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ANALYSIS

Trade and the governance of ecosystem services

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ABSTRACT

We work with a basic general equilibrium model of an economy with an industrial good and a rural good. Industrial good production results in pollution that affects the provision of ecosystem services and thereby the production of the rural good. The assignment of ecosystem rights to the industrial polluters or to the rural pollutees results in differential transaction costs that affect production possibilities between the two goods. Ecosystem rights are assigned to maximize social welfare. Over time, technological change and differences in income superiority affect the choice of the assignment of rights. Opening to trade affects the choice of the assignment of ecosystem rights depending on the nature of technological change, but the relative income superiority of goods no longer affects the assignment of ecosystem rights in a small economy. Thus, among other findings, we demonstrate that the phenomena known as the environmental Kuznets curve does not hold for the protection of ecosystem services in production, or production externalities generally, because trade separates consumption from production.

The environmental economic literature on trade and the environment emphasizes how trade might affect the governance of consumption externalities in the urban environments in which most people live. Because health and environmental amenities are sufficiently superior goods, these environmental qualities will eventually be protected as income increases through trade and development. This emphasis on a particular type of consumption externalities provides the primary support for what has become a near universal belief in the environmental Kuznets curve. Ecological economists, on the other hand, have long stressed how nature's services support agriculture, forestry, and fisheries in largely rural areas (Jansson et al., 1994). Interest has increased dramatically in the services, for example, of soil microbes that sustain soil fertility, natural predators that control agricultural and forest pests, and of marshlands that process waste. The Millennium Ecosystem Assessment (2005) focuses primarily on problems associated with the decline of ecosystem services that contribute to material production. Early in the environment and trade debate, ecological economists stressed how globalization might affect the protection of ecosystem services (Folke et al., 1994). Our formal analysis of how trade affects the governance of ecosystem services indicate that the relationship between trade and ecosystem service governance is complicated, and the argument that the gains from trade will lead to greater protection does not necessarily hold for production externalities. The arguments for an environmental Kuznets curve have been overstated through their focus on sufficiently income superior, consumption externalities.

Primary production sectors depend on the services of nature. Since this has long been understood, numerous institutions were established to encourage soil conservation, protect fresh and coastal waters, and otherwise manage nature to assure the economic productivity of rural areas. Some institutions, like priorities to water, trace back to rights long given rural producers; others, like soil protection, trace to

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the rise of nature conservation movements that arose with rapid industrialization and urbanization during the 19th century. The term "ecosystem services," however, arose during the last quarter of the 20th century as ecologists and economists joined their understandings of ecological and economic systems to re-portray our relationship to nature in the now dominant language of economics. We use the term "ecosystem service governance" to refer to how the combination of pollution and land use controls, both urban and rural, affect the protection, or not, of ecosystem services (Brookes et al., 2002). We explore how technology, relative income superiority, and trade affect the choice of governance of ecosystem services. We provide a positive analysis of how countries are likely to behave if they myopically optimize in response to changing, short-run conditions.

We start in Section 1 with a very brief review of the literature on trade, transaction costs, and environmental governance. In Section 2 we present our simple general equilibrium model and the findings established earlier (Norgaard and Hall, 1974) for a country not engaged in trade. These are our base scenarios illustrating how technological change and social preferences favor, or not, the protection of ecosystem services before trade. In Section 3 we look at how opening up to trade affects the choice of ecosystem governance for a small country. In Section 4, we extend the analysis, though under more restrictive conditions, for a country whose trade affects world prices. Our conclusions are summarized and interpreted in the light of the findings of others in Section 5.

1. Relation of our analysis to the literature

Where there are distortions in the choice between market and environmental goods, a society may be better off constraining trade (reviewed in Copeland and Taylor, 2004). Our own model complements the existing literature in three ways.

First, while the vast majority of the literature stresses how ecosystem services affect our enjoyment of health and amenities, *i.e.* consumption externalities, our contribution stresses the role of ecosystem services in production, or production externalities. When health and amenities are sufficiently superior goods, society will have an incentive to protect them as income increases through trade. However, for ecosystem services that contribute to the production of a tradable good, trade provides the opportunity to purchase or sell them from abroad, and this affects the gains from protecting ecosystem services domestically. The contribution of the income superiority of environmental amenities to stronger environmental governance is over emphasized in the current literature because the role of ecosystem services in the production of tradable goods has been little explored. Bulte and Van Soest (2001) make a similar point without formally exploring the implications for governance.

Second, our analysis incorporates transaction costs. While some types of access to ecosystem services can be divided and assigned as private property, it is inherently more difficult to divide and assign rights to clean water, migrating fish, and biological controls of agricultural pests than to divide and assign labor and capital. The more indivisible and complexly embedded in ecological processes, the larger are the transaction costs associated with monitoring and interpreting the condition of the ecosystem delivering services, determining who is affecting it how, and enforcing rights (Norgaard and Liu, 2007). Some ingenious environmental markets have been created, all characterized by a few points at which monitoring is relatively easy, but they still require public monitoring and enforcement because interests beyond the parties to the market transaction are at stake. For example, transaction costs continue to thwart the implementation of water markets in California (Haddad, 2000; Carey et al., 2002). Complexity, indivisibility, and thereby higher transaction costs are the essence of environmental problems. Yet, with few exceptions (for example, Stavins, 1995; Cason and Gangadharan, 2003), there is a tradition of not including transaction costs in environmental economic models that has been carried over into the trade and environment literature.

Third, our model complements the existing literature by looking at how governance changes under first-best conditions. Most of the trade and environment literature falls into the category of second-best arguments wherein "surprising" outcomes arise from a first-best perspective. However, second-best arguments beg first-best solutions (Krugman, 1997). The models, however, typically imply first-best solutions that do not actually exist because transaction costs have not been included. Brander and Taylor (1998:198-9) provide a clear example:

> Rather obviously, the "first-best" policy would be to solve the open access market failure by establishing some system of appropriate property rights or by using an appropriate harvest tax. *By hypothesis, however, this is either impossible or very costly*, leading to a search for alternative policy instruments. (our underlining)

Had the very costly transactions of the "first-best" policy been included in their model, the policy would have been interior to the possibility frontier and obviously not "first-best" at all. While some solutions are implicitly excluded by transaction costs, the solutions explored in most of the literature are presumed not to have transaction costs.

Not explicitly addressing transaction costs yet implicitly including them in analytical models leads to other contradictions. For example, Chichilnisky (1994) constructed a two-country general equilibrium model of trade to investigate the role of property rights on primary resource exploitation. Her model posits a North country with private property rights where externalities are fully internalized (*i.e.* implying no transaction costs) and a South country with open access to natural resources (implying transaction costs prevent common management) such that private harvesters do not bear the full costs of extraction. The implicit asymmetry in the treatment of transaction costs leads to overproduction in the South and overconsumption in the North relative to the situation where the South also has private property rights and externalities are internalized. Our model differs from that of Chichilnisky in that we have an externality in each country, treat transaction costs the same across countries, and allow each country to internalize its externality to the point where the marginal gains of internalization equal the marginal transaction costs of internalization. The interaction of transaction costs and the assignment of pollution rights on production, consumption, and welfare is a unique contribution of our model.

2. A general equilibrium model with transaction costs of ecosystem governance

Ronald Coase (1937) identified the importance of transaction costs to economic organization while also providing the article (1960) that has confused environmental economists to this day. Alan Randall (1972) provided a clear explanation of the misinterpretation of Ronald Coase's famous article on social cost (1960). Coase himself denied the "Coase Theorem" in his Nobel Address (1991). Yet to this day, environmental economists ignore transaction costs and the assignment of property rights, not infrequently citing Coase. Ezra Mishan (1971) asked why there was an onslaught of legislation protecting the environment during the 1960s. This shift in environmental rights toward consumers and future generations was clear evidence of an environmental Kuznets curve. Norgaard and Hall (1974) proffered an economic explanation for the shift to stronger protection of environmental amenities, showing that this rapid change, perhaps discontinuity, in governance could have been driven by technological change favoring manufactured goods over environmental amenities. Yet Bulte and Van Soest (2001) note: "While there is some ad hoc reasoning regarding the mechanisms driving the EKC, should it exist, formal modeling in this field is scarce." Norgaard and Hall had provided a formal model that could explain the environmental Kuznets curve, but economists simply continued to ignore it, as they have to this day. The model is not easy to use, but like any formal model, it also helps identify the conditions when an EKC would not arise, a discussion notably missing in the mainstream literature on environment and development.

We have adopted the Norgaard and Hall model to fit the conditions of tradable goods. Consider an economy that produces two goods. Let's call them industrial goods and rural goods, **X** and **Y** respectively. Industrial goods should be interpreted broadly for they could include urban industry as well as rural industry, "industrial" agricultural practices, as well as other activities like transportation. The important thing is that industrial goods are relatively less dependent on ecosystem services than rural goods. The production of industrial goods entails externalities that affect the availability of ecosystem services for the production of rural goods while the production processes of rural goods do not have analogous non-market impacts on the production of industrial goods. Efficient production requires the internalization of the externalities. Thus the production possibility frontier in our model, unlike the vast majority in the literature, includes the costs of internalizing externalities, *i.e.* the costs of monitoring, bargaining, and enforcement inherent in environmental governance.

