Foreign aid and transboundary pollution in a dynamic factor endowment model

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Abstract

Constructing a dynamic model of international trade with transboundary pollution, this paper examines the welfare effects of untied foreign aid. By allowing for the dynamic effect of foreign aid on capital and pollution accumulation, foreign has various possibilities. Two outstanding results are: depending on the conditions, (i) both the donor and recipient lose from foreign aid, i.e., aid is Pareto inferior, and (ii) both gain from it, i.e., aid is Pareto improving. These results shed light on the dynamic effect neglected in the existing literature on foreign aid.

Keywords: transboundary pollution, capital accumulation, Pareto-improvement, Pareto-impoverishment.

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1 Introduction

It has been argued that international trade and foreign aid have been two significant forces for economic growth and development of the world as a whole. In a neoclassical framework, it is normally concluded that the opening of free trade benefits all the trading countries and the recipient gains from foreign aid, while the donor loses from it.[1] Looking at the actual cases, however, this theoretical prediction has not always been observed. Then, what causes the prediction to fail?

The question raised above has brought voluminous literature which shows a possibility of losses from trade and the transfer paradox. Focusing on the transfer paradox, the violation of Warlasian stability of the world commodity market, the presence of tariffs and other trade impediments, untied aid, and the presence of the third party can potentially induce the welfare improvement for the donor and the welfare deterioration for the recipient. From another perspective, by constructing a two-country dynamic model without market distortions, Shimomura (1999) demonstrates that indeterminacy of the steady state can become a source for the paradox.

In addition to such development of the literature, there are recent works which investigate under what conditions foreign aid becomes Pareto-improving for the world. Naito (2003) shows this possibility in a static two-country model with transboundary pollution. With the aid of a dynamic two-country model, Shimomura (2006) proves that foreign aid benefits both the recipient and donor when indeterminacy is present.

This paper also explores the welfare consequences of foreign aid in a dynamic model with transboundary pollution. However, our approach has a clear deviation from Naito (2003) and Shimomura (2006) in the sense that we assume two *small open* countries so that the terms of trade effect is *a priori* abstracted. It is well-known that the terms of trade effect plays a key role for the transfer paradox and Pareto-improving foreign aid. Nevertheless, we show that the terms of trade effect is not the only source for these outcomes. Instead, we pay close attention to the dynamic effect of foreign aid on capital accumulation as well as pollution accumulation. To grasp our argument concisely,

[1] We sometimes call this recipient-enrichment and donor-impoverishment result "Samuelson's theorem", following Brakman and Marrewijk (1998).

suppose a Heckscher-Ohlin world with transboundary pollution. In this framework, we show: foreign aid increases the steady state capital stock in the donor country, which accelerates the transboundary pollution when the dirty good is capital-intensive through the Rybzcynski theorem. This pollution expansion effect has the following possibility neglected in the existing literature. Foreign aid is Pareto inferior, namely, not only the donor but also the recipient loses from it.

The plan of the paper is as follows. Section 2 lays out the basic model. Section 3 addresses the saddle point stability of the steady state. Based on these preliminary results, Section 4 considers the welfare effects of permanent foreign aid and Section 5 provides a concluding comment. Furthermore, the Appendix contains a detailed proof of the saddle point stability of the steady state.

2 The model

The model constructed here is comprised of two countries (Home and Foreign), two goods (Goods 1 and 2), and two primary factors (capital and labor). Good 1 is a consumption good and Good 2 is an investment good. Throughout this paper, we assume that both countries are so small that they take the world price as exogenously given.[2] Good 2 serves as a numeraire so that its price is normalized to unity and p denotes the world price of Good 1. The two goods are produced subject to the standard neoclassical production technologies. Then, the production side can be completely described by the GDP function:[3]

$$G(p, K, L) \equiv \max_{K_i, L_i, i=1,2} \{pF_1(K_1, L_1) + F_2(K_2, L_2) \mid K_1 + K_2 \leq K,\ L_1 + L_2 \leq L\},$$

where K and L denote the Home endowment of capital and labor, K_i and L_i, $i = 1, 2$, the inputs of capital and labor in each sector, and $F_i(\cdot)$ each sector's production function, which satisfies all the neoclassical properties including the linear homogeneity. Then,

[2] This assumption has been adopted in the existing literature, e.g., Hatzipanayotou *et al.* (2002, 2005). On the other hand, Chao and Yu (1999, 2005) consider a similar model which explicitly incorporates the terms of trade effect.

