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Dynamic Adjustments to Terms of Trade Shocks: The USA Productivity Boom and Australia.

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Abstract

How has the USA's "new economy" productivity boom affected Australia? We consider this question using a dynamic multi-sector growth model of the Australian and USA economies. We find that productivity growth in the USA durables sector generates small but important gains to Australia. We find that the transmission of growth is generated through increased export demand for Agriculture. Consequently we find that the USA's productivity growth tends to favour Australia's traditional export sectors. Likewise it increases the relative demand for less skilled labour in Australia and reduces the demand for skilled labour and higher education.

Keywords Terms of Trade, Productivity, Economic Growth, Human Capital, Computable General Equilibrium Models.

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1. Introduction

The last 15 years has been an era of unprecedented growth in the USA with labour productivity accelerating by one percent above its post war trend. This acceleration has been associated with new information technology (IT) and IT capital deepening across a range of industries, (Jorgenson and Stiroh, 2000, Jorgenson 2001, Nordhaus 2001). More broadly it is also associated with falling investment prices particularly for Machinery and Equipment, (Greenwood Hercowitz and Krusell, 1997, Gordon 1990).[1]

The Australian economy, however, has performed equally well with a similar acceleration in total factor productivity (TFP) through the 1990's of 0.5-1.4% (Parham 2004). In Australia's case, however, the causes are less well understood. One area of uncertainty is the extent to which the Australian and USA experiences are related. Standard trade theory suggests that an expanding USA export sector would generate terms of trade gains to Australia. Moreover Lee (1995) and Eaton and Kortum (2001) have highlighted the potential for the transmission of growth through trade in capital goods. Specifically, as Australia is a net importer of durable goods, productivity growth in the USA may reduce the relative price of investment in Australia and induce capital accumulation.[2]

The idea that Australia has benefited from the USA productivity acceleration has received considerable attention with respect to the use of imported IT technologies (van Ark 2006, Parham 2004). According to Gretton et al (2002) the adoption of IT capital may explain the strong sectoral productivity growth in Wholesale and Finance sectors during the 1990's. Nevertheless, as documented by Parham (2004),

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[1] The trend of falling investment prices was first identified by Gordon (1990). The importance of Machinery and Equipment investment as a source of growth or income level differences across countries is also highlighted by numerous cross-country growth studies which find that the costs of investment differ substantially across countries and may explain a small but significant fraction of income level differences, De Long, J. B. and Summers, L. H. (1992), Restuccia and Urrutia, (2001).

[2] Eaton and Kortum (2001) find that import price of durable goods is an important factor in determining the domestic relative price of investment. with approximately half the difference in equipment prices across countries can be explained by trade barriers.

during the period 1993-4 to 1998-99 Australian Manufacturing growth slumped. Moreover the sector with the strongest total factor productivity growth was not Communications or Finance but Agriculture. This apparent contrast can be viewed as a curiosity if not a puzzle. At the very least it has been taken as evidence that Australia's surge in productivity growth had several distinct sources (Parham 2004).

The aim of this paper, therefore, is to explore the effects of the USA productivity growth acceleration on income growth in Australia. In particular we focus on the impact of USA productivity growth on Australia's bilateral trade flows with the USA and the effect of these trade flows on investment, education decisions and short to medium term growth rates.

To do this we use a multi-sector multi-region dynamic general equilibrium model calibrated to represent the USA and Australian economies. Economic growth is modeled explicitly through accumulation decisions which depend on international prices as well as on domestic prices. This allows us to consider the short and medium–term growth impacts of USA productivity growth on the Australian economy. Moreover we consider multiple types of capital thus allowing us to explore the impact of price changes on accumulation on Machinery and Equipment capital specifically – as opposed to housing and other types of structures. In addition we also consider the potential long run impact on the supply of skilled labour in Australia, and the effects on skilled and unskilled wages which have been central issues in the "new economy" debate.

We find that productivity growth in the USA durable goods sector has a small but significant effect on growth rates in Australia, with GDP rising by one percent over 10 years. In contrast to the transmission mechanism emphasized in the growth and trade literature, however, the benefits to Australia do not come from lower equipment investment prices but, rather, from an increase in USA demand for Australian exports.

Specifically we find that productivity growth in the USA causes a fall in the output of Australia's durables goods sector and an expansion of agricultural production and exports. This is consistent with the evidence on sectoral productivity growth in Australia during the 1990's. Consequently there is a contraction in Machinery and Equipment investment in Australia and a rise in the relative demand for low skilled labour. Thus we find that the “new economy” growth pattern in the USA tends to raise demand for the “old economy” sectors in Australia.

2. USA Productivity Growth and Durables Prices

The growth of GDP per employed worker in the USA accelerated from 1.1 per cent in 1990-1995 to 2.5 per cent in 1995-2000 and has remained high over the last 5 years. This trend contrasts sharply with Europe where productivity growth fell over the same period (van Ark et al 2003). Again the IT sector and IT related productivity change are argued to be an important source of this boom. According to Eichengreen (2004) the increase in TFP accounts for approximately half of the observed labour productivity growth, with the remainder due to capital deepening in response to a decline in the relative price of investment.

This trend has also been cited as a cause of the widening skill premium in the USA. In particular labour saving technology change is argued to raise the relative demand for skilled labour which is thought to be complementary with capital (Flug and Hercowitz 2000, Krusell, et al 2000). Likewise Drew-Beckar and Gordon (2005) have argued that the productivity boom has not raised incomes evenly but, rather, income growth has been concentrated in the top 10 percent of the distribution.

For Australia Gretton et al (2002) and van Ark (2006) find that there has also been considerable IT capital deepening and it is natural to ask, to what extent has Australia gained from falling prices of IT goods and more broadly falling prices of durable goods imports from the USA? The Bureau of Economic Analysis (2005) report that USA durables import prices have fallen 14.7 percent, relative to the import goods price index, between 1995 and 2004.[3] Likewise durables export price index fell 5.3 percent over the same period relative to the all export goods price index. For Australia there is no equivalent durables price index. Nevertheless import price indices for Australia show substantial declines in *Machinery and Electrical Goods* prices which fell approximately 30% between 1991-2005 (ABS 2005).

