The Short to medium Run Economic Costs of Alternative Emission Reduction Scenarios*

Warwick J. McKibbin**
Centre for Applied Macroeconomic Analysis
in the ANU College of Business and Economics
and
The Brookings Institution and
The Lowy Institute for International Policy

Final Version 8 January 2009

---

* The views expressed in the paper are those of the authors and should not be interpreted as reflecting the views of any of the above collaborators or of the Institutions with which the authors are affiliated including the trustees, officers or other staff of the ANU, Lowy Institute or The Brookings Institution nor does it reflect the views of The Australian Treasury. This is a background paper prepared for the Australian Treasury report on "Australia's Low Pollution Future: The Economics of Climate Change Mitigation". Part of this research was jointly undertaken with Dr Alison Stegman and draws on joint research with Peter Wilcoxen. The authors thank Waranya Pim Chanthapun for excellent research assistance and Nicole Mies for editorial assistance. This research has benefited from collaboration with researchers at the Australian Treasury including Andrew Ceber, Robert Ewing, Meghan Quinn and Robert Scealy.

** Send correspondence to Professor Warwick J McKibbin, Centre for Applied Macroeconomic Analysis, ANU College of Business and Economics, Australian National University, ACT 0200, Australia. Tel: 61-2-61250301, Fax: 61-2-61253700, Email: warwick.mckibbin@anu.edu.au.

1 Introduction

Creating a robust policy framework for dealing with climate change and climate uncertainty is a key global and national policy issue. There is a wide range of possible policy approaches ranging from “cap and trade” to a carbon tax with a Hybrid in between. This report deals explicitly with the approach outlined in the Australian Government’s recent Green Paper on the “Carbon Pollution Reduction Scheme” (CPRS) report. In evaluating the consequences of alternative targets under a CPRS approach, the impacts of such a scheme depends on the extent of reduction targets, the timing of the reductions, the marginal abatement costs of mitigation, and the extent of participation of other countries in a global scheme amongst a wide range of other factors.

One way of assessing various policy options is to use economic models to gain insights into key aspects of various emissions reduction strategies. Even the best of the existing small stock of economic models that can be used to evaluate alternative climate policies are very simple representations of complex economies. They should be used with great care and do not purport to give precise predictions of the world economy. The greatest benefit from using a model is for showing key insights on proposed policies and orders of magnitudes of the quantitative effects of policies and shocks. They are not capable of accurately predicting the outcome of any policy, but they provide substantially more insight than produced by special pleading of both extremes of the policy debate or back of the envelope calculations of economic policies. Results can be highly sensitive to input assumptions as well as the structure of the model.

As part of a collaborative project with the Australian Treasury, this report summarizes the G-Cubed multi-country model highlighting the strengths and weaknesses of this model for policy analysis. It then outlines the modifications that were made to the G-Cubed model in order to more fully answer specific questions on the cost of some alternative climate policies in the specific context of the CPRS approach. The questions addressed are in no way exhaustive. Indeed a small subset of possible policy approaches are explored in this report. Within this subset of policies, the experiments in this report explicitly assume a sequencing of international agreements on climate change that are a subset of a number that might emerge in coming years. They also presume that permit trading across national borders is possible and undertaken at least cost[1].

The primary economic results can, to a first approximation, be interpreted as informing a wide range of policy alternatives around the pricing of greenhouse gas emissions from a global carbon tax or a McKibbin Wilcoxen Hybrid but with second order transfers between countries occurring. In some cases (as noted) these transfers do not change the fundamental insights of the analysis, although in some cases the transfers can be large enough to be of first order in magnitude. Many of the insights from the modeling undertaken can therefore be applied to a wider range of policy considerations and not just a pure global emissions trading system. It is also important to stress that the policies considered in this report are not conventional theoretical "cap and trade" permit trading systems. Emissions are not actually capped in any year. The approaches in this report explicitly assume a target for concentrations of emissions by 2100. There is almost complete banking and borrowing within and across countries in the systems that are modeled (although not complete in some cases) so that emissions in any year do not have to hit a particular target. In a very important sense, the policies modeled are also very similar to national coordinated policies such as the McKibbin Wilcoxen Hybrid[2] except that in the results there are transfer payments between

---

1 In other papers McKibbin and Wilcoxen (2002a,2002b) have argued that wide spread international permit trading is unlikely to occur because of the characteristics of emission permits that are similar to national monies. There has not been a global currency and for the same reason there is unlikely to be a global permit market. Nonetheless it is worth considering what a perfect world of carbon trading might achieve as a benchmark to compare alternative policy approaches.

