partial\tau^F} = 0 \;\Leftrightarrow\; \tau^{F*} = \frac{1}{2}. \tag{37}$$

■

Here, Figure 2 represents the relationship between the manufacturing productivity growth rate $\frac{\dot{M}_t}{M_t}$ and the optimal tax rate $\tau^*$.

[Insert here Figure 2.]

Note that $\tau^{F*} > \tau^{C*}$ because the labor demand in the agricultural sector is zero when an economy exclusively specializes in the manufacturing sector.

## 4.2 Agricultural productivity growth and manufacturing productivity growth

We demonstrate here that a rise in agricultural productivity increases the growth rate of manufacturing productivity in autarky. Conversely, agricultural productivity does not increase growth in the manufacturing productivity in a small open economy. Suppose that the government imposes the optimal tax $\tau^*$ in the following section. We then obtain the following proposition:

**Proposition 3.** *If $\gamma > 0$, then a rise in agricultural productivity increases the growth rate of manufacturing productivity in autarky. Conversely, if $\gamma = 0$, a rise in agricultural productivity does not affect the the growth rate of manufacturing productivity. Furthermore,* *a rise in agricultural productivity also does not affect growth of manufacturing productivity in a small open economy.*

**Proof of proposition 3.** *In a small open economy, the growth rate of manufacturing productivity* $\frac{\dot{M}_t^F}{M_t^F} = \frac{\phi}{4}$. *Hence,* $\frac{\partial \frac{\dot{M}_t^F}{M_t^F}}{\partial A} = 0$.

*Next we consider the case in autarky. Differentiate* $\frac{\dot{M}_t^C}{M_t^C} = \frac{\phi(A-\gamma)^2}{4A^2(1+\beta)}$ *in terms of* $A$. *Then,*

$$\frac{d\frac{\dot{M}_t^C}{M_t^C}}{dA} = \frac{\phi}{2(1+\beta)}\frac{(A-\gamma)\gamma}{A^3} > 0. \tag{38}$$

*Therefore if* $\gamma = 0$, *then* $\frac{\partial \frac{\dot{M}_t^C}{M_t^C}}{\partial A} = 0$. ■

Proposition 3 states that a relationship between agricultural productivity and manufacturing productivity. A rise in agricultural productivity decreases the number of workers needed to produce a subsistence level of the agricultural consumption $\gamma > 0$, and hence, the number of workers in the manufacturing sector and in the public sector both increase.

# 5 Welfare analysis

In this section, we examine the following two cases of total welfare: (A) if the home government intends to specialize in the agricultural sector, trade starts from $t = 0$; and (B) if the home government intends to specialize in the manufacturing sector, the home country is autarkic from 0 to $t_1$ and it specializes in the manufacturing sector from $t_1$ in a small open economy.[9)]

## 5.1 Total welfare

First, we consider case A. The total welfare in a small open economy specializing in the agricultural sector $W_A^F$ from equation (27) is given by

$$W_A^F = \int_0^\infty u_{At}^F e^{-\rho t} dt \tag{39}$$

$$= \frac{J + (1+\beta)\log(A-\gamma) - \log A^* + \log M_0^*}{\rho} + \left(\frac{A^*-\gamma}{A^*(1+\beta)}\right) \cdot \frac{1}{\rho^2}, \tag{40}$$

Next, we consider case B. The total welfare in autarky during $t \in [0, t_1]$ from equation

9) In this section, we do not consider the total welfare in autarky from 0 to infinity. Because the total welfare is always smaller than that under (B), the comparison is not interesting. The detailed discussion is treated in Appendix A.

(30), $W^C$ is given by

$$W^C = \int_0^{t_1} u_t^C e^{-\rho t} dt \tag{41}$$
$$= \left[\frac{1 - e^{-\rho t_1}}{\rho}\right] [J + (1+\beta)(\ln(1-\tau)A - \gamma) - \ln A] + \frac{Q}{\rho^2}[1 - e^{-\rho t_1} - \rho t_1 e^{-\rho t_1}], \tag{42}$$

where, $Q = \phi\tau \left[\frac{(1-\tau)A-\gamma}{A(1+\beta)}\right]$.