Now, imagine a world in which there are no transaction costs to resolving externalities. Then the production possibility curve for efficient combinations of industrial and rural goods, including the costs of controlling the loss of ecosystem services, are defined by the production possibility curve labeled $PP_{T=0}$ in Fig. 1.[1] Since transaction costs are zero (and distributive effects are presumed to be offset by the use of a social indifference curve), this is the production possibility curve regardless of whether producers of industrial goods initially hold rights to affect the level of ecosystem services used by rural producers or whether the rural producers have rights to ecosystem services at their "natural" level.[2]

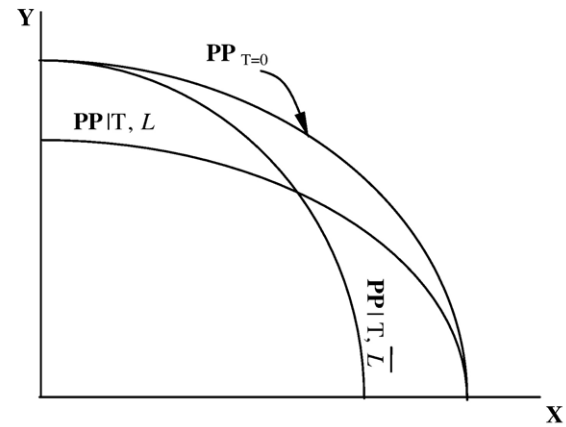

Fig. 1 – Production possibility frontiers.

When there are transaction costs, two distinct production possibility curves emerge: one where industrial producers have rights to affect the level of ecosystem services used by rural producers and one where rural producers have rights to ecosystem services undiminished by industrial producers. For the first case, rural producers must purchase rights in order to reduce the externalities to rural production. Following Mishan (1971), Randall (1972), and Norgaard and Hall (1974), we refer to this as *L* law. In the second case, rural producers hold all of the rights and industrial producers must purchase rights from rural producers in order to engage in production. We refer to this as $\bar{L}$ law. We noted in the introduction the complex historical development of environmental law and the way the law typically evolves on the basis of precedents. This means that what we are simply referring to as the "rights" to affect or to have access to ecosystem services are by no means explicit rights but rather implied or potentially inferable in a myriad of institutions. This ambiguity means that the term $\bar{L}$ really

[1] As in most economic analyses, we are assuming away the possible complications of non-convexity in our possibility frontier (Baumol and Bradford, 1972; Dasgupta and Mäler, 2003).

[2] The distributive effects between the industries can be important over time. Dynamic models of pollution externality resolution show that the returns to capital and other factors of production in the polluting industry are higher if the polluting industry holds the right as compared to when it does not. This leads to the entry of firms and a higher level of production of the polluting good over time, partly through entry of polluting and exit of non-polluting firms (elaborated in Hanley, Shogren, and White, 1997, pages 73–75). For simplicity in our analysis, we are assuming these distributive effects are resolved in the process of reaching consensus on a social indifference curve.

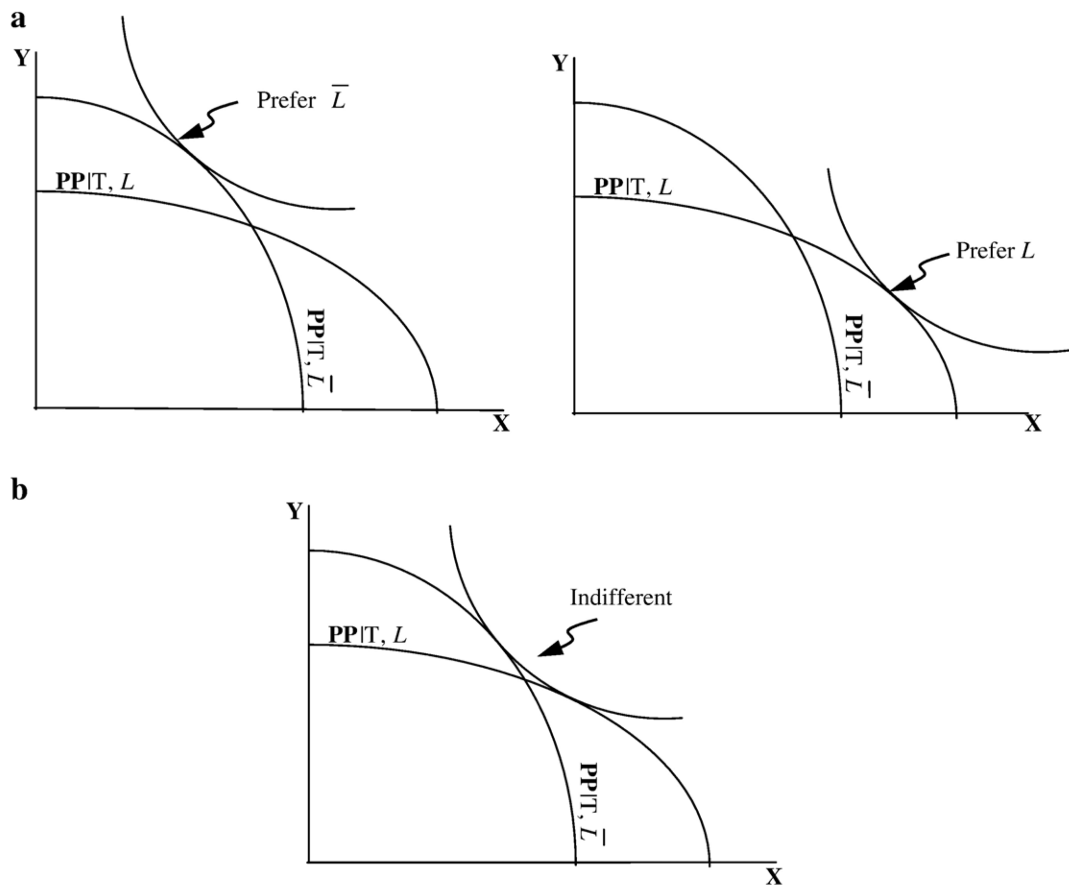

Fig. 2 – a. Social indifference curves determine choice of governance. b. A society indifferent between L and $\overline{L}$ law might consume different mixes of goods.

refers to environmental governance being strongly directed to the protection of ecosystem services.

The labor and capital expended in the transactions of monitoring, bargaining, and enforcement could have been used to produce goods. Thus the production possibility curves for goods with transaction costs will be interior to the production possibility curve without transaction costs. Now consider the situation where only industrial goods are produced. Under L law where industrial producers hold the right, rural producers do not have to purchase rights from industrial producers since rural production is zero. Clearly, at this point, there are no transaction costs. In short, under L law, the production possibility curve with transaction costs is at the same point as the production possibility curve without transaction costs when only manufactured goods are produced. As more rural goods and fewer manufactured goods are produced, however, it is efficient for rural producers to purchase more and more of the rights. We argue that the costs of transacting increase, in terms of goods that could have been produced, as more rights are purchased because of increasing difficulties of reaching, monitoring, and enforcing exchange agreements as more and more rights are exchanged. Thus in Fig. 1 the production possibility curve $\mathbf{PP}_{T,L}$ (where T designates the existence of transaction costs and L that the industrial manufacturers hold the rights), increasingly diverges from $\mathbf{PP}_{T=0}$ as fewer manufactured goods and more rural goods are produced.[3] For the same reasons, under $\overline{L}$ law when the rural producers hold the right to ecosystem services and manufacturers must purchase rights from rural producers to degrade ecosystem services, the production possibility curves with and without transaction costs are at the same point when only rural goods are produced and moves inward as more industrial goods are produced. We can now dispense with the transaction costless frontier $\mathbf{PP}_{T=0}$.

We then invoke social indifference curves to determine whether society is better off under L or $\overline{L}$ law.[4] In Fig. 2a, we

[3] Some readers have been troubled that we attribute transaction costs at the end point of the curve where only rural goods are produced and the production of industrial goods is no longer causing externalities. How can there be transaction costs if there are no longer externalities? The answer is that there are no longer externalities because of the transactions entailed in the purchase of all of the rights and enforcement to assure that no producers of X actually produce.

[4] Neither the presumption of social indifference curves nor imagining a representative agent avoids the myriad distributional issues of real economies or the geopolitical debate we are trying to address. The senior author has a modest preference for social indifference curves because they remind us that we are addressing social choice.

illustrate how the choice of ecosystem service governance can be affected by whether a society has a stronger preference for manufactured or rural goods.

In Fig. 2b, society is indifferent between the two general states of ecosystem law, illustrating how when a choice between them exists, the state of the law itself can have a significant effect on the mix of goods produced as well as the level of ecosystem service protection. If society chooses the "polluter-pays" principle, *i.e.* giving rights to ecosystem service protection to rural producers, for example, fewer industrial goods, less ecosystem services reduction, and more rural goods are produced than under "pollutee-pays" ecosystem governance. Not only are transaction costs clearly visible in terms of reductions in production, but the production differences clearly affect one industry more than the other. Thus L law favors industry and *vice versa*.

This provides a simple illustration of how the assignment of rights affects the efficient market solution when transaction costs are included in the analysis. For this reason, we refer to the two types of ecosystem governance with respect to how each "favors" different industries. Similarly, we also refer to $\bar{L}$ law as stronger ecosystem governance because it favors the rural sector that is hurt by the externalities of industrial production by providing stronger control of the externalities.

In our two-period analysis (period 1: $T=0$ and period 2: $T=1$), both the shape of production possibility frontiers and expansion path of indifference curves can be changed by exogenous forces. Fig. 3a shows the case where technological change happening between periods 0 and 1 favors good X, resulting in a relatively larger increase of X goods being produced (Definition 7 in Appendix A). Fig. 3b shows how the preference change with the rising income may direct the income expansion path to favor Y goods between the periods 1 and 2 (Definition 9 in Appendix A). Hereafter we refer to a preference change such as that illustrated in Fig. 3b as the Y good being the "relatively superior" good.[5]

Comparing environmental amenities and manufactured goods, Norgaard and Hall (1974) demonstrated plausible phenomena for a closed economy leading to what we now call the environmental Kuznets curve. If society starts with manufacturers having the right to pollute (L law), the environmental amenity manifests itself as a relatively superior good) and economic growth is driven by a neutral expansion of inputs or technological change for manufactured goods and amenities, then society will eventually prefer $\bar{L}$ law and transfer the pollution rights to the pollutees. Central to Norgaard and Hall, however, was the more difficult argument with respect to how differences in technological change between the industries affect environmental governance in a closed economy. The assumptions, underlying equations of the model, and key theorems are provided in Appendix A.