[3] Data is from the Bureau of Economic Analysis, National Income and Product Accounts (NIPA) Table 4.2.4.

In view of this evidence we consider an exogenous acceleration in TFP in the durables goods sector in the USA. We calibrate the size of this productivity growth so that the price of durables goods falls by 10%, which is the mean of the import and export price indices for durables in the USA. This results in a 51.7 percent improvement in TFP in the durables sector. We then consider the effect of this productivity growth on factor accumulation and relative income in the USA and, through changes in import and export prices, also on Australia.

3. The Model

3.1 *Structure*

The model consists of three regions, Australia, the USA and the Rest-of-World (ROW).[4] The overall structure is summarized in Table 1. Australia and the USA are modeled as open economies facing exogenous world prices with 6 traded and 5 non-traded commodities and industries. The ROW exports and imports 6 traded commodities. Within each region commodities are identical irrespective of their source. In this respect our model resembles a traditional Hecksher-Ohlin trade model with homogenous goods as opposed to the more common "Armington assumption" of differentiated good by import source.

Each commodity is produced by competitive firms using intermediate inputs and up to 7 factors of production. The exception is the *Education* sector which demands, but does not supply, intermediate services. The agents in each regional economy are: firms; households, and; a government. Final demand spending consists of consumption spending by the government and spending by households on education consumption; investment in *Machinery and Equipment*, *Structures*, and; *Residential Housing*. Each of these spending categories in a CES function of the 11 commodities in each region.

Government spending is assumed to be determined by a simple policy rule that fixes aggregate spending as a proportion of GDP. Government revenue is attained through taxes on consumption, tariffs and factor incomes. A lump sum subsidy is used to redistribute any surplus back to consumers, so that the government budget is

[4] An appendix detailing the model is available upon request.

balanced at each point in time. The long run level of consumption spending is given by a long run-target for the net foreign asset to GDP ratio. The time path for consumption follows from the household minimizing a quadratic loss function of deviations of consumption and net foreign assets from these target values.

Firms are assumed to produce commodities using intermediates and seven factors of production and intermediates. These consist of three reproducible physical capital goods corresponding to each of the three investment types *Machinery and Equipment*, *Structures* and *Residential Housing*. In addition firms employ *Skilled* and *Unskilled* labour. The relative supply of each is endogenously determined through schooling decisions by households. The remaining factors of production are *Land* and *Resources* and these are assumed to evolve exogenously. The Firm's valued added technologies are described by nested constant elasticity of substitution (CES) unit cost functions, which allow for capital-skill complementarity.[5]

The economies' outputs consist of traded and non-traded goods where the non-traded sectors are *Construction*, *Non-traded services*, *Public*, *Housing* and *Education*. These sectors produce a single good for the domestic market. In the traded goods industries, however, output is an aggregate of three destination specific goods – one good destined for the home market, and two others for the other respective export regions. Firms thus maximize revenue by producing the optimal mix of destination specific goods, given the producer prices in each market. The resulting unit revenue functions are assumed to be constant elasticity of Transformation (CET) functional form. Using the envelope theorem the unit supplies to each market are given by the derivative of the revenue function with respect to each market price.

This completes the description of the model at a point in time. A static equilibrium thus consists of 22 zero profit conditions; 22 commodity market clearing conditions, and 14 factor market clearing conditions solving 2×11 commodity prices 2×7 factor prices and 2×11 gross outputs.

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[5] Thus reproducible capital is aggregated in a CES function and this aggregate is an argument in the upper cost function along with *Unskilled labour*, *Land* and *Resources*. With this structure, and given the elasticities given in Table 2, an increase in physical capital will raise the skill premium.

3.2 *Capital Dynamics*

Households choose investment spending to maximize the present value of each capital stock subject to: expected streams of future rentals, the investment price indices; a constant depreciation rate, and quadratic adjustment costs. Households also make education decisions by maximizing the present value of labour earnings from skilled and unskilled labour.

The skilled labour force can be increased through producing students in an education sector. For education investment we assume that there are adjustment costs to increasing the stock of skilled labour reflecting job matching and on-the-job training costs associated with school leavers. Thus households maximize the present value of their labour income stream subject to these learning costs, a depreciation rate for skilled labor which reflects the retirement rate, and the consumer price of education. Hence the costs of acquiring skilled labour include forgone unskilled labour and the costs of purchasing education services.

An inter-temporal equilibrium is a time path of asset price which is consistent with the first order conditions for the household's optimal investment decisions and, in the limit, reaches the steady-state solution. In practice this is solved by requiring that the model reaches a steady-state after a large but finite number of periods, typically over 100 years.

3.3 *Calibration and Solution Method*

The model is calibrated to a year 2000 benchmark using primarily data from the GTAP data base v.6 on trade flows, intermediate usage matrices, consumption taxation, final demands and value added shares.[6] The benchmark is calibrated to steady state growth path where all variables are growing proportionally and prices and factor returns and the debt to GDP ratio are constant.

Calibration requires choosing the parameters of: the unit expenditure functions for each of the spending aggregates; the unit revenue functions that determine the allocation of outputs across international markets, and; the unit cost functions that

[6] The GTAP data base is documented by Dimaranan (2006).

describe factor input choices by firms. These revenue elasticities along with the expenditure and costs function elasticities are given in Table 2.[7]

Calibration also requires two important data extensions of the GTAP data. First the use of a steady state assumption in calibration of the benchmark poses requires us to reconcile industry value added flows with investment spending flows for physical capital.[8] Second the introduction of an education sector requires data on the education production function. We therefore supplement the GTAP inter-industry flow and value added matrices with data on intermediate inputs purchased by the education sector and the value added share for this sector, from official USA and Australian input–output tables.

The concept of a skilled labour we use is a worker with a university degree or comparable post secondary education. Based on this concept we assume a steady state student to population ratio of 3% in both USA and Australia. Likewise private and government higher education expenditure data were used to infer total education spending for each region.[9] Total education spending is 2.7% of GDP for the USA and 2.2% of GDP for Australia. The bulk of this is spending on wage incomes skilled and unskilled labour. The benchmark shares of these factors in education and other factor income shares by industry are reported in Tables 3 and 4.