[3] Any interested reader in the detailed properties of the GDP function is referred to Dixit and Norman (1980), Woodland (1982), and Wong (1995).

the equilibrium output of Good 1 equals the partial derivative of $G(\cdot)$ with respect to p, which is denoted by $G_p(p, K, L)$.

Concerning the GDP function, it is instructive to make a brief comment here since, while we have given a general definition of the GDP function above, we shall specify it in the subsequent sections to sharpen the analysis. Concretely, we employ two types of the GDP function in this paper. The first is a standard Heckscher-Ohlin type. As long as the two goods are produced from both factors and the diversification condition is satisfied, the factor prices becomes a function of only the commodity price, namely, $r = r(p)$ and $w = w(p)$, where r and w respectively give the capital rental rate and wage rate. Then, the GDP function takes the form of

$$G(p, K, L) \equiv r(p)K + w(p)L, \tag{1}$$

and the equilibrium output of Good 1 is equal to $r'(p)K + w'(p)L$. The sign of $r'(\cdot)$ and $w'(\cdot)$ depends on whether Good 1 is capital-intensive from the Stolper-Samuelson Theorem.

The second type of the GDP function to be considered is obtained from the assumption that only Good 1 is produced from two factors and one unit of labor produces one unit of Good 2. Under this circumstance, the GDP function becomes

$$G(p, K, L) \equiv r(p)K + L, \quad r'(\cdot) > 0, \quad r''(\cdot) > 0. \tag{2}$$

Hence, the output of Good 1 is $r'(p)K$. These convenient properties of the specified GDP functions are made use of as the argument proceeds.

The production of Good 1 causes pollution and its effect is transboundary.[4] Without loss of generality, we assume that one unit of Good 1 produced in Home generates the same unit of domestic pollution and one unit of the Foreign production contributes to $\alpha > 0$ units of pollution in Home. Thus, the total amount of pollution in Home at each instant is

$$G_p(p, K, L) + \alpha G_p^*(p, K^*, L^*).$$

We are now ready to set up our dynamic general equilibrium model. Following Shimomura (2006), we assume that only the representative consumer in Home faces an

[4]Naito (2003) also shares the same presumption.

intertemporal utility maximization problem, while the Foreign consumer behaves as a static utility maximizer. Then, the Home consumer's problem is formulated as

$$\begin{aligned}
&\max && \int_0^\infty e^{-\rho t}\left[\ln C - v(Z)\right] dt, \quad v'(\cdot) > 0, \quad v''(\cdot) > 0 \\
&\text{subject to} && \dot{K} = G(p,K,L) - pC - \delta K - T \\
& && \dot{Z} = G_p(p,K,L) + \alpha G_p^*(p,K^*,L^*) - \gamma Z, \quad \delta,\gamma \in (0,1),
\end{aligned}$$

where C and Z are respectively the consumption of Good 1 and the pollution stock, $T > 0$ the international transfer from Home to Foreign, and δ and γ the depreciation rate of capital and the pollution stock.