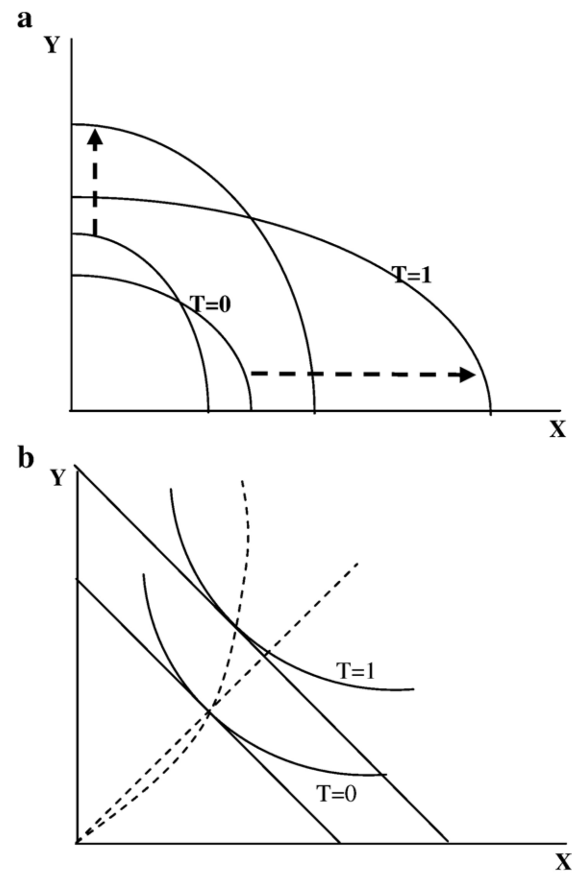

Fig. 3 – a. Technological change favors good X. b. Relative income superiority of Good Y_t.

There is an intuitive interpretation for these results in Norgaard and Hall. From Fig. 1 it can be seen that the transaction costs are effectively borne by the industry that does not hold the rights. When the goods are substitutes, it makes sense to switch consumption toward the good that is becoming disproportionately cheaper through technological change, letting the other industry for which consumption is decreasing bear the transaction costs. When the goods are complements and hence best consumed together, it makes sense for the transaction costs to be borne by the industry that is being favored by technological change since its costs, and hence the relative burden of the transaction costs as well, are becoming lower.

The updated results for a closed economy from Norgaard and Hall (1974) presented in Table 1 are our base cases for

[5] In our model, a relatively superior good is one where relatively more of the good is purchased at the same price as income increases. Norgaard and Hall referred to this as "sufficiently superior." By convention, indifference curves exist through time as income changes, as if people at one level of income could express what their tastes would be at a substantially higher level. Because CES indifference curves are symmetric around rays through the origin, relative income superiority cannot be shown in a consistent set of CES indifference curves. Thus to show one good having greater income superiority than the other, we shift to new indifference curves, sometimes referring to this as "preference change." While our approach flouts convention, it is certainly just as realistic to think of new indifference curves arising with new income, circumstances, and knowledge. The role of relative income superiority on governance is intuitive but somewhat tedious to prove with CES functions. We do not include the proof but can supply it for those who wish to see it.

Table 1 – Summary of the effects of technological change and relative income superiority in a closed economy

Elasticity of substitution	Change in production		Change in consumption	
	Technological change favors	Society eventually prefers	Relative income superiority	Society eventually prefers
Substitutes (0<l<1)	Rural goods	$\bar{L}$	Rural goods	$\bar{L}$
	Industrial goods	L	Industrial goods	L
Complements (l<0)	Rural goods	L	Rural goods	$\bar{L}$
	Industrial goods	$\bar{L}$	Industrial goods	L
Elasticity is 1.0 (l=1)	Rural goods	Maintain prior governance	Rural goods	$\bar{L}$
	Industrial goods	Maintain prior governance	Industrial goods	L

considering how trade affects the governance of ecosystem services.

3. Trade and ecosystem governance for a small country

Imagine a small country with factor endowments, tastes, or production conditions that differ from the rest of the world (ROW) such that there are possibilities for gains from trade. How does opening up to trade of goods affect the governance of ecosystem services?

Our conclusions in the previous section were driven by continuous technological change or factor augmentation and were stated in terms of "eventually," or not, a change would occur. We begin this section by looking at a one time change from a closed to an open economy and our conclusions depend on whether the price change due to trade is sufficiently large or not to drive a change in governance. To start, imagine a country that when closed finds it optimal to give rural producers strong protection of ecosystem services, *i.e.* $\bar{L}$ law. After opening to trade, this country becomes an exporter of industrial goods (Fig. 4). Will the increased production of the industrial goods lead this country to switch to L law because it favors the production of industrial goods? The answer is almost trivial (though a proof is available at Theorem 3.1 in Appendix B). Trade separates consumption from production. In our model, the governance of ecosystem services is determined by levels of production and, for a small country open to trade, these are entirely determined by world prices. Thus neither growth in income through trade nor relative income superiority affects ecosystem governance. Thus if the world price for industrial goods is sufficiently higher than the domestic prices before trade, it will lead to weaker protection of ecosystem services, *i.e.* L law being preferred over $\bar{L}$ law.

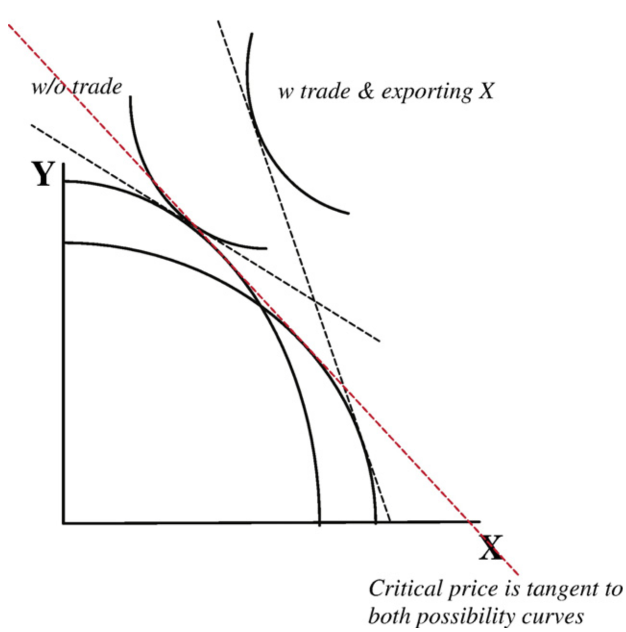

Fig. 4 – Trade Effects for a small country and the critical price line.

Now let's consider the effects of technological change. Corollary 3.1 tells us that, for a small country engaged in trade, the governance of ecosystem services will eventually favor the sector experiencing greater technological change. Now we simply compare our findings from Section 2 with respect to how technological change affects governance without trade and for a small country engaged in trade (see Table 2).

Changes in the international regime over the past few decades have favored capital mobility. While our model does not explicitly include factors of production, differences in factor intensities between the industries and capital mobility would lead to relative shifts in production possibility curves comparable to those illustrated in Fig. 3a. Thus, for example, if industrial manufacturing is capital intensive relative to the rural economy and our small country is relatively capital poor, then increasing capital mobility would be analogous to having technological change favoring industrial manufacturing. The effect of this on the choice of environmental governance,

Table 2 – Summary of the effects of technological change and trade on a small economy

Elasticity of substitution	Technological change (or capital mobility) favors	Society eventually prefers	
		Without trade	With trade
Substitutes (0<l<1)	Rural goods	$\bar{L}$	$\bar{L}$
	Industrial goods	L	L
Complements (l<0)	Rural goods	L	$\bar{L}$
	Industrial goods	$\bar{L}$	L
Elasticity is 1.0 (l=0)	Rural goods	Maintain prior governance	$\bar{L}$
	Industrial goods	Maintain Prior Governance	L

without and with trade in goods, should be comparable to those shown in Corollary 3.1 for technological change.

In contrast to a closed economy, Corollary 3.2 says, relative income superiority no longer affects the choice of environmental governance when a small economy is opening up to trade, because domestic demand is too small to affect the world price.

4. Trade and ecosystem governance for a large country

It proved considerably more difficult to use our model to explore how trade affects the governance of ecosystem services for countries of comparable size, or a very large country trading with the rest of the world (ROW). To make any headway, we had to further simplify our formal model. In some ways, though more difficult to conceive, the simplification is more realistic. Regardless, the simplification helps us see new phenomena.

There is a tradition in the literature of environmental economics to juxtapose the extreme cases of whether the polluter or pollutee should pay, yet pollution rights are rarely so simply defined or distributed. Polluters are typically allowed to pollute up to some limit after which they are penalized. This is comparable to giving polluters some pollution rights, though they cannot trade them, but not all of the pollution rights. As economic and technological conditions change, or new environmental information arises, societies regularly adjust their environmental laws without going to the extreme cases represented by L and $\bar{L}$ in the previous sections. With respect to climate change policy, for example, we see a healthy debate over how carbon rights might best be distributed between rich and poor countries as well as between polluting industries and the public (see, for example, Baer et al., 2000).