Moreover, we show the total welfare in the home country during $[t_1, \infty)$, $W_M^F$, when the home country specializes in the manufacturing sector from $t_1$:

$$W_M^F = \int_{t_1}^{\infty} u_{Mt}^F e^{-\rho t} dt \tag{43}$$
$$= \int_{t_1}^{\infty} \left[J' + (1+\beta)\log\left((1-\tau^{F*})A^* e^{(\phi(1-\tau^{F*})\tau^{F*} - \delta_0^* L_m^*)(t-t_1)} - \gamma\right) + L_m^* \delta_0^*(t-t_1)\right] e^{-\rho t} dt, \tag{44}$$

where, $J' = J - \log A^* + \log M_{t_1}^*$ and $L_m^* = \left[\frac{A^*-\gamma}{A^*(1+\beta)}\right]$.

## 5.2 Onset of trade liberalization and agricultural productivity

Next, we compare cases A with B.

To specialize in the manufacturing sector, the home country must be satisfied with the condition $\frac{M_t^*}{A^*} \leq \frac{M_t}{A}$ at $t_1 \leq t$. Specifically, if $\frac{M_t^*}{A^*} = \frac{M_t}{A}$, then $t = t_1$ and we obtain the following lemma in terms of $t_1$.

**Lemma 1.** *The onset of trade liberalization $t_1$ is obtained as*[10)]

$$t_1 = \frac{(\log M_0^* - \log M_0) - (\log A^* - \log A)}{\frac{\phi}{4(1+\beta)}\left[\frac{A-\gamma}{A}\right]^2 - \delta^* \frac{A^*-\gamma}{A^*(1+\beta)}}. \tag{45}$$

The numerator of equation (45) represents the initial comparative advantage, which is positive from the assumptions of the condition of the initial comparative advantage. Next, the denominator of equation (45) describes the difference between the growth rate of manufacturing productivity in the home country under autarky and in the rest of the world. The difference is positive based on the Assumption 3. If the denominator is negative, then the growth rate of manufacturing productivity in the rest of the world is faster than that in the home country. Hence, the home country cannot have a dynamic comparative advantage in the manufacturing sector over time: there is no onset of trade liberalization. On the other hand, if the denominator is positive, then there is an onset of the trade liberalization $t_1 \in (0, \infty)$.

Furthermore we obtain the following proposition from lemma 1.

10) The derivation of the onset of trade liberalization follows Redding (1999) and Chen (1999).

**Proposition 4.** *The higher the manufacturing productivity of government* $\phi$*, the faster the onset of trade liberalization* $t_1$*.*

**Proof of proposition 4.** *If we differentiate equation (45) in terms of* $\phi$*, then*

$$\frac{\partial t_1}{\partial \phi} = -t_1 \left[ \frac{\frac{1}{4(1+\beta)} \left[\frac{A-\gamma}{A}\right]^2}{\frac{\phi}{4(1+\beta)} \left[\frac{A-\gamma}{A}\right]^2 - \delta^* \frac{A^*-\gamma}{A^*(1+\beta)}} \right] < 0, \tag{46}$$

*where from Assumption 3 we obtain,* $\frac{\phi}{4(1+\beta)} \left[\frac{A-\gamma}{A}\right]^2 - \delta^* \frac{A^*-\gamma}{A^*(1+\beta)} = \frac{\dot{M}_t}{M_t} - \frac{\dot{M}_t^*}{M_t^*} > 0.$■

We explain the intuition of Proposition 4. When the efficiency of public labor increases, the growth rate in manufacturing productivity increases. Hence, a rise in $\phi$ hastens the onset of trade liberalization.

