Economic and Environmental Impacts of Pollution Control in a Multi-Country Model

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EXTENDED ABSTRACT

In the paper we consider the effects of trade expansion on the environment. The key issues are economic well-being and environmental well-being.

Jared Diamond (2005), p378 in his recent book on societal collapse refers to " 'mining' Australia" whereby he means mining in the literal sense of non-renewable resources (through export of coal etc.) and mining of renewable resources (e.g. forests) by exploiting them faster than they are capable of renewing themselves and hence they are declining.

Assessments of free trade agreements base their evaluations of welfare gains through measurements of changes in GDP. Any increase in GDP usually comes about through some combination of trade liberalisation, dynamic productivity gains, allocative efficiency and investment liberalisation. However, the increased trade related to such agreements can have implications for the environment and natural resources that may potentially counteract the gains from increased trade. This paper examines the environmental impact of increased trade between Australia and the US that would result from the adoption of a Free Trade Agreement. The aim is to identify how the environment will be affected by rising trade in terms of changes in pollution flows and changes in the stock of natural resources.

The single country Wonderland model Herbert and Leeves (2002) has been expanded to a multi-country configuration. In particular the model has been divided into two parts, one representing Australia and the other the rest of the world. In this way it differs from the North-South (developed/undeveloped) RAND model Lempert *et al.* (2003) by being specific to certain countries. We calibarte the model to represent Australia and the USA (representing the rest of the world).

The Wonderland model is a non-linear discrete model with sectors for the economy, population and environment. We implement the model using Simulink MathWorks (2005) software that allows easy visualisation of different scenarios.

The aim of the research is to investigate whether Australia's trade agreements have a significant impact on Australia being able to maintain a sustainable economic and environmental system. This sustainable economic and environmental system was shown to be realisable in the expanded single country Wonderland model under certain tax incentive programs Herbert and Leeves (2002). This study investigates whether these tax incentive programs need to be modified significantly to realize the pollution control results in the multi-country model.

The paper finds that the increase in trade liberalisation in the model can have devastating effects on the environment and this can lead to similar effects on the economy. Yet, if with the trade liberalisation the pollution control expenditure mix (between pollution abatement and technology) is altered so that a higher proportion is spent on reducing pollution per unit output rather than reducing pollution flows, then the negative effects of the trade liberalisation can be removed.

1 INTRODUCTION

Assessments of free trade agreements base their evaluations of welfare gains through measurements of changes in GDP. Any increase in GDP usually comes about through some combination of trade liberalization, dynamic productivity gains, allocative efficiency and investment liberalisation. However, the increased trade related to such agreements can have implications for the environment and natural resources that may potentially counteract the gains from increased trade. This paper examines the environmental impact of increased trade between Australia and the US that would result from the adoption of a Free Trade Agreement. The aim is to identify how the environment will be affected by rising trade in terms of changes in pollution flows and changes in the stock of natural resources. As of 2003, trade in goods accounts for over 75% of Australian exports to the US. Our principal exports to US are Machinery and Transport Equipment (24%), Food and Live Animals (22%) Australian Bureau of Statistics (2003). There are also considerable exports of metal ores but these are subject to confidentiality restrictions and listed under "Commodities and transactions not classified elsewhere" , which in total are 15% of exports. Beef is the single major export at 14% followed by metal ores. Clearly, a considerable amount of our exports are resource related. This paper models export flows as more damaging to the environment than other production in the economy because of their more intense resource use. In the negotiation of the Agreement the acknowledgement of environmental impact was limited to conducting reviews to "..seek to ensure that trade and environmental policies are mutually supportive by maintaining Australia's ability to protect and conserve its environment and to meet its international obligations." Recent simulation exercises conducted by Centre for International Economics (2004) concluded that the Free trade agreement would boost welfare through growth in GDP. We use a model of economic and environment interaction Herbert and Leeves (2002); Zhang (1996) to examine if environmental impacts will be significant and possible policy reactions to offset any adverse effects.