Flexibility in the level of governance of ecosystem services in practice simplifies treatment of them in theory. Recall that when only one good is being produced and governance favors that sector, no adjustments in governance are needed, there are no transaction costs, and the economy is effectively on the transaction costless production possibility curve $C|_{T=0}$. As we move from either of these extreme positions, governance is adjusted optimally depending on the mix of goods being produced. Now, imagine an all-knowing central planner who can set the governance of ecosystem services as the mix of goods being produced changes such that the two sectors themselves never need to negotiate the level of governance and hence no transaction costs occur. This assumption allows us to work off simply the one production possibility curve, $C|_{T=0}$, while also being able to say something about the change in governance of ecosystem services. Governance is still driven by transaction costs, though now they are hypothetical transaction costs that are perfectly avoided by a central planner. Considering transaction costs experienced by the central planner would make the change from one governance regime to the next "lumpy," as they are in reality, but not affect the direction of change, the focus of our analysis.

Now consider the case of trade between countries of comparable size or a country big enough to affect world prices. We assume initially that the country imports rural goods and exports industrial goods. Following the previous discussion, we assume that production and governance of ecosystem services are linked in a single constant elasticity of transformation function where each location along the possibility curve reflects the best possible combination of governance of ecosystem services that would have been reached had negotiations over ecosystem service protection between the industries actually occurred. While we do not have actual institutional outcomes, we know that the protection of ecosystem services increases as more rural goods and fewer industrial goods are produced and *vice versa*. For example, in the left graph in Fig. 5, the protection of ecosystem services is stronger at A than at B. Thus a shift in production from A to B would be a "move toward L Law" (for more details, please refer to assumptions in Appendix C).

Now, assuming the preferences and production conditions shown in Fig. 6, we can say that, after engaging in trade, the domestic economy moves toward L with trade while the rest of the world (ROW) moves toward $\bar{L}$ as shown in Fig. 7. It should be fairly intuitive that, for our model, moves in the governance of ecosystem services before and after trade are always in opposite directions between the countries (see Appendix C, Theorem 4.1 and its Corollary for the proof). This is a simple way to show that basic trade theory augmented with a simple model of ecosystem governance supports neither a race to the bottom nor to the top. Governance moves in opposing directions to complement comparative advantage.

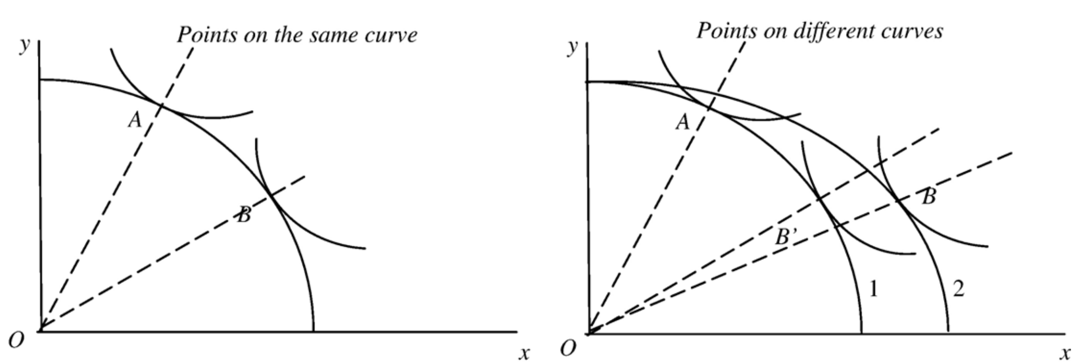

Fig. 5 – Comparison of ecosystem service governance.

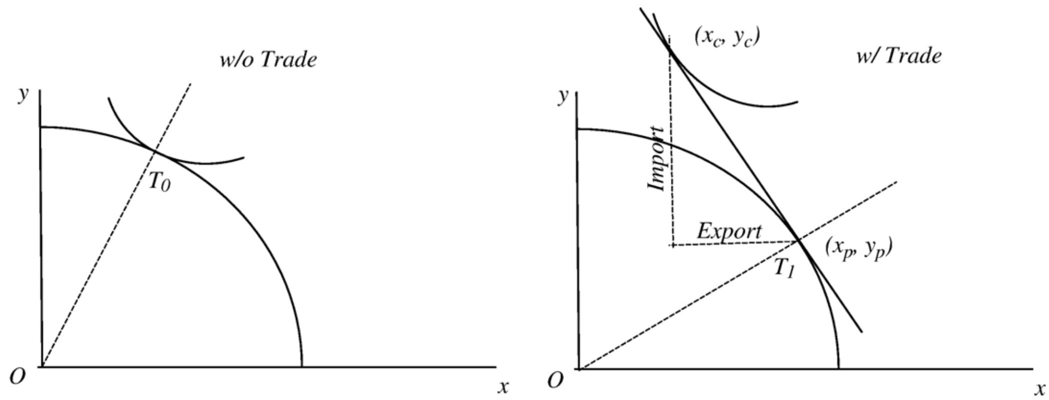

Fig. 6 – Effect of trade domestically.

Theorems 4.2–4.5 in the Appendix suggest the individual effects of technological change and relative income superiority. We would expect the domestic economy to further weaken its protection of ecosystem services, if 1) technological change favors the industrial production domestically; or 2) preference changes toward industrial goods, or 3) technological change favors the production of rural goods in the rest of the world, or 4) industrial good production domestically attracts more foreign investments. On the other hand, the domestic economy would strengthen its protection of ecosystem services, if 1) the rural industry experiences more rapid growth domestically, or 2) expenditures on rural goods at any given price increase faster with income than industrial goods (relative income superiority), or 3) technological change favors industrial production in the ROW, or 4) domestic rural production attracts more foreign investments. Furthermore, as shown in Theorem 4.3, the ecosystem protection domestically may become strengthened when rural production domestically experiences more rapid growth, but it will still be weaker than the governance the country chose before it opened up to trade. This means that technological change alone cannot restore the level of ecosystem service protection back to the level that would have been chosen before trade. And since capital movement has the analogous effects as technological change, our model indicates that neither growth in either industries nor in capital movement could lead the domestic economy back to stronger ecosystem protection of ecosystem services than the pre-trade level. However, if expenditures on rural goods increase faster with income than expenditures on industrial goods, the domestic economy may adopt stronger governance to protect ecosystem services. We have shown that the overall effects of growth in either of the industries and capital mobility are to lead the domestic economy to weaken protection of ecosystem services. So even if relative income superiority eventually leads the country to strengthen its governance of ecosystem services, the outcome with respect to the strength of governance is still ambiguous compared with the pre-trade level.

The major difference from the small country case is that now the preferences of the domestic economy can affect the choice of ecosystem service protection because it affects the relative demand in the world market and thus the relative price. So a change in preference with increasing income toward rural goods may help to restore stronger governance of ecosystem services. Clearly, if both countries choose relatively more rural goods with a rise in income, this will lead to stronger ecosystem governance, and vice versa, the same as in the single country case. As in the small country case, strengthening of ecosystem service protection in one country always accompanies a weakening of governance in the other country, other things being equal.

All the results for trade in the large country case assume the elasticity of substitution for the two goods is 1 (the Cobb–Douglas

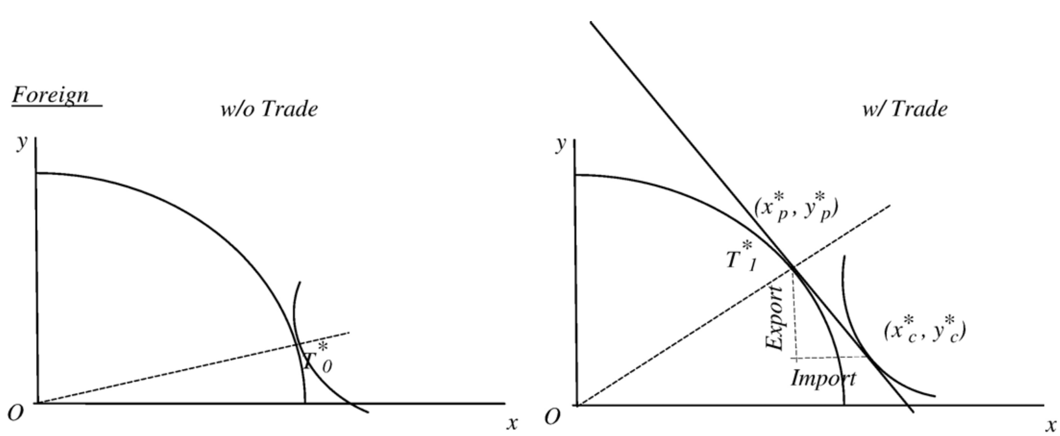

Fig. 7 – Effect of trade on the rest of the world.

form within the general CES function). When they are sufficiently complementary or substitutable, the effects of trade on the protection of ecosystem services will be more complicated. Nevertheless, some conclusions can be inferred from the Cobb–Douglas case. When the two goods are sufficiently complementary, technological change favoring one industry in one country may lead this country to move toward governance favoring the other industry. The direction of change is similar to the closed economy (Theorem 2.2), but the change is less. When the two goods are substitutes, the direction of change in governance is similar to the Cobb–Douglas case, except that the change of governance is greater compared to the case where same technological change happens in a closed economy.