Furthermore, we show that an increase in agricultural productivity, $A$, affects the onset of trade liberalization $t_1$. The following proposition is obtained as follows:

**Proposition 5.** *The effects of agricultural productivity growth on the onset of trade liberalization are ambiguous.*

**Proof of proposition 5.** *If we differentiate equation (45) in terms of* $A$*, then*

$$\frac{dt_1}{dA} = \Gamma \left[\Delta - \Omega\right], \tag{47}$$

*where* $\Gamma = \frac{\phi}{4(1+\beta)} \left[\frac{A-\gamma}{A}\right]^2 > 0$*,* $\Delta = (\log M_0^* - \log M_0) - (\log A^* - \log A)/A > 0$*, and* $\Omega = \frac{\phi}{4(1+\beta)} \left[\frac{A-\gamma}{A^3}\right]^2 \geq 0.$■

From the assumption of the initial comparative advantage and Assumption 3, $t_1$ in equation (47) is always positive. Next, the first term of equation (47) examines the change in comparative advantage. The change makes it even more difficult to obtain a comparative advantage in the manufacturing sector. On the other hand, the second term of equation (47) represents an increase in the manufacturing productivity caused by a transition of labor from the agricultural sector to the manufacturing sector and by an increase in infrastructure supply. Hence, if the second term of equation (47) is higher than the first term, then an increase in the agricultural productivity accelerates industrialization: namely, it decreases in $t_1$.

If the utility function is the Cobb-Douglas type as in Redding (1999), that assumes $\gamma = 0$, then the second term of equation (47) vanishes. Hence, an increase in agricultural productivity always increases $t_1$. We obtain the following lemma from equation (47):

**Lemma 2.** *If* $\gamma = 0$*, then an increase in agricultural productivity always increases* $t_1$*.*

Lemma 2 is similar to the result of Redding (1999). Therefore, Proposition 5 generalizes the results of Redding (1999). Our results depend on the Stone-Geary specification which is $\gamma > 0$. If agricultural productivity is extremely low, the second term of equation (47) is very large. In addition Matsuyama (1992) and Chang et al. (2006) use the Stone-Geary utility function but do not discuss the onset of trade liberalization.

## 5.3 Comparison of total welfare in the two cases

In this section, we compare total welfare in case $A$ with that in case $B$. We obtain the total welfare in case B as follows:

$$W_M = \int_0^{t_1} u_t^C e^{-\rho t} dt + \int_{t_1}^{\infty} u_{Mt}^F e^{-\rho t} dt. \tag{48}$$

If $W_M < W_A^F$, then the home country should not be able to industrialize. On the other hand, if $W_M > W_A^F$, then the home country should be able to industrialize.

We reveal the following proposition.

**Proposition 6.** *Suppose $t_1 > 0$. If $\rho$ is high enough, then the total welfare in case $A$ is higher than that in the case B: $W_M > W_A^F$. Conversely, if $\rho$ is low enough, then the total welfare in case $A$ is lower than that in case B: $W_M < W_A^F$.*

**Proof of proposition 6.** *We compare $u_{A0}^F$ with $u_0^C$, $u_{At_1}^F$ with $u_{t_1}^C$, $u_{At_1}^F$ with $u_{Mt_1}^F$, and $\dot{u}_{At}^F (= \frac{du_{At}^F}{dt})$ with $\dot{u}_{Mt}^F (= \frac{du_{Mt}^F}{dt})$.*

*First, we compare $u_{A0}^F$ with $u_0^C$. Recall that the initial comparative advantage is determined by the assumption: $\frac{M_0}{A} < \frac{M_0^*}{A^*}$. Hence, immediately $u_{A0}^F > u_0^C$.*

*Second, we compare $u_{At_1}^F$ with $u_{t_1}^C$. From equations (25) and (27),*

$$u_{At_1}^F - u_{t_1}^C = (1+\beta)\left[\log(A-\gamma) - \log[(1-\tau)A - \gamma]\right] > 0. \tag{49}$$

*Hence, $u_{At_1}^F > u_{t_1}^C$ is always realized from the assumption of the initial comparative advantage and of the onset of trade liberalization.*