2 See McKibbin and Wilcoxen (2002a,2002b, 2007, 2008)

countries to cover the cost of permits when permits are needed to be purchased by one country from another.

The report is structured as follows. Section 2 summarizes the G-Cubed multi-country model (also fully documented at www.gcubed.com). Section 3 outlines the new extensions to the model that enabled multiple gases to be incorporated for the Treasury report. Section 4 summarizes the baseline that was replicated using assumptions provided by Treasury to be commensurate with the other models in the Treasury report. Section 5 summarizes the four scenarios for concentration targets by 2100 that are explored. Section 6 presents the results of the scenarios expressed as deviations from the imposed baseline of the model. Section 7 summarizes the key insights from the analysis and suggests key areas where future research is needed.

2 The G-Cubed Multi-Country Model

This section outlines a global economic model called G-Cubed which is used in this report to explore different global emissions trading regimes. The G-Cubed model is summarized in Table 1. Full documentation of the version (GGGV83E) used in this report can be found at www.gcubed.com It is a widely-used dynamic intertemporal general equilibrium (or DSGE) model of the world economy with 9 regions[3] and 12 sectors of production in each region. The model produces annual results for trajectories running many decades into the future.

The theoretical structure is outlined in McKibbin and Wilcoxen (1998)[4]. A number of

3 Other versions have more and different regional aggregations but version GGGv83E with modifications as indicated in this report was used for this report.

4 Full details of the model including a list of equations and parameters can be found online at: www.gcubed.com.

Table 1: Overview of the G-Cubed Model (Version GGGv83E)

Regions	
1	United States
2	Japan
3	Australia
4	Europe
5	Rest of the OECD
6	China
7	Oil Exporting Developing Countries
8	Eastern Europe and the former Soviet Union
9	Other Developing Countries
Sectors	
Energy:	
1	Electric Utilities
2	Gas Utilities
3	Petroleum Refining
4	Coal Mining
5	Crude Oil and Gas Extraction
Non-Energy:	
6	Mining
7	Agriculture, Fishing and Hunting
8	Forestry/ Wood Products
9	Durable Manufacturing
10	Non-Durable Manufacturing
11	Transportation
12	Services
Other:	
13	Capital Producing Sector

studies—summarized in McKibbin and Vines (2000)—show that the G-cubed modeling approach has been useful in assessing a range of issues across a number of countries since the mid-1980s.[5]

The model is based on explicit intertemporal optimization by the agents (consumers and firms) in each economy[6]. In contrast to static CGE models, time and dynamics driven by

5 See McKibbin and Vines (2002).

6 See Blanchard and Fischer (1989) and Obstfeld and Rogoff (1996).

short term rigidities are of fundamental importance in the G-Cubed model. The G-Cubed model is also known as a DSGE (Dynamic Stochastic General Equilibrium) model in the macroeconomics literature and a Dynamic Intertemporal General Equilibrium (DIGE) model in the computable general equilibrium literature.

In order to track the macro time series, the behavior of agents is modified to allow for short run deviations from optimal behavior either due to myopia or to restrictions on the ability of households and firms to borrow at the risk free bond rate on government debt. For both households and firms, deviations from intertemporal optimizing behavior take the form of rules of thumb, which are consistent with an optimizing agent that does not update predictions based on new information about future events. These rules of thumb are chosen to generate the same steady state behavior as optimizing agents so that in the long run there is only a single intertemporal optimizing equilibrium of the model. In the short run, actual behavior is assumed to be a weighted average of the optimizing and the rule of thumb assumptions. Thus aggregate consumption is a weighted average of consumption based on wealth (current asset valuation and expected future after tax labor income) and consumption based on current disposable income. Similarly, aggregate investment is a weighted average of investment based on Tobin's Q (a market valuation of the expected future change in the marginal product of capital relative to the cost) and investment based on a backward looking version of Q.

There is an explicit treatment of the holding of financial assets, including money. Money is introduced into the model through a restriction that households require money to purchase goods.