In order to solve this problem, let us set up the current-value Hamiltonian:

$$H \equiv \ln C - v(Z) + \lambda[G(p,K,L) - pC - \delta K - T] + \mu[G_p(p,K,L) + \alpha G_p^*(p,K^*,L^*) - \gamma Z].$$

where λ and μ are respectively the co-state variables associated with Home's capital stock, K, and its pollution stock, Z. Then, the optimality conditions are derived as follows:

$$\begin{aligned}
\frac{1}{C} &= \lambda p \quad \Longrightarrow \quad C = \frac{1}{\lambda p} \\
\dot{K} &= G(p,K,L) - \frac{1}{\lambda} - \delta K - T && (3)\\
\dot{Z} &= G_p(p,K,L) + \alpha G_p^*(p,K^*,L^*) - \gamma Z && (4)\\
\dot{\lambda} &= \lambda[\rho + \delta - r(p)] - \mu r'(p) && (5)\\
\dot{\mu} &= \mu(\rho+\gamma) + v'(Z) && (6)\\
0 &= \lim_{t\to\infty} e^{-\rho t}\lambda K = \lim_{t\to\infty} e^{-\rho t}\mu Z. && (7)
\end{aligned}$$

Note that (5) is obtained by the use of $G_K(p,K,L) = r(p)$ from the foregoing restriction on the GDP function. Four equations consisting of (3)-(6) determine four variables, e.g., K, Z, λ and μ.

This section is closed by describing the Foreign consumer's behavior. The assumption that the Foreign consumer solves a static problem of utility maximization makes its indirect utility function be given by

$$\begin{aligned}
& u^*(C^*) - v^*(Z^*) \\
= \;& u^*\left(\frac{G^*(p,K^*,L^*) + T}{p}\right) - v^*\left(\alpha^* G_p(p,K,L) + G_p^*(p,K^*,L^*)\right), && (8)
\end{aligned}$$

where $u^*(\cdot)$ and $v^*(\cdot)$ stand for the utility/disutility function of Foreign. The equality above follows from the 'static' budget constraint:

$$pC^* = G^*(p, K^*, L^*) + T,$$

and the definition of the ambient pollution level in Foreign country:

$$Z^* = \alpha^* G_p(p, K, L) + G_p^*(p, K^*, L^*).$$

Thus, we assume that Foreign regards this pollution issue simply as flow pollution in which the scale of environmental damages is determined by the amount of current emission amounts alone. We can interpret such a case as the one where the environment is in such a healthy state there that its "assimilative capacity" can prevent the pollutant from accumulating in its environmental body. Alternatively, we can also think of this setup as a case where this nation behaves rather myopically in the sense that it completely ignores the possible future consequences of the current emissions.

This completes the description of the world economy in consideration. From the next section, we shall make use of this model to investigate the welfare effects of foreign aid in a dynamic context.

3 Stability of the steady state

Before conducting the main task of this paper, this section examines the stability property of the steady state in our model. Since only Home faces a dynamic optimization problem, the present dynamic general equilibrium model is comprised of four equations (3)-(6). The characteristic equation associated with the system can be obtained as

$$\begin{aligned} & \begin{vmatrix} r-\delta-x & 0 & \frac{1}{\lambda^2} & 0 \\ r' & -\gamma-x & 0 & 0 \\ 0 & 0 & \rho+\delta-r-x & -r' \\ 0 & v'' & 0 & \rho+\gamma-x \end{vmatrix} \\ = & -\frac{1}{\lambda^2}\left[\lambda^2(\gamma+x)(\rho+\gamma-x)(r-\delta-x)(\rho+\delta-r-x)-(r')^2 v''\right] \\ \equiv & -\frac{1}{\lambda^2}\Gamma(x)=0, \end{aligned} \tag{9}$$

where x denotes the eigenvalue of the Jacobian matrix evaluated at the steady state such that $\dot{K} = \dot{Z} = \dot{\lambda} = \dot{\mu} = 0$.

Based on the characteristic equation of (9), we can prove the saddle point stability of the steady state. This statement is formally summarized in:

Proposition 1. *The steady state of the present dynamic general equilibrium model is saddle point stable if $\rho + \delta - r < 0$.*

Proof. See Appendix. **Q. E. D.**

4 Welfare effects of foreign aid

Having confirmed the saddle point stability of the steady state, we are now in a position to do a comparative statics analysis in the steady state and evaluate the effects of a permanent increasing in the amount of foreign aid.