*Third, we compare $u_{At_1}^F$ with $u_{Mt_1}^F$. The following results are then obtained:*

$$u_{Mt_1}^F - u_{At_1}^F = (1+\beta)\left[\log\left[(1-\tau)A^* - \gamma\right] - \log[A-\gamma]\right] \tag{50}$$

*From equation (50), if $(1-\tau)A^* > A$, then $u_{At_1}^F < u_{Mt_1}^F$, and conversely, if $(1-\tau)A^* < A$, then $u_{At_1}^F > u_{Mt_1}^F$.*

*Forth, we calculate $\dot{u}_{Mt}^F - \dot{u}_{At}^F$ as follows:*

$$\dot{u}_{Mt}^F - \dot{u}_{At}^F = \frac{\frac{M_t}{M_t^*}\left[\frac{\dot{M}_t}{M_t} - \frac{\dot{M}_t^*}{M_t^*}\right]}{(1-\tau^{F*})A\frac{M_t}{M_t^*} - \gamma} > 0 \tag{51}$$

*Based on assumption 3, equation (51) is always positive.*

*To summarize, if the periods of the autarkic periods are short, then total welfare in case B is higher than in the case A: $W_M > W_A^F$. In addition, if the discount rate $\rho$ is low enough, the industrialization periods are evaluated highly, and hence the total welfare in case B may be higher than that in case A.* ■

Figure 3 depicts the transition of utility for each case.

[Insert here Figure 3.]

In Figure 3, the utility at point A is larger than that at point C, and furthermore the utility at point D is also larger than that at point B. Furthermore, if $(1-\tau)A^* < A$, then point E is larger than point D, and conversely, if $(1-\tau)A^* > A$, then then point E is smaller than point D.

Next, we investigate the effect of an increase in agricultural productivity. Recall from Proposition 5 that an increase in agricultural productivity may hasten the onset of trade liberalization. A decrease in $t_1$ is equivalent to the hastening of industrialization in a small open economy. Hence, an increase in agricultural productivity shortens autarky periods $[0, t_1]$ and prolongs the industrialization periods $[t_1, \infty]$. Therefore, if agricultural productivity increases, then $W_M > W_A^F$ may be achieved even if $W_M < W_A^F$ before an increase in the agricultural productivity. The case is considered in detail by using numerical calculation in Appendix B.

In this paper, the government provision of infrastructure continues infinity. On the contrary, Chang et al. (2006) consider only the "Big Push" policy: the government only provides initial infrastructure. Hence, their paper cannot investigate continuous policy effects on the onset of trade liberalization and total welfare. Furthermore, Chang et al. (2006) do not examine explicit welfare analysis or compare total welfare between cases.

# 6 Conclusion

We set up the framework of a dynamic Ricardian trade model with a supply of infrastructure provided by the government. Our paper shows that agricultural productivity growth and infrastructure supply promote a dynamic comparative advantage in the manufacturing sector. If the home country has a comparative advantage in the manufacturing sector, then it corresponds with the onset of trade liberalization.

First, we show that an increase in labor efficiency in the public sector hastens the onset of trade liberalization and this improves total welfare through a dynamic comparative advantage in an autarkic manufacturing sector.

Second, we show that an increase in agricultural productivity may reinforce a dynamic comparative advantage in the manufacturing sector. Agricultural productivity growth increases manufacturing productivity through worker transition, but an increase in agricultural productivity also directly reinforces a comparative advantage in the agricultural sector. Thus, the two effects offset. If the subsistence level of agricultural consumption is high enough, then an increase in the agricultural productivity promotes a dynamic comparative advantage in the manufacturing sector. In fact, an increase in agricultural productivity actually promotes a comparative advantage in the manufacturing sector because it is highly possible that the agricultural subsistence level of many developing countries in the world is relatively high.