The model also allows for short run nominal wage rigidity (by different degrees in different countries) and therefore allows for significant periods of unemployment depending on the labor market institutions in each country. This assumption, when taken together with the explicit role for money, is what gives the model its "macroeconomic" characteristics.

(Here again the model's assumptions differ from the standard market clearing assumption in most CGE models.)

The model distinguishes between the stickiness of physical capital within sectors and within countries and the flexibility of financial capital, which immediately flows to where expected returns are highest. This important distinction leads to a critical difference between the quantity of physical capital that is available at any time to produce goods and services, and the valuation of that capital as a result of decisions about the allocation of financial capital. In climate policy this effect is important since climate policies affect expected future returns to capital differently in different sectors.

As a result of this structure, the G-Cubed model contains rich dynamic behavior, driven on the one hand by asset accumulation and, on the other by wage adjustment to a neoclassical steady state. It embodies a wide range of assumptions about individual behavior and empirical regularities in a general equilibrium framework. The interdependencies are solved out using a computer algorithm that solves for the rational expectations equilibrium of the global economy. It is important to stress that the term ‘general equilibrium’ is used to signify that as many interactions as possible are captured, not that all economies are in a full market clearing equilibrium at each point in time. Although it is assumed that market forces eventually drive the world economy to a neoclassical steady state growth equilibrium, unemployment does emerge for long periods due to wage stickiness, to an extent that differs between countries due to differences in labor market institutions.

The main weaknesses of the model is the degree of disaggregation of sectors which means the model can’t be used to explore details of small disaggregated sectors. Also the representation of technology is via a production function approach rather than specific technologies. This is not such as drawback in an aggregated model because there is no such thing as an aggregated technology that doesn’t look like a traditional production function. This prevents the analysis of specific detailed policy interventions, but other models exist which can do this however without the macroeconomic and financial richness of the G-Cubed model.

3 Model developments undertaken for this project

There were a number of enhancements introduced into the model to enable the assessment of multiple greenhouse gases in addition to carbon dioxide emissions from energy combustion which is already modeled.

a) Emissions

A new prototype module for calculating emissions of methane (CH4), nitrous oxide (NO), non combustion carbon (NC) and waste was added to the G-Cubed model. In the version used in this report we calculated emissions in the following way. CH4, NO and non combustion carbon emissions are assumed to be based on the output of each sector. First we calculate an emissions coefficient (using 2001 data) where for example the coefficient for sector i is:

$Cc\_ch4_i = CH4emissions_i / Output_i$

$Cc\_n2O_i = N2Oemissions_i / Output_i$

$Cc\_ncc_i = NCCemissions_i / Output_i$

Emissions from households are assumed to be proportional to consumption of different goods. For example, emission of CH4 from households' consumption of gas is calculated as

$Cc\_ch4G_i = CH4emissions_i / Consumption_i$

Sectoral emissions from waste are assumed to be proportional to sectoral gross output. For example the emissions coefficient of CH4 from waste is:

Cc_ch4W_i= CH4emissions from $waste_i$ /$OUTPUT_i$

These emission coefficients are all calculated in a spreadsheet using data supplied by Treasury, and fed into the model through the file SETPARAMETERS.CSV

The full set of new parameters is contained in Table 2:

Table 2: New Treasury Parameters

Type	Name	Definition
parameter	cc_ch4(goods,regions)	'emissions coefficients, methane' ;
parameter	cc_ch4G(goods,regions)	'emissions for gas, methane' ;
parameter	cc_ch4W(goods,regions)	'emissions for waste, methane' ;
parameter	cc_n2o(goods,regions)	'emissions coefficients, nitrous oxide' ;
parameter	cc_n2oW(goods,regions)	'emissions for waste, nitrous oxide' ;
parameter	cc_ncc(goods,regions)	'emissions coefficients, non combust co2' ;

We also defined new variables:

Table 3: New Treasury Variables

Type	Name	Definition	Type	Units
variable	EMME(regions)	'methane emissions'	end,	mmtgdp ;
variable	EMNO(regions)	'nitrous oxide emissions'	end,	mmtgdp ;
variable	EMNC(regions)	'non carbon emissions'	end,	mmtgdp ;
variable	EMTC(regions)	'total carbon emissions'	end,	mmtgdp ;
variable	EMTCEQ(regions)	'total carbon equivalent emissions'	end,	mmtgdp ;
variable	TCARCH4(regions)	'unit tax on carbon equivalent methane '	end,	cent ;
variable	TCARNO(regions)	'unit tax on carbon equivalent nitrous oxide'	end,	cent ;
variable	TCARNC(regions)	'unit tax on non combustion carbon emissions'	end,	cent ;

b) Concentrations and Temperatures

The G-Cubed model only produces profiles for annual greenhouse gas emissions. The emissions profiles from the model are copied into an Excel worksheet, which converts the G-Cubed profiles into a form suitable for the MAGICC climate calculator, which in turn yields concentrations, temperature forcing, and the change in temperature forcing.

4 Baseline Projections and reference scenario

In the G-Cubed model, projections are usually made based on a range on input assumptions. There are two key inputs into the growth rate of each sector in the model. The first is the economy wide population projection. The second is the sectoral productivity growth rate. In Bagnoli et al (1996) and McKibbin Pearce and Stegman (2007), we outline the approaches for modeling catch-up in sectoral growth rates in the G-Cubed model. In this report we modify the usual approach followed in G-Cubed to incorporate assumptions provided by Treasury for population and productivity growth by sector to be consistent with the projections from the other economic models. This is not ideal but it is the only way that the different models can have the same baseline projection for growth and emissions. Given these exogenous inputs for sectoral productivity growth and population growth, we then solve the model with the other drivers of growth, capital accumulation, sectoral demand for other inputs of energy and materials, all endogenously determined. Critical to the nature and scale of growth across countries are these assumption plus the underlying assumptions that financial capital flows to where the return is highest, physical capital is sector specific in the short run, labor can flow freely across sectors within a country but not between countries, and that international trade in goods and financial capital is possible subject to existing tax structures and trade restrictions.

Thus the economic growth of any particular country is not completely determined by the exogenous inputs in that country since all countries are linked through goods and asset markets. Carbon emissions from combustion are determined in the model by the amount of fossil fuels (coal, oil, natural gas) that are consumed within each country in each period. Other emissions depend on the assumption made in the previous section. These primary factors are endowed within countries but can also be traded internationally subject to transportation costs (captured implicitly through the elasticities of substitution between each good in the model). Thus economic growth can occur within a country, without any particular pattern implied for energy use. The pattern for energy use will be dependent on the underlying inputs into the growth process.

The baseline for global emissions is shown in Chart 1 below.

5 Alternative Scenarios

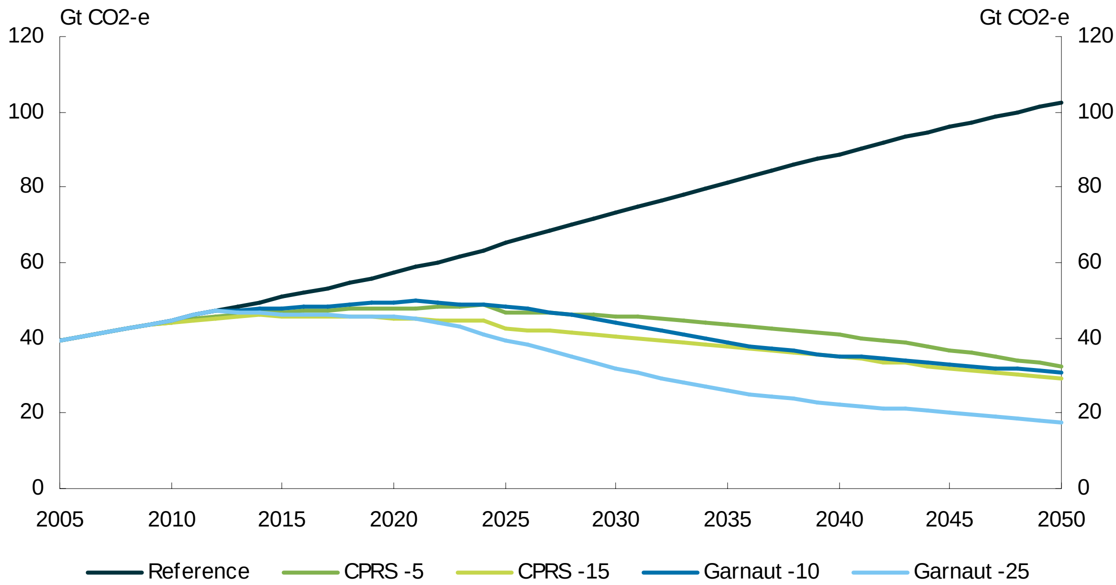
Based on directions from Treasury, four different target scenarios were modeled with different assumptions about when countries would join a global greenhouse policy regime. These regimes and the timing of regions joining are set out in Table 4.