Totally differentiating (3)-(6) with respect to the endogenous variables and T yields

$$\begin{bmatrix} r-\delta & 0 & \frac{1}{\lambda^2} & 0 \\ r' & -\gamma & 0 & 0 \\ 0 & 0 & \rho+\delta-r & -r' \\ 0 & v'' & 0 & \rho+\gamma \end{bmatrix} \begin{bmatrix} dK \\ dZ \\ d\lambda \\ d\mu \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} dT. \tag{10}$$

Letting the determinant of the coefficient matrix be denoted by Δ, it is given by

$$\begin{aligned} \Delta &\equiv \begin{vmatrix} r-\delta & 0 & \frac{1}{\lambda^2} & 0 \\ r' & -\gamma & 0 & 0 \\ 0 & 0 & \rho+\delta-r & -r' \\ 0 & v'' & 0 & \rho+\gamma \end{vmatrix} \\ &= -\frac{1}{\lambda^2}\left[\lambda^2\gamma(\rho+\gamma)(r-\delta)(\rho+\delta-r) - (r')^2 v''\right] > 0, \end{aligned}$$

under the saddle point stability. By resorting to the standard procedure, the effects of a small change in T on K, Z and λ are respectively derived as follows:

$$\frac{dK}{dT} = \frac{-\gamma(\rho+\gamma)(\rho+\delta-r)}{\Delta} > 0 \tag{11}$$

$$\frac{dZ}{dT} = \frac{-r'(\rho+\delta-r)(\rho+\gamma)}{\Delta} \tag{12}$$

$$\begin{aligned}\frac{d\lambda}{dT} &= \frac{(r')^2 v''}{\Delta} > 0 \qquad (13)\\ \frac{d\mu}{dT} &= \frac{r'v''(\rho+\delta-r)}{\Delta}.\end{aligned}$$

These comparative statics results have clear interpretations. From (11), foreign aid enhances capital accumulation in the donor country. This is because the permanent provision of foreign aid reduces Home's disposable income in each point of time, which decreases the consumption as well. Thus, saving and capital accumulation are enhanced, from which the capital stock at the steady state increases. This, in turn, favorably affects its welfare from (13) since λ represents the marginal utility of K, namely, the shadow price of K and the steady state capital increases as a result of aid. A similar argument applies to (12). The effect of aid on Z and its shadow price μ depends on the factor intensity ranking between the goods.

In the first benchmark case of the Heckscher-Ohlin technology, $dZ/dT > 0$ if and only if Good 1 is capital-intensive, i.e., $r' > 0$. On the other hand, in the second example of (2), $dZ/dT > 0$ necessarily follows from $r' > 0$. We can intuitively understand this by recalling the Rybzcynski type relationship in a factor endowment model. That is, (11) convinces us that foreign aid increases the steady state capital stock. Then, the output of Good 1 also increases under $r' > 0$.

The comparative statics results above are now utilized in order to assess the welfare effects of foreign aid in the steady state. For this purpose, let us define each country's welfare as a function of T. The felicity of Home in the steady state is

$$\begin{aligned} & \ln C - v(Z) \\ = \; & \ln\left(\frac{1}{\lambda p}\right) - v(Z) \\ = \; & -\ln\lambda - v(Z) + constant \\ \equiv \; & U(\lambda(T), Z(T)). \qquad (14)\end{aligned}$$

The Foreign counterpart is given by (8):

$$u^*(C^*) - v^*(Z^*)$$

$$
\begin{aligned}
&= u^*\left(\frac{G^*(p,K^*,L^*)+T}{p}\right) - v^*\left(\alpha^* G_p(p,K,L) + G^*(p,K^*,L^*)\right) \\
&\equiv U^*(T, K(T)). \qquad (15)
\end{aligned}
$$