Third, we investigate the onset of trade liberalization and compare total welfare in an economy specializing in agriculture over time with one that the total welfare that adds the welfare during autarkic periods to that during specializing in manufacturing sector periods. The results are that total that adds the welfare during autarkic periods to that during specializing in manufacturing sector periods may be higher than that of specializing in the agricultural production over time.

Our paper assumes that the government imposes a tax that maximizes the manufacturing productivity growth rate. Hence, the optimal tax rate is simple. However, an optimal tax rate generally does not maximize total welfare. Therefore, it may be interesting to consider a case with a tax rate that maximizes total welfare.

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# Appendix A: total welfare during autarky over time

This paper mainly compares the welfare that adds the welfare during autarkic periods to that during specializing in manufacturing sector periods with the total welfare of specializing in the agricultural sector over time. Here, total welfare during autarky over time is considered.

Total welfare in an economy specializing in the agricultural sector in $[0, \infty] \in t$, $W^{C\infty}$, is derived as follows,

$$W^{C\infty} = \int_0^\infty u_t^C e^{-\rho t} dt = \frac{J + (1+\beta)[\ln(1-\tau)A - \gamma] - \ln A}{\rho} + \frac{Q}{\rho}. \tag{52}$$

If the onset of trade liberalization exists $t_1 > 0$ in the economy, then the total welfare after $t_1$ in autarky is higher than that in a small open economy. Therefore,

$$W^{C\infty} < W_M. \tag{53}$$

On the other hand, we cannot explicitly verify the significance of the relationship between $W_A^F$ and $W^{C\infty}$. For example, if the labor efficiency of the public sector $\phi$ is high enough, then $W^{C\infty}$ may be higher than $W_A^F$.

# Appendix B: numerical analysis

In this section, using numerical analysis, we calculate $t_1$ and compare $W_M$ with $W_A^F$.

The parameters in the model are specified as $\rho = 0.03$, $\phi = 1$, $A = A^* = 1$, $M_0 = 0.5$, $M_0^* = 1$, $\beta = 0.5$ and $\delta^* = 0.1$. The optimal tax rate that maximizes the real GDP is $\tau^{C*} = 0.45$ under autarky and $\tau^{F*} = 0.5$ in a small open economy. Furthermore, we described the results under these specifications, as is standard.

## Agricultural productivity and the onset of trade liberalization

This subsection calculates $t_1$ and re-examines Proposition 5 using a numerical analysis. Hence, the onset of trade liberalization $t_1$ under $\gamma = 0.4$ is compared with that under $\gamma = 0$. In addition, we show an increase in agricultural productivity hastens the timing of trade liberalization: $t_1$ under $A = 1$ is compared with that under $A = 1.5$. The results are summarized in Table 1.

| $t_1$ | $\gamma = 0$ | $\gamma = 0.4$ |
|---|---|---|
| $A = 1$ | 6.9 | 34.7 |
| $A = 1.5$ | 10.9 | 22.1 |

Table 1: Onset of trade liberalization and the agricultural productivity

As demonstrated in Table 1, an increase in agricultural productivity delays the onset of trade liberalization in the case of $\gamma = 0$. This is because an increase in the agricultural productivity only increases the comparative advantage in the manufacturing sector.

At the same time, an increase in agricultural productivity hastens the onset of trade liberalization in the case of $\gamma = 0.4$. This is for the following two reasons. First, an increase in agricultural productivity directly decreases the comparative advantage in manufacturing. Second, an increase in productivity promotes a movement of labor from the agricultural sector to the manufacturing and public sector. Therefore, the latter effect is larger than the former, as shown in Table 1.

## Comparison of welfare

Furthermore, we compare the following: (a) the benchmark case($A = 1$, $\phi = 1$), (b) the case of $A = 2$ (ceteris paribus), and (c) the case of $\phi = 2$ (ceteris paribus). We only investigate the case of $\gamma = 0.4$.

Table 2 summarizes the results of the onset of trade liberalization $t_1$ for each case.