Due to well known instability problems that exist in growth models with perfect foresight, solving the model in non trivial (see Dixon et al 1992). A solution consists of a steady state solution and a dynamic path conditional given the steady state and initial conditions. The latter solution is solved using a modified Fair-Taylor method

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[7] Revenue elasticities are taken from Tarr and De Melo (1992).

[8] Specifically in a steady state there is a parametric relationship between factor incomes and factor investment spending for each of the endogenous factors, *Machinery*, *Structures*, and *Residential Housing,*. This means that total value added by each sector is proportional to total investment spending. Faced with data from both sources we scaled the value added data to be consistent with investment spending data. In practice this only required a small adjustment to value added shares.

[9] Specifically the data were taken from ABS (2004) for Australia and U.S. Census Bureau (2004) for the USA.

for solving two-point boundary value problems developed by Wilcoxen (1988).[10] This involves integrating the eight state variables for a sufficiently long finite period so that the infinite horizon solution is approximated, usually in excess of 100 years.

4. Results

The counterfactual experiment is a durables sector specific productivity shock in the USA. This productivity shock is neutral in terms of its impact on factors employed in the *Durables* sector. However it is specific to *Durables* sector. As discussed the size of the productivity increase is chosen to reduce USA durables prices by 10%. This requires a 51.7% decline in the unit cost function in the durables sector. The change is introduced as an unanticipated increase which is fully realized in year 1.[11]

The results are reported Figures 1–3 and more detailed results are given in Table 5. Figure 1 reports the long run (steady state) changes in industry composition of the increase in USA durables productivity. It can be seen that the USA *Durables* sector expands considerably and this leads to increased factor demands from that sector. These factor demand increases are supplied by contractions in other traded sectors. The induced structural change in Australia is something of a mirror image with a large expansion of the agricultural sector and a contraction of durable goods.[12]

The link between the changes in industry structure in the USA and Australia is through the international trade flows. These can be seen in Figure 2 where we report the changes in Australia's trade flows with the USA. The results in Figure 2 show that USA productivity growth generates a significant increase in Australian exports in all sectors except *Durables*, but particularly in *Agriculture*. Overall this represents a substantial (70%) increase in USA–Australia trade volumes.

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[10] The algorithm can be obtained from http://wilcoxen.cp.maxwell.syr.edu/pages/828.html

[11] We have also experimented with phasing the shock in over a period of 10 years. As might be expected this gives very different short run dynamics. In particular when the shock is phased in it allows agents to foresee the productivity growth and engage in inter-temporal trade. In particular they reduce investment spending and raise consumption spending in the short term.

[12] It should be noted that the Durables sector is very small in Australia so that this large percentage change does not represent a large change in the absolute levels of factor demands in that sector.

Thus, in the small open economy framework employed here with perfect capital mobility between sectors, there are substantial long run adjustments in the sectoral composition of output. The changes in industry outputs are generated by changing commodity prices which, for given capital stocks, affect relative factor returns via Stolper-Samuelson effects. Specifically the increase in export demand in the USA generates increases in export prices in Australia which raise the demand for factors employed intensively in that sector. In this case the demand for *Agriculture* tends to raise the demand for *Unskilled labour* (*Lu*). Likewise a decline in Australian *Durables* sector output tends to reduce demand for *Skilled* labour (*Ls*).

In additional, however, falling commodity prices can induce reductions in the relative price of investment inducing accumulation as emphasized by Lee (1995) and Eaton and Kortum (2001). Falling investment costs could in principle offset or amplify the effects on factor returns. To evaluate the overall affects of factor accumulation we consider a summary of the dynamic paths of the main variables is given in Figure 3.

First we consider the response in the USA. It can be seen in panels 3.vii to 3.xii that the exogenous productivity growth in the USA durables sector induces a 10 percent increase in USA real GDP in the long run due to capital deepening. This fits with the stylized facts of an acceleration in labour productivity growth rates of about one percent per year. The productivity growth generates substantial *Machinery and Equipment* capital deepening - increasing by 23%. There is short to medium term increase in the relative wage of skilled workers and a long term increase in skilled labour supply.

For Australia there is a one percent increase in real GDP over 10 years (panel 3.i). While this is only a fraction Australia's total productivity growth over the last decade it represents a potentially important contributing factor. It can be seen, first, that there is very little accumulation of *Machinery and Equipment* capital. All factor returns tend to increase in the short term except *Skilled Labour* (*Ls*). The increase in the return to *Machinery and Equipment* is very modest however and it can be seen that overall there is very little impact on the stock of *Machinery and Equipment* in Australia (panel 3.ii and 3.iv). Specifically falling *Durables* output in Australia dampens the return to *Machinery and Equipment* capital and also dampens domestic

Durables prices responses – which might have otherwise reduced the price of *Machinery and Equipment* investment.

Conversely, for Australia, there is an expansion of *Agriculture* and a large increase in the return to *Unskilled Labour* (*Lu*). There is also a relatively large expansion of *Structures and Residential Housing*. Hence the responses of the skill premium in Australia and the USA are very different. In the USA, productivity growth in *Durables* induces substantial capital deepening and skilled labour accumulation. Wages of skilled and unskilled labour both rise but there is a significant increase in the skill premium in the short term. However the long run responses show that increase in the skilled labour force eventually erodes and reverses the change skill premium. In the long run there is a 6% increase in skilled labour and the skill premium declines.

In Australia, however, there is a one percent fall in the skill premium on impact leading to a decline in skilled labour accumulation in the medium term. These effects are much smaller in absolute magnitude than the USA reflecting the much smaller overall changes in economic output. Nevertheless the USA productivity growth does cause a 3% decline in the output of *Education* relative to GDP on impact (see Table 5).