5. Summary and discussion of findings

Our model documents that the governance of ecosystem services entering into production is sensitive to trade under first-best conditions. The relationship between trade and governance is intuitive at one level, yet becomes quite complicated through the interactions of technology and taste over time. First, the effect of opening to trade alone is to shift ecosystem governance in the direction that favors the sectors in which each country has its comparative advantage. Second, since trade separates production from consumption, it also separates the governance of ecosystem services from consumption. This means the role of relative income superiority under increasing income is severed or much reduced, breaking the links driving the environmental Kuznets curve. Third, basic trade theory supports neither a race toward stronger or weaker ecosystem service governance. While these basic findings are fairly intuitive from basic trade theory, they are neither in the existing literature nor a part of policy debates on trade and the environment. Our basic findings are novel but, given their intuitiveness, not surprising. What is surprising is that our findings are neither a part of economic understanding nor a part of political discourse after nearly two decades of academic and political debate.

Some of our results are less intuitive and more surprising. Taste change that favors the imported good will also favor shifting ecosystem service rights toward the sector producing the imported good, but the shift is not as great for the same taste change had it occurred before trade. Thus a country importing rural goods will protect its ecosystem services more forcefully if taste change favors rural goods, but it would have protected them even more were it not engaged in trade. We also show that, for example, if industrial goods manifest themselves as relatively superior, taking a larger portion of rising income, domestically or in the rest of the world, then the protection of ecosystem governance will weaken domestically and in the rest of the world with rising income.

A few important caveats are also in order. Comparative static analysis has significant limitations when stock effects are important. Our model assumes ecosystem services can be instantaneously increased without investment and have no thresholds below which they collapse. There are analogous problems with capital stocks and labor skills embedded in comparative static analyses that are conventionally ignored as well. Obviously, this is neither the case for predominantly physical systems like the global climate nor predominantly biological systems and our concern with biological diversity. Governance of ecosystem services not only needs to address long term dynamics, but the two foregoing examples also remind us that many of the ecosystem costs of national economic activity and the benefits of ecosystem governance are global rather than national.

The use of explicit functional forms means we can carry our analysis further than simply using general functional properties, but it also means that our analyses are limited to these forms. The consumption possibility frontiers we have used are continuous and concave to the origin. It is mathematically convenient and probably encompasses the relevant range of the general policy issues. As mentioned in Norgaard and Hall (1974), discontinuities are possible at the axes if externalities have fixed costs, and the frontiers can be convex when externalities become sufficiently extreme. If the convex region is relevant for analysis, then preference of the laws should be further investigated. In the two-country case, only the Cobb–Douglas form is sufficiently simple to allow us to explore how trade affects ecosystem governance. However, this already shows huge differences in the effects of technological change, preference change, and capital movement compared to the closed economy and small country case.

In spite of these limitations, our model helps document a key issue for the literature on environmental Kuznets curves. When a small economy opens to trade, consumption and income superiority no longer affect the assignment of rights to ecosystem services supporting the production process because trade separates consumption from production. While this finding is obvious from the nature of trade and our model, the distinction between ecosystem services entering into production and those affecting utility directly is neither made by economists who have provided empirical documentation for the apparent existence of environmental Kuznets curves (Cole, 2003; Dinda, 2004) nor by economists drawing on the apparent existence of environmental Kuznets curves in treatises on trade, growth, and the environment (reviewed in Copeland and Taylor, 2004).[6] This is all the more surprising since the empirical documentation of the EKC arose and was invoked early in the trade and environment debate (Grossman and Krueger, 1993).[7] Our findings, though in many ways obvious from trade theory,

[6] Copeland and Taylor (2004) acknowledge in their conclusions (page 66) that the environmental Kuznets curve literature places too much emphasis on income as the driver (while our analysis brings in technological change as well).

[7] To further complicate matters, the early empirical work was based on cross-country analyses of per capita income levels and environmental conditions at a time before trade was being heavily promoted as an engine of growth. Presumably one would want to control for the extent that a country's per capita income was due to trade to explain environmental outcomes with respect to the influence of trade, but trade as a factor influencing environmental governance is missing in the underlying models.

further confirm that efforts to establish relationships between factors associated with economic growth and environmental governance need to be more specific with respect to the extent that ecosystem services affect the production of goods or of utility directly, the extent to which trade drives development, and the extent to which production, consumption, or other factors actually frame environmental governance.

While our model draws on a social indifference curve to neatly determine optimal ecosystem governance, actual politics entail multiple constituents with competing interests. While our model is driven by the transaction costs of a particular assignment of ecosystem service rights, it ignores the transaction costs of changing the distribution of rights, and this is the typical focus of environmental politics. Our model assumes the externality only affects production costs, not the quality of the environment realized by citizens, and that production conditions determine environmental governance. In short, our model suggests that even under relatively simple conditions, trade and environment will likely be complicated and politically contentious issues. Making the conditions more general will not reduce the complexity of the possible outcomes, the main point of our analyses. Our model helps document the complexity of intertwined factors affecting trade and ecosystem governance as the global economy evolves.

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Appendix A

Since the model developed by Norgaard and Hall (1974) has not been used since its initial publication, we re-present their model, underlying definitions, and key theorems and corollaries. Proofs can be found in the appendix of Norgaard and Hall (1974).

We assume constant elasticity of transformation in the production of the two goods x and y. The transformation frontiers before and after technological change are:

$$\mathbf{PP}_0|T,L \quad \alpha_1 y^{k_0^*} + \beta_0 x^{k_0^*} = b_0 k_0^* \tag{A.1}$$

$$\mathbf{PP}_0|T,\bar{L} \quad \alpha_0 y^{k_0} + \beta_1 x^{k_0} = b_0 k_0 \tag{A.2}$$

$$\mathbf{PP}_1|T,L \quad \alpha_3 y^{k_1^*} + \beta_2 x^{k_1^*} = b_1 k_1^* \tag{A.3}$$

$$\mathbf{PP}_1|T,\bar{L} \quad \alpha_2 y^{k_1} + \beta_3 x^{k_1} = b_1 k_1 \tag{A.4}$$

$$0 < \alpha_2 \le \alpha_0 < \alpha_1;\ \alpha_2 < \alpha_3;\ k > 1,\ \text{for all k}.$$
$$0 < \beta_2 \le \beta_0 < \beta_1;\ \beta_2 < \beta_3;\ 0 < b_0 < b_1.$$

Next, we introduce social indifference curves with constant elasticity of substitution.

$$U = c\left(\delta y^l + \gamma x^l\right)^{1/l} \text{ where}: \ l \le 1,\ \delta \ge 0,\ \gamma \ge 0, \text{ and } c > 0$$

For different periods, we have:

$$U_0 = c\left(\delta_0 y^{l_0} + \gamma_0 x^{l_0}\right)^{1/l_0} \tag{A.5}$$

$$U_1 = c\left(\delta_1 y^{l_1} + \gamma_1 x^{l_1}\right)^{1/l_1} \tag{A.6}$$

We define the following conditions:

1. *Weak regularity conditions*: Technological change is weakly regular if $k_0 < k_1$;
2. *Strong regularity conditions*: Transaction costs are strongly regular if $k_0 = k_0^* = k_0$ and $k_1 = k_1^* = k_1$; 1 and 2 are called the regularity conditions;
3. Transaction costs are weakly neutral to the legal structure when $\alpha_0/\alpha_1 = \beta_0/\beta_1$ in period 0 and $\alpha_2/\alpha_3 = \beta_2/\beta_3$ in period 1;
4. Transaction costs are strongly neutral to the legal structure when they are weakly neutral and strong regularity conditions hold;
5. Transaction costs are weakly neutral to technological change under L law when $\alpha_3/\alpha_2 = \alpha_1/\alpha_0$ and under $\bar{L}$ law when $\beta_3/\beta_2 = \beta_1/\beta_0$;
6. Transaction costs are strongly neutral to technological change if they are weakly neutral, $k_0 = k_1$, and the strong regularity conditions hold;
7. Technological change favors **X** when $\alpha_2 = \alpha_0$, $\beta_2 < \beta_0$; favors **Y** when $\beta_2 = \beta_0$, $\alpha_2 < \alpha_0$; and
8. **X** and **Y** are both neutral to technological change when $\alpha_2 = \alpha_0$ and $\beta_2 = \beta_0$.
9. **Y** is a relatively superior good, iff (if and only if) $\frac{\gamma_0}{\delta_0} > \frac{\gamma_1}{\delta_1}$ (i.e. the income expansion path is curved toward the Y axis); and **X** is a relatively superior good, iff $\frac{\gamma_0}{\delta_0} < \frac{\gamma_1}{\delta_1}$ (i.e. the income expansion path is curved toward X axis).

Theorem 2.1. *If strong regularity conditions hold and* **Y**(**X**) *is a relatively superior good, then* $\bar{L}$ *(L) law will eventually be preferred.*

Corollary 2.1. *If transaction costs are strongly neutral to technological change, the elasticity of indifference curve is 1 ($l = 0$), and* **Y** *is a relatively superior good, then* $\bar{L}$ *Law is eventually preferred, no matter the initial legal structure is L Law or* $\bar{L}$ *Law.*

Theorem 2.2. *If technological change favors* **Y**, *the elasticity of substitution is greater than 1, $k > 1$ the strong regularity conditions hold, and transaction costs are weakly neutral to technological change under L Law, then* $\bar{L}$ *Law is eventually preferred.*

Corollary 2.2. *If technological change favors* **X**, *$0 < l < 1$, $k > 1$, transaction costs are weakly neutral to technological change under* $\bar{L}$ *Law, and strong regularity conditions hold, then L Law is eventually preferred.*

Theorem 2.3. *If technological change favors* **Y**, *$l < 0$, i.e. elasticity is less than 1; $k > 1$, transaction costs weakly neutral to technological change under L Law, and strong regularity conditions hold, then L Law is eventually preferred.*

Corollary 2.3. *If technological change favors* **X**, *$l < 0$, $k > 1$, transaction costs are weakly neutral to technological change under* $\bar{L}$ *Law,* *and strong regularity conditions hold, then $\bar{L}$ Law is eventually preferred.*

Theorem 2.4. *If transaction costs are strongly neutral to technological change, neither good is superior, and the elasticity of substitution is one, then society prefers to maintain its initial legal structure no matter whether it is L Law or $\bar{L}$ Law.*

Appendix B

Theorem 3.1. *If the world price of the exported good is sufficiently high and transaction costs are strongly regular, a country will switch its environmental law to favor the exported good.*

Under a general form of production possibility frontiers:

$$T, L \quad \alpha_1 y^{k_2} + \beta_0 x^{k_2} = bk_2 \tag{B.1}$$

$$T, \bar{L} \quad \alpha_0 y^{k_3} + \beta_1 x^{k_3} = bk_3 \tag{B.2}$$

Suppose x is the exported good, starting from the situation where $\bar{L}$ is initially preferred, letting $k=k_2=k_3$, we have:

1. if $P_r<P_c$, $\bar{L}$ Law will be preferred. Note, however, that
2. if $P_r>P_c$, L Law will continue to be preferred, and that
3. if $P_r=P_c$, society is indifferent to $\bar{L}$ Law and L Law.