Further details can be found in the Government's Report. The assumptions in Table 4 result in the emissions paths for the world in Chart 1 from the report.

Table 4: Four Scenarios

Scenario	Concentration Stabilization	Participation	Key assumptions
CPRS-5	550 ppm by 2100	2010 Annex B, China 2015, all developing by 2025	Full banking, limited international trading until 2020, rights based on gradual divergence from reference scenario
CPRS-15	510 ppm by 2100	2010 Annex B, China 2015, all developing by 2025	As above
Garnaut-10	550 ppm by 2100	All countries from 2013	Full international trading, contraction and convergence allocation of emission rights
Garnaut-25	450 ppm by 2100	All countries from 2013	As above

Chart 1: Global emissions and allocations

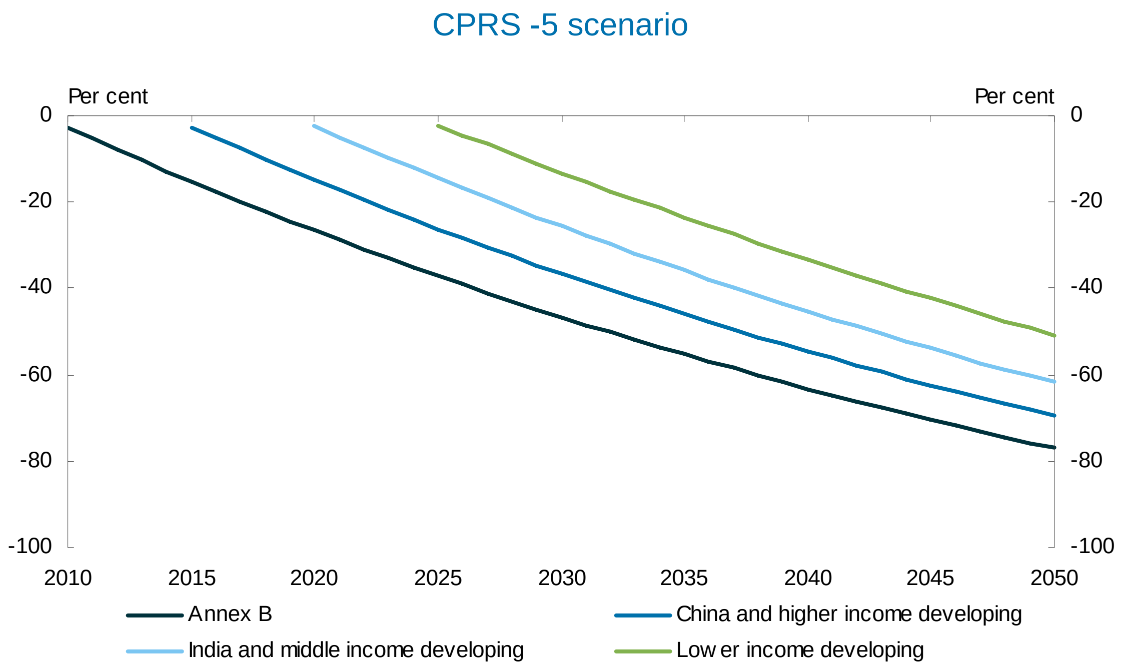


Source: Australian Government (2008); Chart 4.2

The allocation of permits in the Garnaut scenarios is based on a contraction and convergence model with eventual convergence of emission per capita (see Garnaut (2008)). The allocation in the CPRS scenarios are summarized for CPRS-5 in Chart 2.

It is important to stress that these results do not contain any shielding support for affected industries as it was difficult to implement in the model within the time available for undertaking the analysis.

Chart 2: Multi-stage emission allocations: relative to reference scenario



Source: Australian Government (2008). Chart 4.4.