Thus the effect of USA productivity growth on USA *Durables* in Australia is to raise the output of *Agriculture*; increase the relative demand for *Low Skilled* labour; cause a substantial fall in Australian *Durables* production, and; cause a small fall in *Skilled Labour* accumulation. In the context of the "old economy – new economy debate" the results very much point to the USA productivity growth enhancing Australia's "old economy sectors." Cost reductions in USA *Durables* do not induce a parallel expansion in Australian *Machinery and Equipment Capital* or a rising demand for *Skilled Labour*. Rather the main effect appears to be through increased import demands for Agriculture in the USA. This result contrasts with the mechanisms discussed by Lee (1995) and Eaton and Kortum (2001) who emphasize the potential for international transmission of growth via falling prices of capital imports.[13]

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[13] Sensitivity tests with alternative values of the elasticities of transformation in The CET revenue function have predictable implications for the changes in the sectoral outputs. Specifically doubling

5. Conclusion

We have considered the effects of acceleration in *Durables* sector productivity in the USA using a multi-sector dynamic trade model of a three region economy, Australia, the USA and the ROW. The results for the USA support other recent studies, since, in the presence of capital-skill complementarity, the productivity increase raises skilled wages in the USA and generates capital deepening of *Machinery and Equipment*. The principle question of interest however is the extent to which these effects impact on Australia?

The changes in the USA affect Australia through the terms of trade - which in turn have dynamic consequences through changes in factor returns and changes in investment costs. Interestingly we find that there is no substantial accumulation of *Machinery and Equipment* capital in Australia. Nevertheless GDP in Australia increases by one percent over 10 years. This income growth is sustained by substantial changes in output and trade patterns across the economy. In particular there is a large increase in exports of *Agriculture* to the USA. The rising demand for agricultural output also leads to a rise in the demand for *Unskilled Labour*. Consequently schooling enrollments fall in the short term and the skilled workforce declines in the long term.

The results may help understand part of Australia’s productivity history during the last 10-15 years. In particular as argued by Parham (2004) Australia’s sectoral pattern of productivity growth has been mixed with productivity growth in Communications and Financial Service sectors but also Agriculture. The results here indicate that this may reflect the effect of the external “new economy” growth is to strengthen Australia’s comparative advantage in traditional export sectors.

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these elasticities tends to make the output responses larger. These sensitivity tests however do not reveal any change in the qualitative story described here and have only small implications for the main aggregates.

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Table 1: Sectors, Factors and Regions in the Model

Commodities	*Factors*	*Regions*	*Spending Aggregates*
Agriculture	Machines	USA	Consumption
Minerals	Structures	Australia	Government
Low Tech	Residential Housing	ROW	Machines
Int Manufacture	Skilled Labour		Structures
Durables	Unskilled Labour		Residential Housing
Traded Services	Land		Education
Construction	Resources		
Non Traded Services			
Public			
House			
Education			

Table 2 Parameter Values

CET Revenue Function Parameters	
Elasticity of transformation in CET revenue functions - *Agriculture*	3.9
Elasticity of transformation in CET revenue functions - *Minerals*	2.9
Elasticity of transformation in CET revenue functions - *Low Tech*	2.9
Elasticity of transformation in CET revenue functions - *Intermediate Manufactures*	2.9
Elasticity of transformation in CET revenue functions - *Durables*	2.9
Elasticity of transformation in CET revenue functions - *Traded Services*	0.7
Nested CES Cost Function Parameters	
Elasticity of substitution between all Reproducible Capital types and *Unskilled Labour*, *Resources and Land*	0.67
Elasticity of substitution between all *Machinery*, *Structures*, and *Housing* Capital	1.67
CES Spending Aggregates	
Elasticity of Substitution in expenditure functions – *Consumption*	1.2
Elasticity of Substitution in expenditure functions – *Government*	1.2
Elasticity of Substitution in expenditure functions - Investment in *Machinery and Equipment*	1.2
Elasticity of Substitution in expenditure functions - Investment in *Structures*	1.2
Elasticity of Substitution in expenditure functions - Investment in *Residential Housing*	1.2

Table 3: Value Added Shares by Industry - Australia

	Machinery and Equipment	*Structures*	*Residential Housing*	*Skilled Labour*	*Unskilled Labour*	*Land*	*Resources*
Agriculture	0.24	0.14	0.00	0.09	0.41	0.11	0.01
Minerals	0.18	0.41	0.00	0.06	0.11	0.00	0.24
Lowtech	0.31	0.10	0.00	0.21	0.38	0.00	0.00
Int Manufacture	0.34	0.15	0.00	0.21	0.30	0.00	0.00
Durables	0.29	0.09	0.00	0.26	0.36	0.00	0.00
Traded_Serives	0.29	0.12	0.00	0.37	0.22	0.00	0.00
Construction	0.22	0.22	0.00	0.20	0.37	0.00	0.00
Non Traded Services	0.16	0.15	0.00	0.25	0.44	0.00	0.00
Public	0.04	0.09	0.00	0.74	0.13	0.00	0.00
House	0.00	0.00	0.69	0.00	0.02	0.29	0.00
Education	0.04	0.09	0.00	0.61	0.26	0.00	0.00

Table 4: Value Added Shares by Industry - USA

	Machinery and Equipment	*Structures*	*Residential Housing*	*Skilled Labour*	*Unskilled Labour*	*Land*	*Resources*
Agriculture	0.27	0.14	0.00	0.13	0.37	0.09	0.01
Minerals	0.09	0.19	0.00	0.13	0.24	0.00	0.35
Lowtech	0.24	0.07	0.00	0.25	0.44	0.00	0.00
Int Manufacture	0.23	0.09	0.00	0.30	0.38	0.00	0.00
Durables	0.19	0.05	0.00	0.44	0.32	0.00	0.00
Traded_Serives	0.28	0.10	0.00	0.50	0.11	0.00	0.00
Construction	0.14	0.13	0.00	0.25	0.48	0.00	0.00
Non Traded Services	0.13	0.11	0.00	0.20	0.55	0.00	0.00
Public	0.04	0.09	0.00	0.56	0.31	0.00	0.00
House	0.00	0.00	0.66	0.00	0.02	0.33	0.00
Education	0.02	0.05	0.00	0.65	0.28	0.00	0.00