The relative price $P_r = \frac{\text{price of good } x}{\text{price of good } y}$, and critical price $P_c = \left(\frac{\alpha_0^{\frac{1}{k-1}} - \alpha_1^{\frac{1}{k-1}}}{\beta_0^{\frac{1}{k-1}} - \beta_1^{\frac{1}{k-1}}}\right)^{\frac{k-1}{1}}$.

Proof. Under $\bar{L}$ Law, the first order condition yields: $x_{\bar{L}} = \left(\frac{P_r\alpha_0}{\beta_1}\right)^{\frac{1}{k-1}} y_{\bar{L}}$.

Substituting back, we get: $y_{\bar{L}} = \left(\frac{B}{\alpha_0\varphi_{\bar{L}}}\right)^{\frac{1}{k}}$,

where $B=bk$, and $\varphi_{\bar{L}} = 1 + \left(\frac{\alpha_0}{\beta_1}\right)^{\frac{1}{k}} P_r^{\frac{k}{k-1}}$.

Similarly, under L Law we have: $x_L = \left(\frac{P_r\alpha_1}{\beta_0}\right)^{\frac{1}{k-1}} y_L$ and $y_L = \left(\frac{B}{\alpha_1\varphi_L}\right)^{\frac{1}{k}}$

Then

$P_r<P_c \Rightarrow \frac{\varphi\bar{L}}{\varphi_L} > \left(\frac{\alpha_0}{\alpha_1}\right)^{\frac{1}{k_0-1}} \Rightarrow \varphi\bar{L}\left(\frac{B}{\alpha_0\varphi\bar{L}}\right)^{\frac{1}{k}} > \varphi_L\left(\frac{B}{\alpha_1\varphi_L}\right)^{\frac{1}{k}} \Rightarrow P_r x\bar{L} + y\bar{L} > P_r x_L + y_L$

which means $\bar{L}$ Law will be preferred.

Similarly,

$P_r<P_c \Rightarrow P_r x_{\bar{L}} + y_{\bar{L}} < P_r x_L + y_L \Rightarrow L$ Law will be preferred;

$P_r = P_c \Rightarrow P_r x_{\bar{L}} + y_{\bar{L}} = P_r x_L$
$+ y_L \Rightarrow L$ Law and $\bar{L}$ Law are indifferent; as claimed.

Therefore, the theorem holds after claim 2. Fig. 4 helps to illustrate the situation with the critical line in red.

Corollary 3.1. *For a small country engaged in trade, the assignment of the property right will eventually go to the industry experiencing greater technological change.*

With trade, $P_r=P_w$, where P_w is the relative price in the world market. Consider the case where the domestic economy is small such that P_w is not affected by the domestic economy, then when technological change favors **X**, eventually, $P_r>P_c$, L Law will be preferred; when technological change favors **Y**, eventually, $P_r<P_c$, $\bar{L}$ Law will be preferred. That is, with trade, the industry that is experiencing more technological change will eventually get the pollution rights.

More conveniently, we can prove this as follows: Since production is determined by the tangency of the production possibility curve and world price line, and the elasticity of this price line is infinite, the claim follows from Corollary 2.2 found in Appendix A.

Corollary 3.2. *With trade, if the home is a small country, the indifference curve of the home country no longer affects the relative price that is determined in the world market. Thus the choice of environmental law is no longer affected by which good is superior.*

Appendix C

The additional key assumptions for this section are:

10. The CES social indifference curve is assumed to be the simplest form when $l=0$, i.e. the familiar Cobb–Douglas form: $U=Cy^{\delta}x^{\gamma}$, where $\delta+\gamma=1$, and the elasticity $\sigma=1$.
11. For simplicity, k and k^* are held constant over time; and the two countries have the same proportional neutral change embodied by b and b^*, and thus conveniently, they can be considered as constants over time.
12. We only define the rule for comparing preference of laws at different locations on the same curve (or parallel curves). Now we assume transactions costs are neutral to the legal structure, locations at different possibility curves of one country over time can be compared after coordinate conversion: $Y=y\alpha^{1/k}$, and $X=x\,\beta^{1/k}$, which converts different functional forms into parallel curves X^k+Y^k=some constant. Or equivalently, we can compare the slopes of rays normalized by $(\alpha/\beta)^{-1/k}$. For example: the following approaches are equivalent for the right graph in Fig. 5 in the text. A (x_a, y_a), $B(x_b, y_b)$, $B'(x'_b, y'_b)$

- $X_i=x_i\beta_i^{1/k}$, $Y_i=y_i\alpha_i^{1/k}$, $i=a, b$; *then compare* Y_i/X_i.
- Compare the normalized slope $\frac{y_i/x_i}{(\beta_i/\alpha_i)^{1/k}}$
- Compare $r_1=y_a/x_a$ with $r_2=(y_b/x_b)(\beta_a/\alpha_a)^{1/k}/(\beta_b/\alpha_b)^{1/k}$, and since only slope matters, the intersection of ray r_2 and curve 1, B', is the equivalent point of B on curve 1.

If not stated otherwise, these assumptions are applied to the following theorems.

Now for the following derivation and proofs, we assume the trade pattern considered in Fig. 6 in the text. Before trade, the equilibrium occurs at T_1, with trade, the equilibrium moves to T_2. Now we want to explore the relationships among the world relative price p (the negative slope of the price line in the figure), the level of imports F_y, and the level of exports F_x.

CET : $\alpha y^k + \beta x^k = bk$ and CES : $U = Cy^{\delta}x^{\gamma}$
$k>1$

$$\mathrm{MRT}|_{(x_p,y_p)} = \frac{dy}{dx} = -\frac{\beta x_p^{k-1}}{\alpha y_p^{k-1}} = -p$$

$$\mathrm{MRS}|_{(x_c,y_c)} = \frac{dy}{dx} = -\frac{\gamma y_c}{\delta x_c} = -p$$

Now we have a system of equations together with CET and CES to solve for (x_p, y_p) and (x_c, y_c):

$$\beta x_p^{k-1} = p\alpha y_p^{k-1} \tag{C.1}$$

$$\gamma y_c = p\delta x_c \tag{C.2}$$

$$y_c - y_p = p(x_p - x_c) \tag{C.3}$$

From Eq. (C.1) and CET, we obtain:

$$x_p = \left[\frac{bk}{\beta(1+t^{-1})}\right]^{1/k}, y_p = \left[\frac{bk}{\alpha(1+t)}\right]^{1/k}, \text{where } t = p^{k/(k-1)}(\alpha/\beta)^{1(k-1)} \tag{C.4}$$

Then with Eqs. (C.2). and (C.3), we have:

$$x_c = \gamma(1+t^{-1})^{(k-1)/k}(bk/\beta)^{1/k}, y_c = \gamma(1+t)y_p = \gamma(1+t)^{(k-1)/k}(bk/\alpha)^{1/k} \tag{C.5}$$

where t was defined above.

Therefore, domestic economy imports $F_y = y_c - y_p$ can be expressed as a function in terms of p, α, β, γ, and δ:

$$F_y = f_1(p, \alpha, \beta, \gamma, \delta) = (bk/\alpha)^{1/k} G_1 \tag{C.6}$$

where, $G_1 = \delta(t+1)^{(k-1)/k} - (t+1)^{-1/k}$

Similarly, Domestic Export $F_x = x_1 - x_2$ can also be expressed as a function in terms of p, α, β, γ, and δ:

$$F_x = f_2(p, \alpha, \beta, \gamma, \delta) = (bk/\beta)^{1/k} G_2 \tag{C.7}$$

where $G_2 = (t^{-1}+1)^{-1/k} - \gamma(t^{-1}+1)^{(k-1)/k}$

$$\text{CET} : \alpha^* y^k + \beta^* x^k = b^* k^*$$

$$\text{CES} : U = C^* y^{\delta^*} x^{\gamma^*}$$

$$k^* > 1$$

Let ROW import and export be F_x^* and F_y^*, respectively. By symmetry, without repeating the same steps we can also derive these quantities as a function of α^*, β^*, δ^*, γ^*, and world price. By equating the world price, we can see that the import and export in the Domestic economy and ROW achieved at the trade equilibrium are functions of supply and demand in both countries. To facilitate comparative static analysis in the coming theorems, signs of the partial derivatives of these quantities with respect to parameters that determines production possibility frontier and indifference curve, are presented in Table 3.