The model is based on the work in recent papers, Nordhaus (1991, 1992); Tahvonen (1995); Zhang (1996) where the implications for intertemporal pollution control under conditions where pollution damage occurs as a result of accumulation in the stock of pollution and the time derivative of the pollution stock. Dasgupta and Mäller (1995) produce evidence to suggest that the environment's resilience diminishes when the environment deteriorates. Hence, adverse effects on output from environmental damage may increase above some critical rate of pollution flow, other things being equal (Smulders, 1995).

The model used in this study explicitly links economic growth to the health of the environment. We examine the trade-off between growth and the environment within a compact, non-linear, discrete time, numeric, model which has complex dynamics. As in Zhang (1996), growth implies deterioration in environmental conditions, and we explicitly model the links between the technology of pollution production, the flow of pollutants and the stock of pollutants. Hence, we are able to assess the effects of varying the emphasis of government pollution control expenditure between improving the technology of pollution production and direct expenditure on increasing pollution control. This can shed useful insights into pollution control strategies, particularly in countries like Australia where exports are dependent on environmental resources that are crucial for production and are the dominant sector of the economy.

The paper uses the linkage between the economy, environment, knowledge and technology of two trading blocks to illustrate complex and undesirable transient dynamics for the economy and environment. It is shown that pollution control expenditure can avert undesirable outcomes arising from expanded trade between these blocks and the mix of pollution control expenditure strategies is crucial to realise acceptable responses.

2 THE MODEL

We develop a model based on Sanderson (1994) and Zhang (1996). The model uses a standard economic framework with a one sector neoclassical growth model with competitive markets for goods, labour and capital and appropriate terms for exports and imports. A key feature of the model is that the stock of natural capital is determined by the rate of flow of pollutants and the speed of the regenerative process. Each section of the model will be presented below. All variables are described in Table 1 and the parameters set out in Table 2. All parameters are ≥ 0.

Variable	Description
Y	income
I	net income
Q	production
K_p	physical capital stock
K_n	natural capital stock
L	labour force
Z	knowledge
B	crude birth rate
D	crude death rate
N	population
F	flow of pollutants
C	total pollution control expenditure
C_1	expenditure on pollutant flows
C_2	expenditure on pollution technology
P	quantity of pollution
M	Australian imports
X	Australian exports
Y_{USA}	American Income

Table 1. Model Variables

2.1 Economy

$$
\begin{aligned}
Q_t &= Z_t^{\xi_1} K_{n,t}^{\xi_2} K_{p,t}^{\xi_3} L_t^{\xi_4} e^{-\xi_5 F_{t-1}} && (1)\\
Y_t &= (1-\tau)(Q_t + X_t) - M_t && (2)\\
C_t &= \tau Q_t && (3)\\
C_{1,t} &= \gamma C_t && (4)\\
C_{2,t} &= (1-\gamma) C_t && (5)\\
L_t &= \beta_2 N_t && (6)\\
Z_{t+1} &= \frac{\eta_1 (Q_t + X_t)}{Z_t^{\eta_2}} - \eta_3 Z_t && (7)\\
K_{p,t+1} &= \delta_1 (Q_t + X_t) - \delta_0 K_{p,t} && (8)\\
X_t &= \rho_{USA} Y_{USA} && (9)
\end{aligned}
$$

Equation 1 defines the economy's output (Q) and is a standard Cobb-Douglas production function. The last term in Equation 1, ($e^{-\xi_5 F_{t-1}}$) represents the lagged effect of pollution flow (F) on output productivity. The lower the stock of natural capital (K_n), the lower the level of output. This is a reasonable assumption, especially for a natural resource dependent economy like Australia.

Equation 2 states that income (Y) is output after deduction of taxes and allowances for imports (M) and exports (X). Here τ represents a tax levied to raise funds for pollution control expenditure (C) as shown in Equation 3. The government has two choices for pollution control expenditure. Firstly, it can spend money directly on pollution abatement (C_1) Equation 4. Secondly, money can be spent on improving the economy's pollutant technology (C_2) Equation 5.