Table 5 Dynamic Paths of Key Variables

Dynamic Responses to USA Productivity Growth: Australia (% Change)

	Year 1	Year 5	Year 10	Year 100
Real GDP per capita	0.7	0.7	1.0	1.2
Real Consumption per capita	0.5	1.2	0.8	1.4
Invesment in Machinery and Equipment	-2.3	-0.8	-0.1	-0.6
Investment in Structures	0.3	1.9	2.5	1.0
Investment in Housing	1.3	1.7	1.8	1.4
Real return to Machine and Equipment	0.5	0.8	0.9	0.6
Real return to Structures	1.5	1.2	1.1	0.3
Real return to Housing	1.9	2.1	1.0	0.3
Real Skilled wages	-0.1	-0.1	0.3	1.0
Real Unksilled wages	0.9	0.6	1.0	1.1
Land rents	5.0	5.3	4.8	4.9
Resource rent	-0.5	1.0	2.8	2.6
Skill Premium	-1.0	-0.7	-0.6	-0.1
Education Output relative to GDP	-3.2	-1.7	-1.2	-1.5
Ls/Lu	-0.1	-0.3	-0.4	-0.5
Internal Exchange Rate (pT/pNT)	-1.2	-1.2	-1.1	-1.1
Terms of Trade	1.3	1.8	2.1	1.8
Trade Surplus	0.5	-0.3	0.0	0.0
Openness	8.2	9.1	9.7	9.5

Dynamic Responses to USA Productivity Growth: USA (% Change)

	Year 1	Year 5	Year 10	Year 100
Real GDP per capita	2.7	5.3	7.1	10.0
Real Consumption per capita	6.1	3.8	4.2	9.2
Invesment in Machinery and Equipment	1.1	-0.8	-3.0	-4.9
Investment in Structures	2.7	6.5	6.0	2.6
Investment in Housing	2.6	2.4	2.7	2.3
Real return to Machine and Equipment	-1.5	-10.5	-15.0	-16.5
Real return to Structures	0.0	3.0	2.7	0.6
Real return to Housing	8.0	3.2	1.7	0.6
Real Skilled wages	1.7	5.6	7.6	6.5
Real Unksilled wages	0.6	3.9	5.8	8.7
Land rents	6.3	2.6	2.3	5.4
Resource rent	-38.0	-28.5	-24.3	-24.0
Skill Premium	1.1	1.7	1.6	-2.0
Education Output relative to GDP	6.1	5.4	3.5	-3.2
Ls/Lu	0.4	1.9	3.6	9.9
Internal Exchange Rate (pT/pNT)	-7.3	-8.1	-8.7	-8.9
Terms of Trade	-11.6	-9.2	-8.3	-9.1
Trade Surplus	-3.8	-0.5	0.7	0.0
Openness	10.5	13.8	14.4	11.0

Figure 1: Long run Output responses in USA and Australia (percentage change from base)