Theorem 4.1. *When the Domestic economy engages in trade with the ROW with the trade pattern as assumed in Fig. 6, it is moving toward L.*

Proof. Here by assuming the Domestic economy imports y, we have $y_c > y_p$, i.e. $\delta(t+1)y_p > y_p \Rightarrow \delta(t+1) > 1$

$$\therefore t > \frac{1-\delta}{\delta} = \frac{\gamma}{\delta} \tag{C.8}$$

Let the slope of line OT_0 be r_0, and the slope of line OT_1 be r_1.

Table 3 – Summary of partial derivatives ("+" indicates greater than 0, and "–" indicates less than 0)

Functions	$\partial\bullet/\partial\alpha^{(*)}$	$\partial\bullet/\partial\beta^{(*)}$	$\partial\bullet/\partial\delta^{(*)}$	$\partial\bullet/\partial\gamma^{(*)}$	$\partial\bullet/\partial p$
Domestic Import $F_y = y_c - y_p$	+	–	+	–	+
Domestic Export $F_x = x_p - x_c$	+	–	+	–	+
ROW Import $F_x^* = F_x = x_p - x_c$	–	+	–	+	–
ROW Export $F_y^* = F_y = y_c - y_p$	–	+	–	+	–

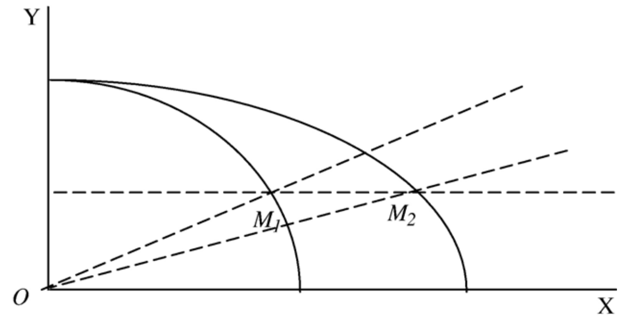

Fig. 8 – Equivalent points on two curves.

Known from previous derivation that $r_0 = (\gamma\alpha/\delta\beta)^{-1/k}$; while Eqs. (C.1), (C.4), and (C.8)

$\Rightarrow r_1 = \frac{y_p}{x_p} = (\beta/\alpha p)^{1/(k-1)} = \left(\frac{t\alpha}{\beta}\right)^{-1/k} < (\gamma\alpha/\delta\beta)^{-1/k} = r_0$, i.e. the Domestic economy is moving toward L. □

Corollary 4.1. *When ROW engages in trade, it is moving toward $\bar{L}$.*

Lemma 4.1. *For two CET curves, C_1: $\alpha y^k + \beta_1 x^k = bk$ and C_2: $\alpha y^k + \beta_2 x^k = bk$, point M_1 (x_1, y_1) on C_1 is equivalent to the point M_2 (x_2, y_2), i.e. they have the same preference of the laws,[8] if $y_1 = y_2$. (Similarly, if only α's are different, then M_1 and M_2 are equivalent if $x_1 = x_2$.)*

Proof. As stated in Assumption 12, when transactions costs are assumed to be neutral to the legal structure, it is sufficient to show that $\frac{y_i/x_i}{(\beta_i/\alpha_i)^{1/k}}$, $i = 1, 2$, are the same (Fig. 8).

$$\because \alpha_1 = \alpha_2 = \alpha, y_1 = y_2$$
$$\therefore \beta_1 x_1^k = bk - \alpha y_1^k = bk - \alpha y_2^k = \beta_2 x_2^k$$
$$\therefore x_1/x_2 = (\beta_2/\beta_1)^{1/k}$$
$$\therefore \frac{y_1/x_1}{(\beta_1/\alpha_1)^{1/k}} \Big/ \frac{y_2/x_2}{(\beta_2/\alpha_2)^{1/k}} = \frac{x_2/x_1}{(\beta_1/\beta_2)^{1/k}} = 1$$
□

Lemma 4.2. *Without trade, the country will retain its legal structure during technological change.*

Proof. Without loss of generality, assume that technological change happened to good x, and since we only care about the slope of rays from the origin, parallel curves can be considered as equivalent. Therefore, for simplicity, let b's be the same.

Now we can use the same notation in Lemma 4.1, and let the indifference curve be:

$$U = Cy^\delta x^\gamma$$

Using Lemma 4.1, it is sufficient to show that $y_1 = y_2$ (Fig. 9). From the derivation from previous chapters, We have:

$$y_1 = [\delta bk/\alpha_1(1+\gamma)]^{1/k}$$
$$y_2 = [\delta bk/\alpha_2(1+\gamma)]^{1/k}$$

Since when only good x experiences technological change and good x does not, we have $\alpha_1 = \alpha_2$, I get $y_1 = y_2$. □

[8] The following phrases have the same meanings when used in proof: preference of the laws, distribution of the pollution rights.

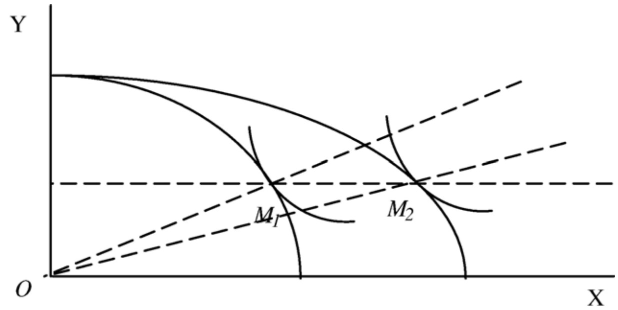

Fig. 9 – Two equivalent points.

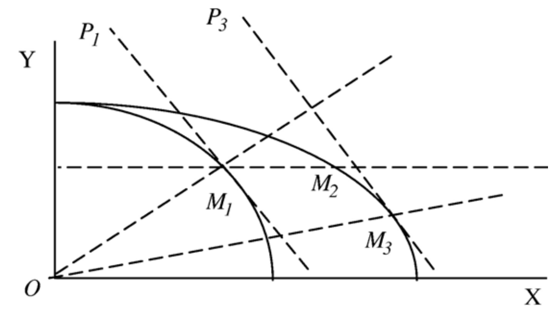

Fig. 10.

Lemma 4.2 shows that the conclusion we obtained in the previous model setup for the $l=0$ case is consistent in our current modified model setup.

Theorem 4.2. *With Trade, assuming the trade pattern does not change, technological change favoring the export good in one country will lead to moving toward the law that favors the export good in that country, while the opposite happens in the other country.*

Because of symmetry we only need to prove: With trade, when technological change happened to good x in Home country, the legal structure will move toward L, while Foreign will move to $\bar{L}$.

We can use the same notation in Lemma 4.1 and Lemma 4.2. M_1 is the tangent point of price line P_1 and CET curve C_1, M_2 is the equivalent point of M_1 on C_2, M_3 is the tangent point of P_3 and C_2, where $P_3//P_1$, and M_i (x_i, y_i). P_2 is the price line tangent to C_2 at M_2 (not shown in Fig. 10).

Let F_{xi}, F_{yi} be Home export and import in period i; F^*_{xi}, F^*_{yi} be Foreign import and export in period i, $i=1$, 2. In period 1, We have $F_{x1}=F^*_{x1}$, and $F_{y1}=F^*_{y1}$. Let the slope of the price lines at M_j be $-p_j$, $j=1$, 2, 3. We have $p_1=p_3>p_2$.(the analogy of the Rybczynski model 1955). As the transformation frontier is a smooth function, it is sufficient to prove that in period 2, the new equilibrium price is between p_1 and p_1, such that the new tangent point is located between M_2 and M_3. Once this is satisfied, we see the country is moving from M_2 (the equivalent point of M_1) downward.

First, we derive the sign of difference import and ROW export at world price p_2 and p_3.

$$\because \frac{\partial f_i}{\partial \beta}<0(\text{C.6, C.7, and Table 4}), \text{and } \beta_1>\beta_2, p_1=p_3, i=1,2$$
$$\therefore F_{x1}=f_2(\alpha,\beta_1,p_1)<f_2(\alpha,\beta_2,p_3)=F_{x2}(p_3)$$
$$F^*_{x1}=f^*_2(\alpha^*,\beta^*,p_1)=f^*_2(\alpha^*,\beta^*,p_3)=F^*_{x2}(p_3)$$

Similarly we have $\therefore F_{y1}<F_{y2}(p_3)$ and $F^*_{y1}=F^*_{y2}(p_3)$

$$\because F_{x1}=F^*_{x1}, F_{y1}=F^*_{y1}$$
$$\therefore F^*_{y2}(p_3)<F_{y2}(p_3), \text{ i.e. } F_{y2}(p_3)-F^*_{y2}(p_3)>0$$

On the other hand, at M_2,

$$\because y_1=y_2 \text{ and } y_i=\left[\frac{bk}{\alpha(1+t_i)}\right]^{1/k};$$

where $t_i=p_i^{k/(k-1)}(\alpha/\beta_i)^{1/(k-1)}, i=1,2$

$$\therefore t_1=t_2$$
$$\therefore F_{y2}(p_2)=f_1(\alpha,\beta_2,p_2)=(bk/\alpha)^{1/k}\left[\delta(t_2+1)^{(k-1)/k}-(t_2+1)^{-1/k}\right]$$
$$=(bk/\alpha)^{1/k}\left[\delta(t_1+1)^{(k-1)/k}-(t_1+1)^{-1/k}\right]=f_1(\alpha,\beta_1,p_1)=F_{y1}$$

While $\frac{\partial f^*_1}{\partial p}<0 \Rightarrow F^*_{y2}(p_2)>F^*_{y2}(p_1)=F^*_{y2}(p_3)$

$$\therefore F_{y2}(p_2)<F^*_{y2}(p_2), \text{ i.e. } F_{y2}(p_2)-F^*_{y2}(p_2)<0$$

Then we show that new equilibrium occurs at price between p_2 and p_3. Holding other parameters constant, we can construct a function $g(p)=F_{y2}(p)-F^*_{y2}(p)$ it is continuous and monotone increasing because

$$\frac{dF_{y2}(p)}{dp}=\frac{\partial f_1}{\partial p}>0 \text{ and } \frac{dF^*_{y2}(p)}{dp}=\frac{\partial f^*_1}{\partial p}<0$$

And we have already shown that $g(p_3)>0$, and $g(p_2)<0$, therefore, $\exists\ p_e\in(p_2,p_3)$, such that $g(p_e)=0$, when the new trade equilibrium occurs. Let the new point be M_e (x_e, y_e), I have $y_3<y_e<y_2$, slope $OM_e<$slope OM_2. Since M_2 is the equivalent point of M_1, we can conclude that the legal structure is moving toward L.