Accordingly, a permanent increase in foreign aid affects each country's welfare as follows:

$$
\begin{aligned}
\frac{dU}{dT} &= U_\lambda \frac{d\lambda}{dT} + U_Z \frac{dZ}{dT} \\
&= \frac{-1}{\lambda}\frac{d\lambda}{dT} - v'\frac{dZ}{dT} \\
&= \frac{-1}{\lambda}\frac{(r')^2 v''}{\Delta} + v'\frac{r'(\rho+\delta-r)(\rho+\gamma)}{\Delta}, \qquad (16)
\end{aligned}
$$

and

$$
\begin{aligned}
\frac{dU^*}{dT} &\equiv U_T^* + U_K^* \frac{dK}{dT} \\
&= u^{*\prime}\frac{1}{p} + v^{*\prime}\alpha^* r' \frac{\gamma(\rho+\gamma)(\rho+\delta-r)}{\Delta}. \qquad (17)
\end{aligned}
$$

First of all, (16) implies that we can decompose the impact of foreign aid on Home's welfare into two terms. The first term in (16), which captures the direct income effect, is always negative, whereas the second term can be either positive or negative, depending on the factor intensity ranking between the two goods. Especially, it is negative (resp. positive) if and only if $r' > 0$ (resp. $r' < 0$). The intuition behind this result is quite simple. As mentioned above, foreign aid increases the steady state pollution under $r' > 0$ due to the Rybczynski effect. This enhances the negative externality due to the pollution and makes the second term come out negative. The parallel applies to the case with $r' < 0$.[5]

In a similar way, (17) indicates that foreign aid has two distinguishable effects on Foreign's welfare. The first term in (17) is a direct income effect, which is necessarily positive. On the other hand, the second term is negative (resp. positive) if and only if

[5] Note that the second term never appears in a static model since $Z = G_p(p,K,L) + \alpha G_p^*(p,K^*,L^*)$ is not affected by the change in T.

$r' > 0$ (resp. $r' < 0$). The intuition goes as follows. An increase in T induces the steady state value of K to go up because of (11). This increase in K in turn contributes to the rise in Z if Good 1 is capital-intensive and hence its effect on the Foreign welfare is detrimental.

Based on the results derived above, we can prove two propositions as regards the welfare implications of foreign aid. The first is:

Proposition 2. *Foreign aid is Pareto-improving under $r' < 0$ and $v'' \approx 0$.*

Proof. Under $r' < 0$, Foreign gains from the transfer regardless of the factor intensity ranking. Moreover, an increase in T decreases Z under $r' < 0$, which favorably affects the Home welfare. Hence, this positive effect dominates and Home also gains from giving foreign aid under $v'' \approx 0$. **Q. E. D.**

While Proposition 2 makes an affirmative assessment on foreign aid in the presence of transboundary pollution and dynamics, completely the opposite conclusion is also possible. That is:

Proposition 3. *Foreign aid is Pareto-inferior under $r' > 0$ and if α^* is sufficiently large.*

Proof. It is trivial that Home loses from the transfer since both the direct effect and the effect through the increased pollution have a negative impact on U. Furthermore, if α^* is sufficiently large, the negative effect dominates in the overall impact on the Foreign welfare. Hence, both countries lose from the international transfer in this case. **Q. E. D.**

Remark 1. While this paper has focused on the theoretical possibility of financial aid's being Pareto-inferior as well as Pareto-improving, Samuelson's Theorem and the transfer paradox are also possible in our model.[6] For example, suppose $r' < 0$, i.e., Good 1 is

[6]Samuelson's Theorem is referred to the result that aid has a negative effect on the donor's welfare and positive effect on the recipient's welfare. This terminology is borrowed from Brakman and Marrewijk (1998).

labor-intensive. Then, Foreign necessarily gains from aid but Home possibly loses from it. In particular, this is likely to occur if v'' is sufficiently large. In an analogous fashion, the transfer paradox, namely, the donor-enrichment and recipient-impoverishment transfer tends to be possible if $r' > 0$ and α is sufficiently large.