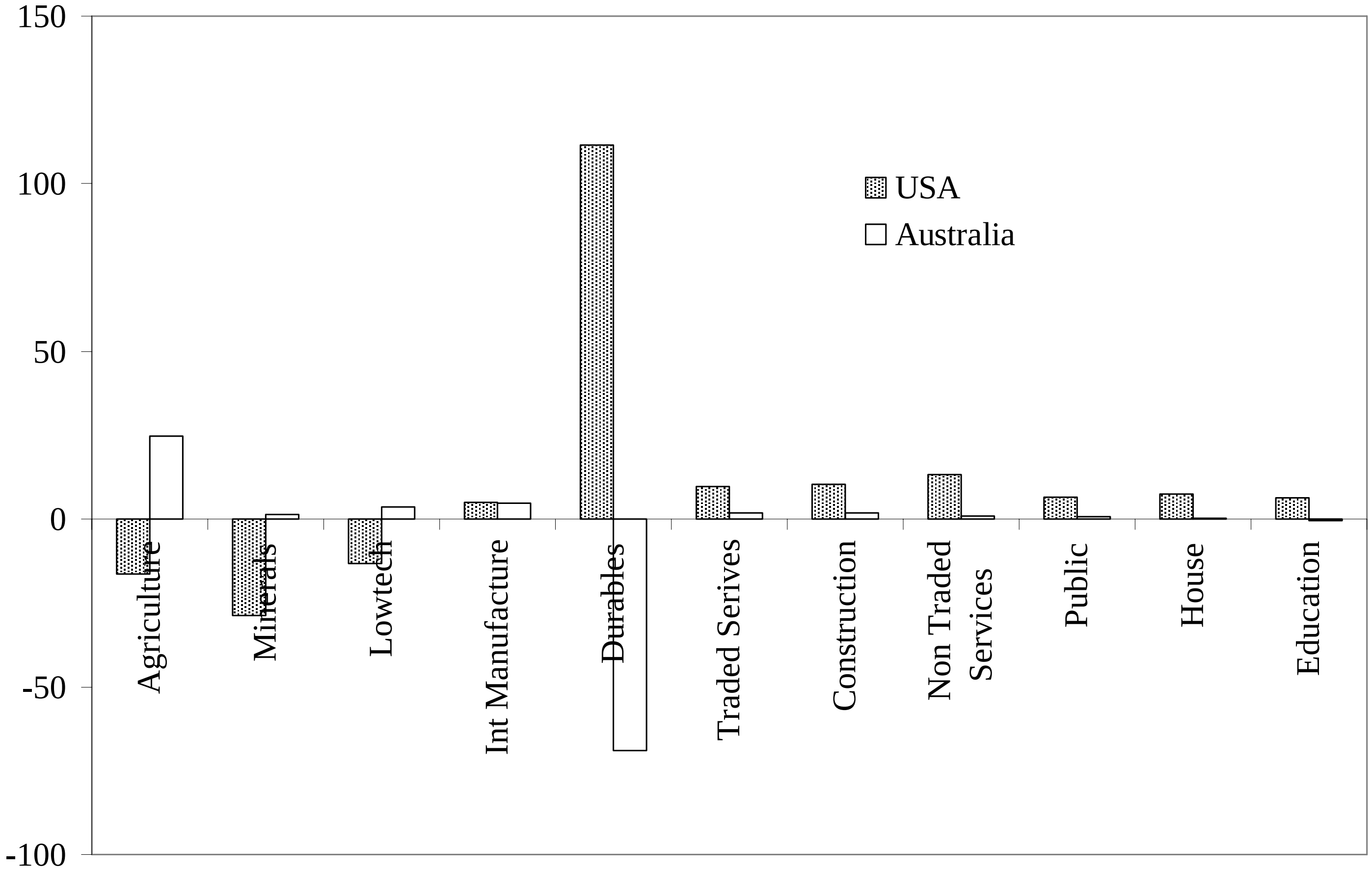
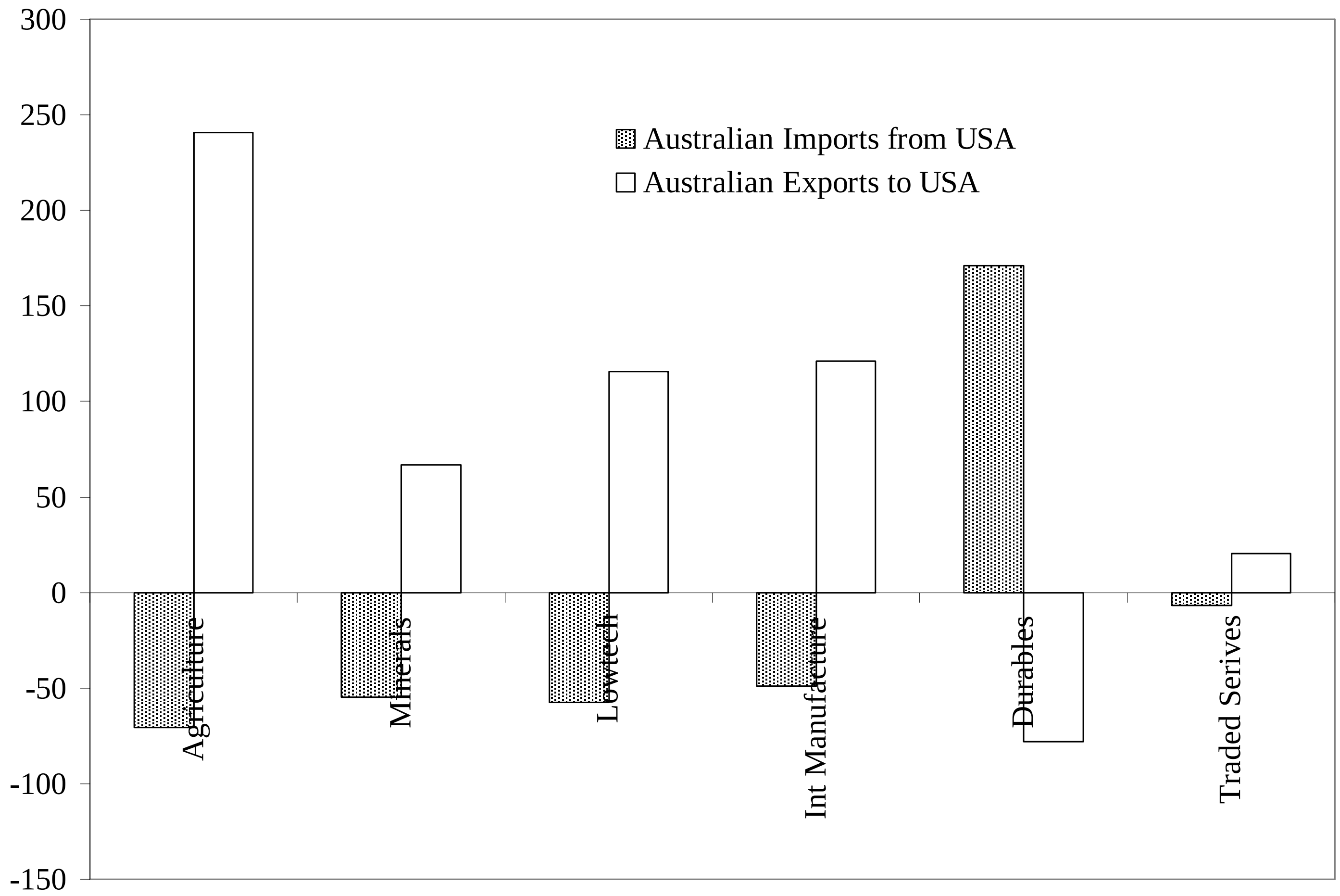


Figure 2: Long run Change in USA Australia Bilateral Trade (percentage change from base)



Appendix

This appendix gives an overview of the dynamic CGE model used in "Dynamic Adjustments to Terms of Trade Shocks: The USA Productivity Boom and Australia" by Richard G. Harris and Peter E. Robertson, presented at the Australian Conference of Economists, 2005, Curtin Business School, Perth, WA.

The structure of the model is similar to a small open economy trade model. It consists of three regions, the *USA*, *Australia* the *Rest-of-World* aggregate. Domestic prices and capital stocks are endogenous in the *USA* and *Australia*. In the *Rest-of-World* region aggregate supply and prices are exogenous. However the export supplies of the *Rest-of-World* with respect to *USA* and *Australia* are endogenous and depend, in particular, on the domestic market prices in these regions, which are also endogenous. The following discussion details the structure of the model.