Here, we only treat the case where $\gamma = 0.4$.

| | (a) | $(b)$ | $(c)$ |
|---|---|---|---|
| $t_1$ | 34.7 | 20.8 | 8.7 |

Table 2: Onset of trade liberalization

From Table 2, we find that $t_1$ in both (b) and (c) are lower than in (a). The results show that propositions 4 and 5 are realized.

Next, we calculate total welfare in autarky from 0 to $t_1$, $W^C$, and that in an economy specializing in the manufacturing sector from $t_1$, $W_A^F$, for each case. The results of $W_M^F$ and $W^C$ are summarized in Table 3.

| | $W^C$ | $W_M^F$ | $t_1$ |
|---|---|---|---|
| (a) | $-10.1$ | 103.0 | 34.7 |
| (b) | 17.0 | 160.6 | 20.8 |
| (c) | $-19.0$ | 415.8 | 8.7 |

Table 3: Onset of trade liberalization and the welfare of home country from 0 to $t_1$ and from $t_1$ to infinity

Finally, we compare $W_A^F$ with $W_M$ which is sum $W^C$ and $W_M^F$ in Table 3, and Table 4 summarizes the results.

In the benchmark case, $W_A^F$ is larger than $W_M$. Therefore, the home country should not trade with the rest of the world under (a). In the other cases, the industrialization policy should be implemented because $W_M$ is larger than $W_A^F$ because of an increase in agricultural productivity or an improvement of the labor efficiency in the public sector.

| | $W_A^F$ | $W_M$ |
|---|---|---|
| (a) | 97.6 | 92.9 |
| (b) | 146.6 | 177.5 |
| (c) | 97.6 | 396.7 |

Table 4: Total welfare $W_M$ and total welfare $W_A^F$.

In the $\gamma = 0.4$ case, a rise in agricultural productivity increases total welfare under industrialization $W_M$. On the other hand, if $\gamma = 0$ which Redding (1999) assumes, then a rise in agricultural productivity decreases the total welfare $W_M$. The reason is that a rise in agricultural productivity delays industrialization: an increase in agricultural productivity delays the onset of trade liberalization.