Remark 2. We should now differentiate our result from those of the predecessors. As we have repeatedly mentioned above, our result is not obtainable in a static model. If we reduce our model into a static one, Samuelson's Theorem always holds. This is because we have assumed way the terms-of-trade effect of foreign aid. Hence, the presence of transboundary pollution plays no important role in such a model.[7]

On the other hand, Shimomura (2006) proves that Pareto-improving foreign aid is theoretically possible in a dynamic model with the terms-of-trade effects. In his argument, indeterminacy of the steady state plays an decisive role in obtaining the outcome of the Pareto-improving transfer. However, we have shown that a Pareto-improvement is possible even if the steady state is saddle point stable.

5 Concluding remarks

Highlighting the environmental interrelationship of the modern world economy, this paper has identified the potential welfare effects of foreign aid in a dynamic model. We have shown that foreign aid can have drastically different implications via the channels of capital and pollutant accumulations. Under certain conditions, foreign aid immiserizes both the donor and recipient by worsening the transboundary pollution issue. In contrast, it can be Pareto-improving in the sense that both countries gain under other sets of conditions. We have seen in this article that the factor intensity ranking and the degree of negative externalities from the pollution play important roles in determining the welfare implications of foreign aid.

Our analysis complements the recent contribution made by Hu, Nishimura and Shimomura (2006) which explores the dynamic effect of capital accumulation on the comparative

[7]Note that the same does not apply to another model. Naito (2003) shows the Pareto-improving transfer in the context of transboundary pollution.

statics results addressed by Jones (1971). In this sense, it is inappropriate to conjecture that the static results carry over to dynamic models even if the analysis is confined to the steady state.

In this article, we deliberately ignored the terms of trade effect of foreign aid so as to facilitate and sharpen the analysis, following Hatzipanayotou *et al.* (2002, 2005). However, this simplifying assumption could be unacceptable depending on the situations. It is left to our future study to incorporate the terms of trade effect although the model becomes immensely complicated.

Appendix: proof of Proposition 1

What we shall show below is that $\Gamma(x)$ in the characteristic equation (9) has two negative and two positive eigenvalues. To this end, let us expand $\Gamma(x)$ as follows:

$$\begin{aligned}
\Gamma(x) &\equiv \lambda^2(\gamma+x)(\rho+\gamma-x)(r-\delta-x)(\rho+\delta-r-x) - (r')^2 v'' \\
&= -\lambda^2[x^2-\rho x-\gamma(\rho+\gamma)][x^2-\rho x+(r-\delta)(\rho+\delta-r)] - (r')^2 v'' \\
&\equiv -\lambda^2 X^2 - \lambda^2[(r-\delta)(\rho+\delta-r)-\gamma(\rho+\gamma)]X + \lambda^2\gamma(\rho+\gamma)(r-\delta)(\rho+\delta-r) \\
&\quad - (r')^2 v'' \\
&= 0,
\end{aligned}$$

where $X \equiv x^2 - \rho x = x(x-\rho)$. Under $\rho+\delta-r<0$, the above quadratic equation of X has two positive solutions. From the definition of X, this implies that there can be three possibilities such that (i) all values of x are negative, (ii) all values of x are larger than ρ, and (iii) two values of x are negative and the other two are larger than ρ. The rest of our tack is to show that only (iii) survives.

To see this, take another careful look at the characteristic equation:

$$\begin{aligned}
\Gamma(x) &= -\lambda^2 x^2(x-\rho)^2 - \lambda^2[(r-\delta)(\rho+\delta-r)-\gamma(\rho+\gamma)]x(x-\rho) \\
&\quad +\lambda^2\gamma(\rho+\gamma)(r-\delta)(\rho+\delta-r) - (r')^2 v'' \\
&= 0.
\end{aligned}$$

It is easily seen that $\Gamma(\rho) = \Gamma(0) = \lambda^2\gamma(\rho+\gamma)(r-\delta)(\rho+\delta-r) - (r')^2 v'' < 0$. Relating this fact to the foregoing arguments, the locus of $\Gamma(x)=0$ is drawn as in Figure 1. The figure convinces us that there are two positive and two negative roots associated with $\Gamma(x) = 0$. This means that the steady state exhibits saddle point stability because we have two state variables, K and Z, and two co-state variables, λ and μ. This establishes Proposition 1.