A1. Technology

Firms in *Australia* and the *USA* use intermediate goods and primary factors of production to produce a real gross output flow, g_i, in each industry *i*. The inputs of the valued added aggregating vector are the reproducible inputs, *Machinery and Equipment*, $V_{M,i}$, *Structures*, $V_{S,i}$, *Residential* capital, $V_{D,i}$, and *Skilled Labour*, Ls_i. The exogenously evolving inputs are *Unskilled-Labour*, Lu_i, *Land*, $V_{N,i}$ and *Resources*, $V_{E,i}$. Thus, for *Australia* and the *USA* we have a value added function

$$v_i = f_i(V_{M,i}, V_{S,i}, V_{D,i}, Ls_i; Lu_i, V_{N,i}, V_{E,i}) \qquad (1.)$$

Dual to the value added aggregator, $v_{i,}$, is a cost function

$$c_i = \chi_i(w_{M,i}, w_{S,i}, w_{D,i}, ws_i; wu_i, w_{N,i}, w_{E,i}) \qquad (2.)$$

Intermediate goods and the intermediate and value added aggregates are combined with fixed coefficients. Let M_i denote an intermediate input aggregate in each industry *i*. Then

$$M_i = \min_j \left(\frac{Y_{ji}}{a_{ji}} \right) \quad (3.)$$

where a_{ji} is a technological parameter and Y_{ji} is the quantity of good *j* used as an input in sector *i*. The real gross output flow g_i, in each industry *i*, is then

$$g_i = \min(M_i, f_i(v_i)) \quad (4.)$$

A2 Commodity Supply

In the traded goods industries gross output is an aggregate of three destination specific goods-one good destined for the home market, and two others for the other respective export regions. For each region *R*, where the regions are *USA Australia* (AUS) and *Rest-of-World* (*ROW*) gross output for traded good sector, *i*, is

$$g_i^R = g_i^R(x_i^{USA}, x_i^{AUS}, x_i^{ROW}) \quad (5.)$$

where g_i^R is convex and linear homogenous in its arguments. Dual to it is the unit revenue function given by

$$r_i^R(p_i^{USA}, p_i^{AUS}, p_i^{ROW}) \quad (6.)$$

where the p_i^R are producer prices in each region, $p_i^R = q_i^R/(1+\tau)$ and τ is determined by any relevant consumption taxes and tariffs. The revenue function is assumed to be of the Constant Elasticity of Transformation (CET) form. The regional supply functions are obtained from this revenue function using the envelope theorem. Thus, letting subscripts denote a partial derivative, the set of supplies per unit of gross output for industry *i*, g_i^R, in the *USA* to its home market, *Australia* and to the *Rest-of-World* is $\{r_{i1}^{USA}, r_{i2}^{USA}, r_{i3}^{USA}\}$. Likewise for Australia the unit supplies to *USA*, home and *Rest-of-World* is $\{r_{i1}^{AUS}, r_{i2}^{AUS}, r_{i3}^{AUS}\}$, and for *Rest-of-World* the unit supplies to *USA*, *Australia* and the *Rest-of-World* are $\{r_{i1}^{ROW}, r_{i2}^{ROW}, r_{i3}^{ROW}\}$. In the non-traded goods industries gross output is simply a single output industry.

A3 Demand

Intermediate demands for each industry i are given by

$$\sum_j a_{ij}^R \; g_j^R \tag{7.}$$

Final demands for each commodity, except education services, are determined by aggregate spending types $z \in \{C, G, M, S, R)$ where; C denotes consumption spending; G is *Government Spending*; M is investment in *Machinery and Equipment*; S investment in *Structures* and; D is *Residential Housing*. For each spending type in each region, there is a constant elasticity of substitution (CES) unit expenditure index function.

$$e_z^R(\mathbf{q}^R) \tag{8.}$$

where $\mathbf{q}^R$ is the vector of consumer prices for each region. Shepherd's Lemma gives a vector of commodity demands generated by each component of final demand

$$d_{zi}^R = \frac{\partial e_z^R}{\partial q_i^R} Q_z^R \tag{9.}$$

where $Q_z^R \, e_z^R$ is the total spending on each element of the list of spending types z, and Q_z^R in the real quantity index for each of these spending types.

The level of spending on each type is determined through inter-temporal maximization decisions by households, except for government spending, G. Government spending is assumed to be determined by a simple policy rule that fixes aggregate spending as a proportion of GDP.

$$G^R / Y^R = \omega \tag{10.}$$

A lump sum subsidy is used to redistribute any surplus back to consumers, so the government budget is balanced at each point in time.

For investment spending aggregates *M*, *S*, and *D*, the aggregate spending at a point in time is determined by households who choose an optimal investment plan to maximize the net present value of the rental stream of the asset, given an adjustment cost function $C\left(Q_k^R, V_k^R\right)$. Assuming quadratic adjustment costs we obtain an investment demand equation for each asset type *k*, as

$$Q_k^R = \left(\frac{\Pi_k^R - p_k^R}{b_k u_k^R} + \gamma + \delta_k \right) V_k^R \quad k \in \{M, S, D\} \tag{11.}$$

where Π_k^R is the shadow price of a unit of capital of type *k*, b_k is a parameter of the adjustment cost function, γ is the steady state growth rate of the economy and u_k refer to after tax rentals on physical capital.

In addition to physical capital, the households make schooling decisions to augment their skilled labour supplies. At a point in time the labour force in each region, *Australia* and the *USA*, consists of skilled workers Ls^R, unskilled workers, Lu^R, and those who at are school acquiring human capital, H^R, where $H^R = \zeta\ E^R$ and E^R is the annual number of new graduates each of whom has attended school for ζ years. Hence we treat H^R as a decision variable. We assume schooling is purchased in a competitive market at price p_{ed}^R. Total spending on education services is given by $H^R\ A_{ed}^R\ p_{ed}^R$ where A_{ed}^R is a technical parameter that represents the level of costs per student and p_{ed}^R is the consumer price for education, inclusive of education subsidies.

We assume further that new graduate faces costs in entering the workforce due to on-the-job-training costs, which affects their productivity. This is captured by the adjustment cost function $C_H(H^R, Ls^R)$. Given quadratic adjustment costs we derive a schooling demand equation for each region.

$$H^R = \left(\frac{\Pi_s^R - u_u^R - p_{ed}^R A_{ed}^R}{b\ u_s} + \beta\xi \right) Ls \tag{12.}$$

where and u_s and u_u refer to after tax wages for skilled and unskilled labour.