Equation 6 indicates that the labour force (L) is a proportion of the population (N). The process of creation of knowledge (Z) is defined in Equation 7. Following Zhang (1996), we constrain knowledge accumulation to result from learning by doing.

In Equation 8, K_p is the stock of physical capital and is related to production (Q) and exports (X). Equation 9 defines Australia's exports (X) in terms of USA income (Y_{USA}).

2.2 Population

$$
\begin{aligned}
B_t &= \beta_0 \left[\beta_1 - \left(\frac{e^{\beta Y_t}}{1 + e^{\beta Y_t}}\right)\right] && (10)\\
D_t &= \alpha_0 \left[\alpha_1 - \left(\frac{e^{\alpha Y_t}}{1 + e^{\alpha Y_t}}\right)\right] \\
& \quad \left[1 + \alpha_2 (1 - K_{n,t})^{\theta}\right] && (11)\\
N_{t+1} &= N_t \left[1 + \left(\frac{B_t - D_t}{1000}\right)\right] && (12)
\end{aligned}
$$

Population growth is represented by Equations 10 to 12. The level of population, N, is measured as the difference between the crude birth rate, B, and death rate, D. Both the economy and the environment interact with the population. Increases in net income lead to decreases in the birth and death rates. The death rate is also influenced by the stock of natural capital, whereby decreases in the stock cause the death rate to rise. This is a plausible assumption if significant changes in the level of the natural resource can act as a proxy for the health of the community (reducing medical access and nutrition through its strategic importance in the economy).

2.3 Environment

$$
\begin{aligned}
F_t &= N_t (Q_t + X_t) P_t \\
& \quad -\kappa \left(\frac{e^{\epsilon_0 C_{1,t}}}{1 + e^{\epsilon_0 C_{1,t}}}\right) && (13)\\
K_{n,t+1} &= \nu \left[\frac{e^{\ln\left(\frac{K_{n,t}}{1-K_{n,t}}\right) + \lambda K_{n,t}^{\rho} - \omega F_t}}{1 + e^{\ln\left(\frac{K_{n,t}}{1-K_{n,t}}\right) + \lambda K_{n,t}^{\rho} - \omega F_t}}\right] && (14)\\
P_{t+1} &= \left[\frac{\tanh(-2\pi (C_{2,t} - \frac{1}{2})) + 1}{2}\right] \ldots \\
& \quad \left[\chi \left(Q_t + X_t\right)^{-\epsilon_1} P_t\right] && (15)
\end{aligned}
$$

The environment is modeled by three equations. The first, Equation 13, describes the annual flow of pollutants (F). These are determined by the population (N), output (Q), exports (X), pollution per unit of output (P) and the amount spent on pollution control measures (C_1). The flow also depends on the effectiveness of pollution control measures denoted by the parameter κ.

Equation 14 specifies the interaction between the flow of pollution and the stock of natural capital. Natural capital is normalised and can vary between being complete where $K_n = 1$ and no stock where $K_n = 0$. Obviously, natural capital is adversely affected by a higher pollution flow. However, the equation allows for natural capital to regenerate itself and offset the pollution flow of earlier periods. The speed of natural resource regeneration is governed by the parameter ν $(0 \leq \nu \leq 1)$. This representation ensures that regeneration can never be complete. Some of the flow of productive services provided by natural resources are lost for ever after a period of stock reduction, this could occur through biodiversity loss and the elimination of the more productive natural resources.

In Equation 15 we model pollution per unit of output. The first term (in brackets) represents the response of pollution generated by production to government expenditure aimed at reducing the level of pollution per unit of output Herbert and Leeves (2002). It is assumed that there is some exogenous rate of reduction in pollution over time. In addition, the term χ (with $0 \leq \chi \leq 1$) allows for other time related improvements (or possible deteriorations) in pollution per unit of output that are not related to the state of the economy or government expenditure Herbert and Leeves (2002). The next term indicates that improvements in pollution per unit of output can occur due to increases in the levels of output and exports. Thus whilst output and exports increase the flow of pollutants (in Equation 13), they also reduce pollution per unit output as producers become more aware of the commercial value of preserving the natural resource stock.