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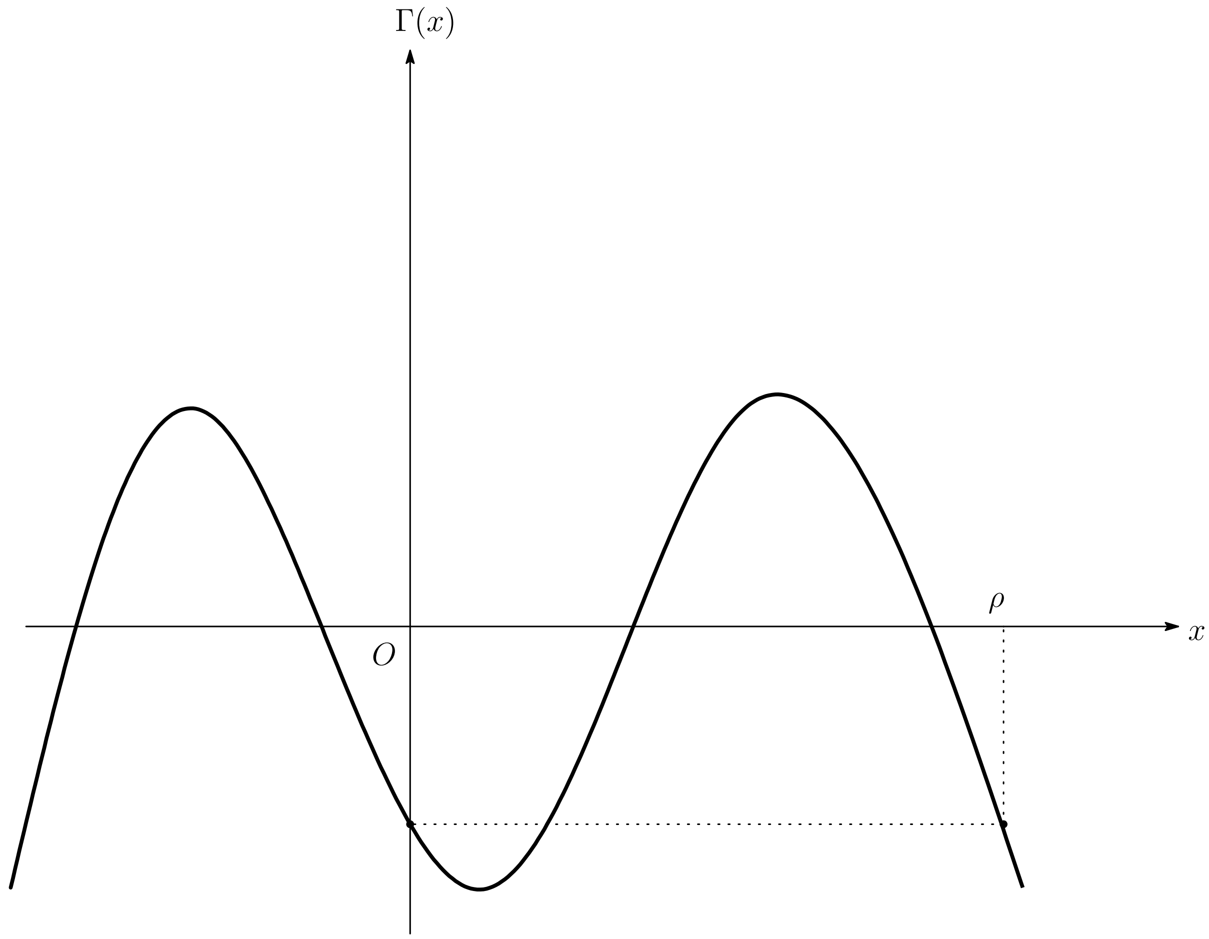

Figure 1: The characteristic equation: $\Gamma(x) = 0$