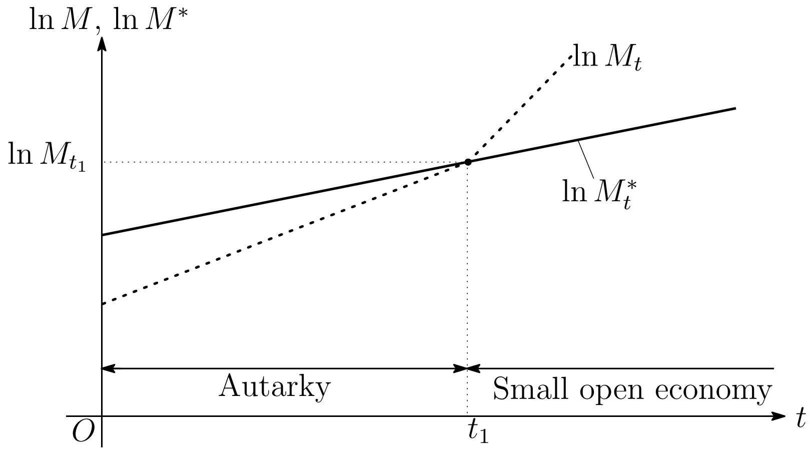


Figure 1: Transition of the manufacturing productivity

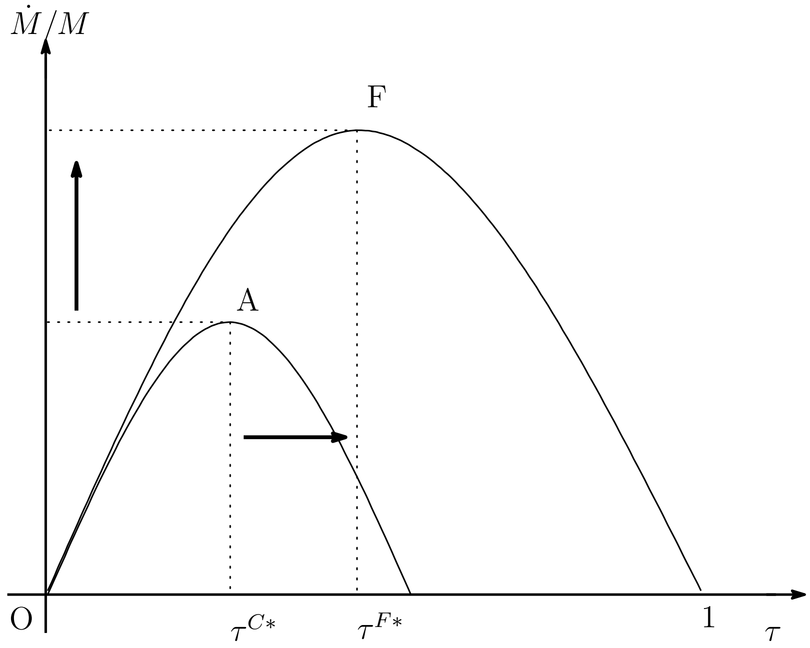


Figure 2: Growth rate of manufacturing productivity and the optimal tax rate in autarky and in a small open economy.

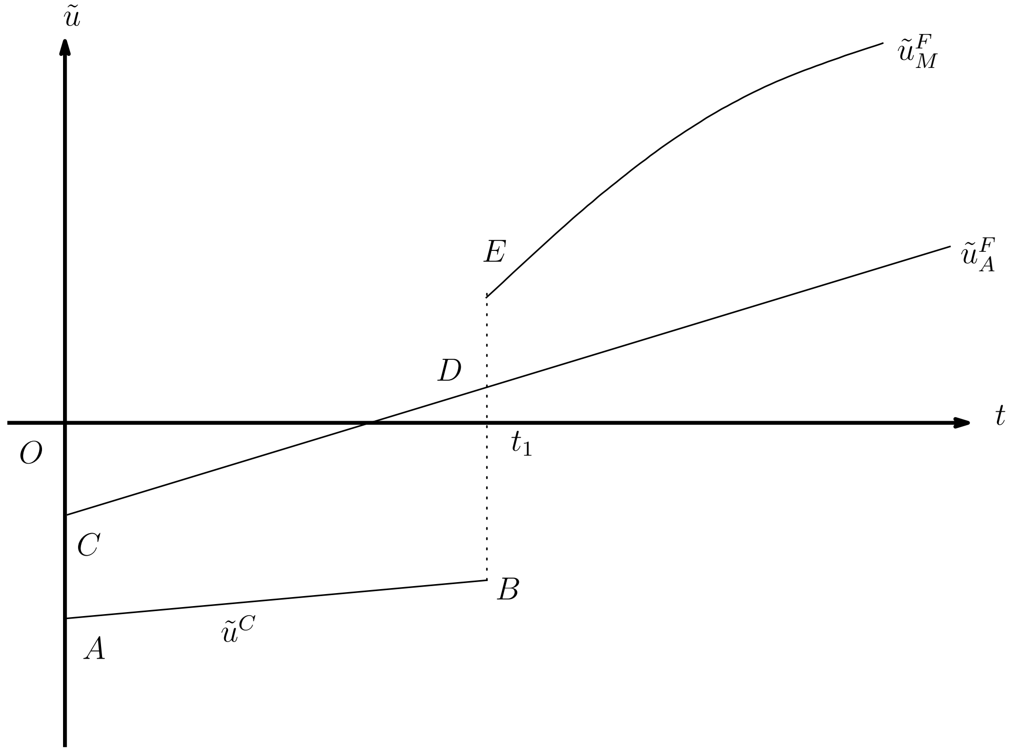


Figure 3: Transition of the indirect utility in the case of $\tilde{u}^C$, $\tilde{u}_A^F$, and $\tilde{u}_M^F$ under the condition of $(1-\tau)A^* > A$.