3 SIMULATING THE MODEL WITH SIMULINK

We decided to model the system using Simulink MathWorks (2005). Initially we used two cross-coupled Wonderland blocks with different parameter magnitudes for Australia and the USA. Since we were using the USA, we decided that due to the vast distances between Australia and the USA that the environment of one would not affect the environment of the other.

For simplicity we have modelled only the effect of Australian exports on the local economy and environment. This is shown in Figure 1. Here can be seen the Wonderland model with the addition of exports and imports. We have assumed that the USA income is 100 times that of Australia and that a fraction ρ_{USA} is used to purchase Australian exports.

In terms of Australian production, we have added the value of USA exports to each term containing a production function (Q) in the Wonderland equations. This can be seen in Figure 2 for the pollution per unit output equation (Equation 15).

Although not shown, we found it advantageous to split the model into a number of interconnected discrete blocks. We have blocks for the economy, trade, taxation, environment and pollution. We have brought the main parameters outside of the main block so that they can be easily changed.

In preparing the model we made extensive use of the

Parameter	Value	Parameter	Value
ξ_1	0.05	ξ_2	0.2
ξ_3	0.5	ξ_4	0.3
ξ_5	0.02	β_2	0.6
η_1	0.01	η_2	0.5
η_3	0.01	δ_0	0.1
δ_1	0.3	λ	1
α	0.09	α_0	10
α_1	2.5	α_2	2
β	0.08	β_0	40
β_1	1.375	θ	15
κ	1	ϵ_0	0.02
ρ	0.2	ω	0.1
ν	0.8	ϕ	0.5
ϵ_1	0.01	χ	1
τ	0.1	ρ_{USA}	0.04
γ	0.5		

Table 2. Model Parameters

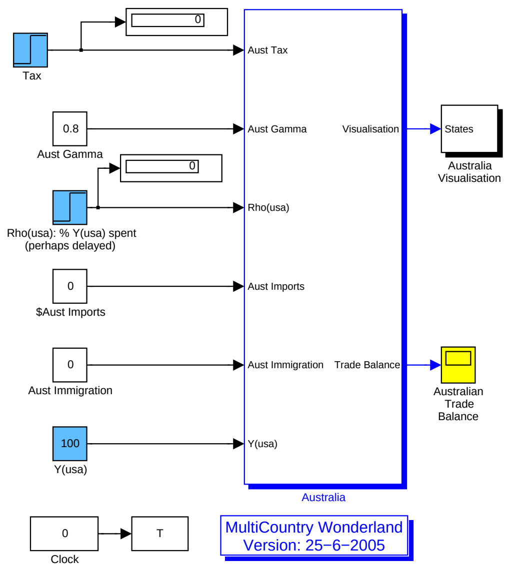

Figure 1. The main Simulink model

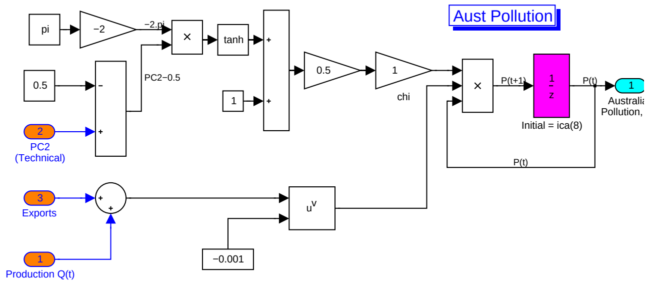

Figure 2. The pollution block

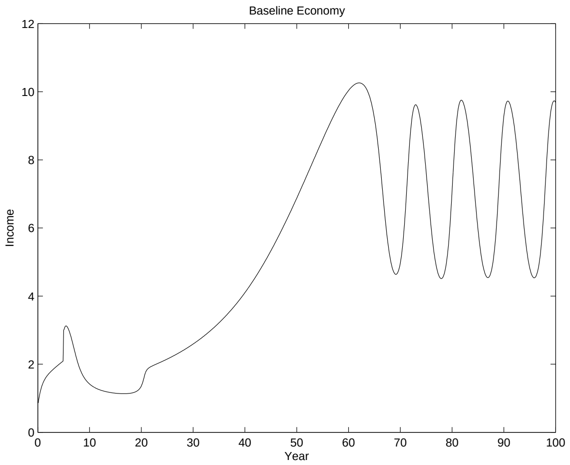

Figure 3. Base Economy.