Since $p_e<p_3=p_1$, we can conclude that Foreign is moving toward $\bar{L}$.

Theorem 4.3. *With Trade, assuming the trade pattern does not change, technological change favoring the import good in one country will lead to moving toward the law that favors the import good in that country, while the opposite happens in the other country, but both countries cannot reach the pre-trade level of the environmental law.*

By symmetry, we only need to prove the following:

With trade, when technological change happened to good y in Home country, the legal structure will move toward $\bar{L}$, but can never reach the pre-trade level while Foreign will move to L, but also cannot reach the pre-trade level. (**Bounded Movement**)

The proof will follow the same logic as the previous one.

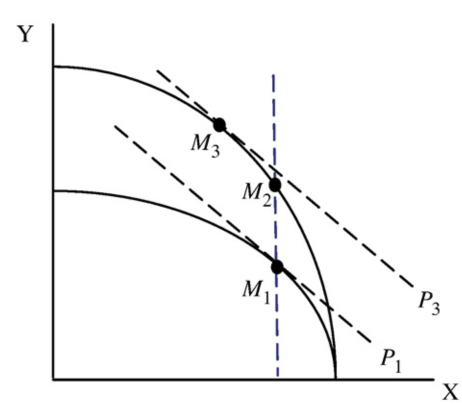

Fig. 11.

Table 4 – The direction of the change in ecosystem service protection for comparably sized countries

	Domestic tech change		ROW tech change		Expenditures on rural goods increase faster with income	Expenditures on industrial goods increase faster with income
	Rural	industrial	rural	Industrial		
Domestic	$\bar{L}$	L	L	$\bar{L}$	$\bar{L}$	L
ROW	L	$\bar{L}$	$\bar{L}$	L	$\bar{L}$	L

In Fig. 11, M1 is the tangent point of price line P_1 and CET curve C_1, M_2 is the equivalent point of M_1 on C_2, M_3 is the tangent point of P_3 and C_2, where $P_3//P_1$, and M_i (x_i, y_i).

Let F_{xi}, F_{yi} be Home export and import in period i; F^*_{xi}, F^*_{yi} *be Foreign import and export in period i, i=1, 2. In period 1, I have* $F_{x1}=F^*_{x1}$, *and* $F_{y1}=F^*_{y1}$. Let the slope of the price lines at M_j be $-p_j$, $j=1, 2, 3$. I have $p_1=p_3<p_2$.

$$\because \frac{\partial f_i}{\partial \alpha} > 0 (C.6, C.7, \text{ and Table 4}), \text{ and } \alpha_1 > \alpha_2, p_1 = p_3, i = 1, 2$$
$$\therefore F_{x1} = f_2(\alpha, \beta_1, p_1) > f_2(\alpha, \beta_2, p_3) = F_{x2}(p_3)$$
$$F^*_{x1} = f^*_2(\alpha^*, \beta^*, p_1) = f^*_2(\alpha^*, \beta^*, p_3) = F^*_{x2}(p_3)$$

$$\because F_{x1} = F^*_{x1}, F_{y1} = F^*_{y1}$$

$$\therefore F^*_{x2}(p_3) > F_{x2}(p_3), \text{ i.e. } F_{x2}(p_3) - F^*_{x2}(p_3) < 0$$

On the other hand, at M_2, which is the equivalent point of M_1 on C_2, I have $x_2=x_1$, that is the x values for the two points are equal. Same as in Theorem 4.2, $F_{x2}(p_2)=F_{x1}$.

While $\frac{\partial f^*_2}{\partial p} < 0, p_1 < p_2 \Rightarrow F^*_{x2}(p_2) < F^*_{x2}(p_1) = F^*_{x2}(p_3)$

$$\therefore F_{x2}(p_2) > F^*_{x2}(p_2), \text{ i.e. } F_{x2}(p_2) - F^*_{x2}(p_2) > 0$$

Holding other parameters constant, we can construct a function $g(p)=F^*_{x2}(p)$, it is continuous and monotone increasing because $\frac{dF_{x2}(p)}{dp} = \frac{\partial f_2}{\partial p} > 0$ and $\frac{dF^*_{x2}(p)}{dp} = \frac{\partial f^*_2}{\partial p} < 0$.

And we have already shown that $g(p_3)<0$, and $g(p_2)>0$, therefore, $\exists\, p_e \in (p_2,p_3)$, such that $g(p_e)=0$, when the new trade equilibrium occurs. Let the new point be M_e (x_e, y_e), we have $x_3<x_e<x_2$, slope $OM_e>$slope OM_2. Since M_2 is the equivalent point of M_1, we can conclude that the legal structure is moving toward $\bar{L}$. Let M_4 be the tangency of indifference curve and C_2. From Theorem 4.1 and Lemma 4.2, we know that M_4 is above the new equilibrium M_e, therefore Home cannot reach the pre-trade level of the environmental law.

$\because p_e>p_3$, $\therefore$ Foreign is moving toward L, but according to Theorem 4.1 and Lemma 4.2, its environmental law is still above the pre-trade level.

Theorem 4.4. *With trade, other things held constant and the trade pattern does not change, both countries will move toward L, if x is the relatively superior good.* **(Unbounded Movement)**

Proof. Let $F=F_x-;F^*_x$, according to Table 4, $\frac{\partial F}{\partial \gamma}<0, \frac{\partial F}{\partial \delta}>0, \frac{\partial F}{\partial p}>0$. If **X** is the relatively superior good, $\frac{\gamma_1}{\delta_1}<\frac{\gamma_2}{\delta_2}$ (as defined in Appendix A), where the subscripts denote the periods 1 and 2.

We know $\gamma+\delta=1$, so above inequality means $\gamma_1<\gamma_2, \delta_1<\delta_2$, this would reduce F. To restore F to 0, i.e. the equilibrium, I need to increase p. Therefore, the new equilibrium point is moving down along the curve in both countries, which is equivalent to say that both countries are moving toward L.

If one good is sufficiently relatively superior (e.g. $\frac{\gamma_2}{\delta_2}\to\infty$), this change will continue without bound. □

Theorem 4.5. *Suppose good* **X** *is capital K intensive, then when capital K is moving from the Domestic economy to ROW as Domestic economy opens up to trade, comparing to the earlier state without exporting capital, the Domestic economy will move toward* $\bar{L}$, *and Foreign will move to L, if two countries have the same tastes, i.e. same indifference curve* Fig. 12.

Proof. When K moves from Domestic to ROW, the change of the production possibility frontiers is analogous to technological change happening in x industry in ROW. And the budget

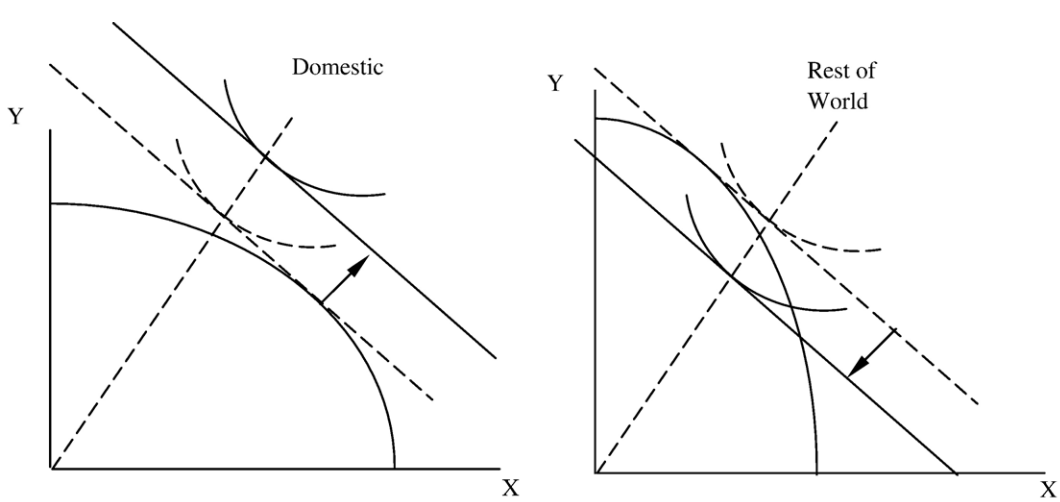

Fig. 12 – Capital movement.

constraint shifts out Δ amount in the Domestic economy and shifts in the same Δ amount in ROW. This makes no difference if we still use the dashed line above to derive the equilibrium, because after the shift, the same amount will be added to the domestic imports and foreign exports, and deducted from domestic exports and foreign imports, so that the equilibrium stays the same.

Therefore, using Theorem 4.4 we can conclude that the domestic economy moves toward $\bar{L}$, while the rest of the world moves toward L. □

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