Consumption spending is determined by household maximization of an inter-temporal utility function of consumption at each date, and the deviation in net foreign assets from a target stock. This gives rise to an aggregate consumption demand per person of;

$$c_t^R = \bar{c}^R (1+\gamma - n)^t + \alpha(1+\gamma - n)^t (f_t^R - \bar{f}^R)^t \qquad (13.)$$

for *Australia* and *USA*, where $\bar{c}^R$ is the steady state level of consumption per person in region *R*, γ-n is the growth rate of consumption per worker and $\bar{f}^R$ is the current and target level of net foreign assets to GDP ratio in region *R*.

A4 Static Equilibrium

In a *static* equilibrium the Π_k^R, $\bar{c}^R$ and $\bar{f}^R$, are taken as given along with the endowment vectors V_k^R. Formally we have:

Definition 1. A static equilibrium is a set of producer prices, $p_i^R = q_i^R/(1+tax)$; factor prices, w_k^R and gross outputs g_i^R for two regions, *Australia* and the *USA*, which for given values of Π_k^R, $\bar{c}^R$ and $\bar{f}^R$ and V_k^R, satisfy:

Zero profits;

$$r_i^R = \sum_{j=1}^n a_{j,i}^R q_j^R - c_i^R$$

Goods market clearing;

$$r_{i1}^{USA} g_i^{USA} + r_{i1}^{AUS} g_i^{AUS} + r_{i1}^{ROW} V_i^{ROW} = \sum_j a_{ij}^{USA} g_j^{USA} + a_{ie}^{USA} y_e^{USA} + \sum_z d_{zi}^{USA} \qquad i = 1 \cdots 6$$

$$r_{i2}^{USA} g_i^{USA} + r_{i2}^{AUS} g_i^{AUS} + r_{i2}^{ROW} V_i^{ROW} = \sum_j^n a_{ij}^{AUS} g_j^{AUS} + a_{ie}^{AUS} y_e^{AUS} + \sum_z d_{zi}^{AUS} \qquad i = 1 \cdots 6$$

$$g_i^R = \sum_j a_{ij}^R g_j^R + a_{ie}^R y_e^R + \sum_z d_{zi} \qquad i = 7 \cdots 10, \quad R \in \{USA, AUS\}$$

Factor market clearing;

$$V_k^R - C\left(Q_k^R, V_k^R\right) = \sum_i \frac{\partial c_i^R}{\partial w_k} g_i^R \quad k \in \{M, S, D, Ls\}, \;\; R \in \{USA, AUS\}$$

$$V_k^R = \sum_i \frac{\partial c_i^R}{\partial w_k} g_i^R \quad k \in \{Lu, N, E\}, \;\; R \in \{USA, AUS\}$$

A static equilibrium thus consists of 22 zero profit conditions; 22 commodity market clearing conditions, and 14 factor market clearing conditions solving 2×11 commodity prices, q_i^R; 2×7 factor prices, w_k^R and 2×11 gross outputs g_i^R.

A5 Dynamics

The dynamic path for the economy is described by the following equations of motion for $2 \times 8 + 1$ state variables. These are the 7 primary factors in each region, the population of each region and the world endowment. For each region $R \in \{USA, AUS\}$ we have

$$\begin{aligned} V^R{}_{k,t+1} &= Q^r{}_{k,t} + (1-\delta_k) V^r{}_{kt}, \quad k \in \{M, S, D\} \\ Ls_{t+1}^R &= Ls_t^R (1-\delta_s) + E_t^R \\ V^R{}_{k,t+1} &= V^R{}_{kt}, \quad k \in \{N, E\} \\ Pop^R{}_{t+1} &= (1+g_t) Pop^R{}_t \end{aligned} \tag{14.}$$

For the *Rest-of-World* region we have an exogenously growing world endowment.

$$V_{t+1}^W = (1+g_t^W) V_t^W \tag{15.}$$

In addition for $R \in \{USA, AUS, ROW\}$ there is a net foreign asset balance for each region which evolve as,

$$F_{t+1}^R = surp_t^R + (1+r) F_t^R, \tag{16.}$$

Where $surp_t^R$ is the trade surplus for region *R* at time *t*.

To complete the description of the economies optimal dynamic path model we need to describe the dynamic path for asset prices. These are also given by the household inter-temporal maximization problems. Suppressing the region index we, in each region and for each physical asset *k*, we have;

$$\Pi_{kt}^{k} = \frac{1}{1+\rho}\left[(u_{k,t+1} - u_{k,t+1}C_2^k(Q_{k,t+1}, V_{k,t+1}) + (1-\delta_k)\Pi_{k,t+1}^{k}\right], \quad k \in \{M,S,R\} \qquad (17.)$$

$$\Pi_{st}^{H} = \frac{1}{(1+\rho)}\left[u_{s,t+1}(1 - C_2^H(H_{t+1}, LS_{t+1})) - u_{u,t+1} + (1-\delta_e)\Pi_{s,t+1}\right] \qquad (18.)$$

Again we have suppressed the regional index for clarity. Thus there are four dynamic asset price equations in each region associated with each of the 4 endogenous capital stocks in each region.

A6 Steady State

In the steady-state we have the requirement that the growth rate of each capital stock must be equal to γ, the long run growth rate. For each region $\{USA, AUS\}$ this gives,

$$\frac{Q_k^R}{V_k^R} = \delta + \gamma \qquad (19.)$$

$$\frac{H^R}{Ls^R} = \beta\xi \qquad (20.)$$

$$\Pi_k^R = p_k^* = \frac{w_k^*}{\rho + \delta_k} \qquad (21.)$$

$$\Pi_E^R = u_u + p_{ed} = \left(\frac{1+\lambda}{(1+\rho) - (1-\delta)(1+\lambda)}\right)(u_s - u_u) \qquad (22.)$$

where λ is the steady state growth rate of GDP per worker productivity.

Finally the steady-state condition for the target stock of foreign assets, *f* to be constant is,

$$\bar{f} = \frac{1+\gamma}{\gamma - r}(1-\bar{c}+\omega-gov-inv) \qquad (23.)$$

where ω , gov and inv are, respectively, tax, government spending and investment spending as a fraction of GDP.