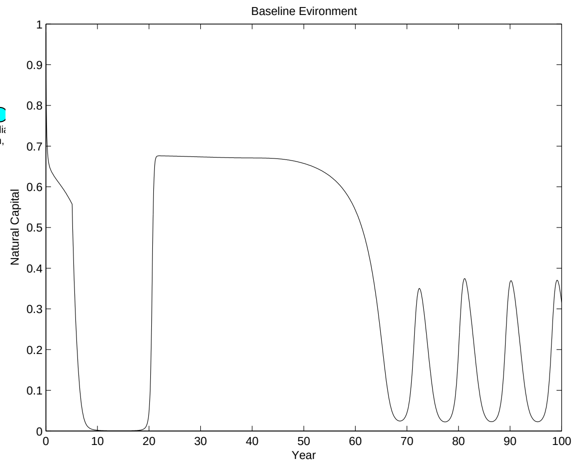

Figure 4. Base environment

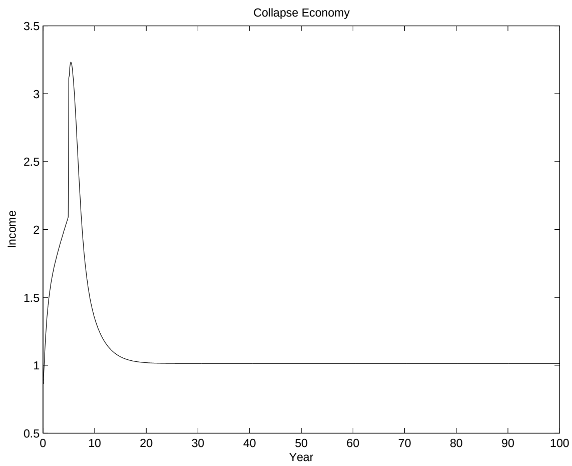

Figure 5. Collapsed economy

input-output blocks such as the scope and display and the termination. These were peppered throughout our model and allowed us to monitor the performance at the block and component level.

4 SIMULATING THE FREE TRADE AGREEMENT

4.1 Baseline

In Figures 3 and 4 we present our baseline projections for the economy and the environment for Australia. In this case ρ_{USA}, being the current export level to the USA, is set at 0.04, τ is 0.1 and γ is 0.5. The transient dynamics take about 60 years and then the model enters an oscillatory steady state with a cycle of approximately 10 years. The transient period represents a growth phase for the economy, with income rising. This is initially at the expense of the environment as natural capital is depleted to low levels. The environment restores before entering the steady-state. In the steady-state the environment averages about 20% of its pristine level and the economy averages about 6 times higher than the initial condition.

In summary the model simulates an economy that initially grows rapidly at the expense of deleting natural resources, and then evolves into an oscillatory steady-state with cycles in the economy and depletion of natural capital.

4.2 Collapse Through Expanding Exports

We simulate the free trade agreement by increasing Australian exports during the transient dynamics period of the model. Specifically we increase exports by 12.5% as predicted in the Free Trade Agreement (increase ρ to 0.045) in year 5.

The effects of the export expansion are shown in Figures 5 and 6. This is the effect of a free trade agreement felt as a step increase in exports. We observe that the society initially experiences a growth in income but then suffers a collapse of the type considered by Jared Diamond (2005). The economy stagnates and the economy is in a destroyed situation

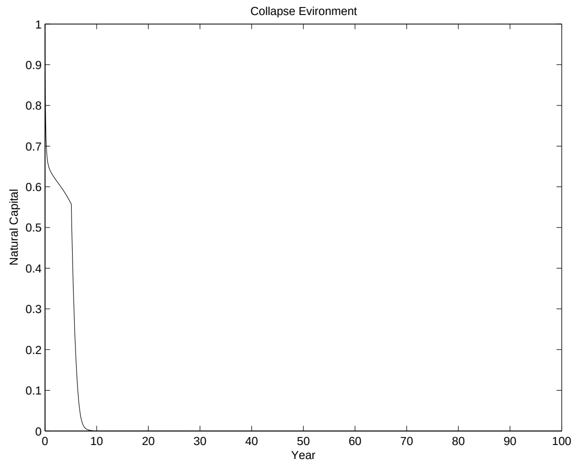

Figure 6. Collapsed environment.

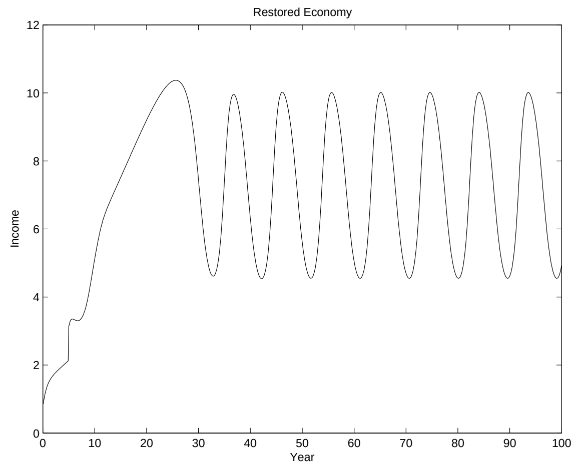

Figure 7. Restored economy

with natural capital at near zero. No sign of recovery is observed.

4.3 Pollution Control Expenditure

The collapse generated by the expansion in exports can be avoided if, at the same time as expanding exports, the pollution control expenditure in the model is directed so that a higher proportion is spent on reducing pollution per unit output, than on fixing pollution flows. In this case γ was set to 0.4 compared to the previous scenarios where it was 0.5. This scenario is shown in Figures 7 and 8. Note the the economy more quickly reaches its steady-state and that there is a slightly higher income than in the baseline scenario. A similar situation occurs with the environment.

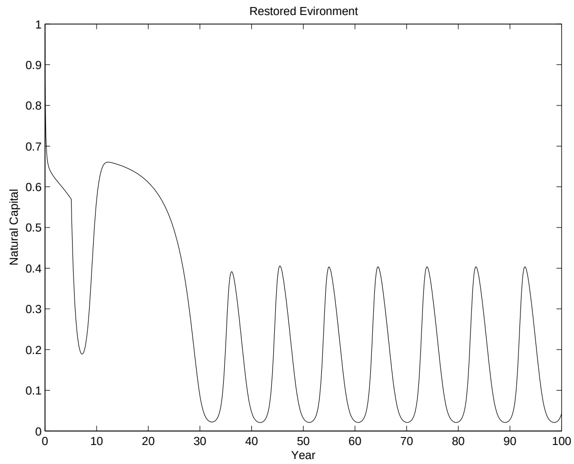

Figure 8. Restored environment

5 CONCLUSION

This paper examined the impact of an Australia-US free trade agreement in a model where there is an interdependence between economic growth and environmental quality. The model allowed for pollution control expenditure to be directed towards pollution abatement or towards the pollution effects of production technology. Certain plausible assumptions about the impact of increased trade on pollution generating activites were made. It was shown that the expansion in exports could have significant adverse implications for a resource based economy like Australia. However, pollution control expenditure can be beneficial in this scenario for the sustainability of natural capital and economic growth. In fact, if timely increases in pollution control expenditure occur, the economic benefits from increased trade are gained with the natural capital stock evolving in a very similar path to the pre-trade agreement state. Therefore, the government should be proactive in promoting environmentally efficient production technologies rather than being reactive to the pollution effects of production on natural resources. Our analysis does not consider the changes in investment flows that may accompany free trade agreements (CIE 2004). This could accelerate the divergence away from resource dependence and so lessen the environmental impacts outlined here.

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