Results for the four scenarios are contained in Figures 1 through 20. In these figures the focus is on the issues in which the G-Cubed model has a comparative advantage relative to the other models: the short to medium term macroeconomic adjustment (including in labour markets where there is not assumed to be full employment) and the domestic and international financial implications of the policies. Results are presented for each region in the model for carbon prices, real Gross Domestic Product (GDP); Real Gross National Product (GNP); private investment, the current account, employment, inflation, real interest rates, the value of the share market; and the real effective exchange rate (defined as an increase is an appreciation). Results are presented as percentage deviation relative to the reference scenario, except for the current account which is percent of GDP deviation from the reference scenario and inflation and interest rates which are expressed as percentage point deviation from reference scenario (1 is 1 percentage point or 100 basis points). Results are presented for the period 2010 to 2035 because the focus is on the short to medium run even though the model was run out to 2050.

The results for carbon price in $US per ton of CO2-e are contained in Figures 1 and 2. The carbon price is assumed to rise at the real rate of interest (by assumptions provided by Treasury) with the initial jump sufficient to reach the global concentration target for each scenario. Note that in Figure 1 there is a common global price for carbon for the Garnaut scenarios because all countries participate in the global carbon market. Differentiation occurs in the allocation of emissions permits across countries. The price paths are very smooth because there are no restrictions, nor market failures in these scenarios.

The results for carbon prices for the CPRS scenarios in the Green Paper are contained in Figure 2. In this case a similar methodology is used except that countries enter the markets at different times and there are some restrictions on trading. This shows up in the price volatility especially for high marginal cost countries such as Japan, Europe and the Former Soviet Union. Removal of trade restrictions enables more smoothing of the carbon price. There is a slight spike in Australia in 2019 as constraints on trading are reached.

Several issues stand out in the results. The first is that the restrictions on permit trades causes volatility in some variables for some countries. Spikes in carbon prices translate into spikes in economic activity. This will vary in practice depending on a range of assumptions. Secondly as countries face a binding emissions constraint, their GDP falls in the early years of entry significantly. The short run dynamics and the long run averaging of costs over many years are quite different in their implications than the short run adjustment. Under the Garnaut-450 trajectory, Australia's GDP is projected to fall by over 2 percent lower on average than base over the first five years (see Figure 3). A large part of the economic costs occur up front and then gradually rise over time as adjustments occur, and firms and households have time to adjust to the new innovations induced by the carbon price. For industrialized economies the GDP reduction in the first five years range from 0.25 percent for

Japan to 3 percent for the rest of the OECD in 2013 for the 450ppm scenario and two thirds of that for the 550ppm scenario. Interestingly for the Garnaut scenarios developing countries (who also enter in 2013) face similarly large GDP losses, in particular OPEC economies face enormous losses in GDP in the initial years of 12 percent of GDP for the 450 scenario. Even allowing income transfers through permit trading does not reduce the GDP losses, although it does reduce the GNP losses since permit transfers are included in GNP. Despite these transfers, GNP is still below base from 2013 in both Garnaut scenarios. It is clear that despite the transfers through permit trading to developing countries there are still negative implications of taking a domestic carbon price at the same time as the industrial economies. Just transferring money for permits is not sufficient to give substantial differentiation in economic costs. This point is not new and is familiar from a decade of literature (see for example McKibbin, Shackleton and Wilcoxen (1999).

The results for GDP and GNP for the Green Paper CPRS scenarios are contained in Figures 4 and 6. Recall that the carbon pricing policy begins earlier than the Garnaut scenarios - in 2010 - and have a different phasing on the timing of each country's entry. Costs rise sharply in high abatement cost countries like Japan, Europe and Former Soviet Union until 2020 due to limits on trading[7].

Results for private investment for each scenario are shown in Figures 7 and 8. There are two different forces acting on private investment in each economy. The announcement of the policy in 2007 to begin either in 2010 or 2013 mean that some sectors that are carbon intensive will anticipate the decline in the return on capital in their sector and cut back investment. Other firms will ramp up investment in anticipation of the gains to new technologies and investments in non carbon emitting inputs. This anticipation effect is

---

7 Spikes in prices that can be possible under the system modeled can be eliminated as argued by McKibbin and Wilcoxen (2008) in a coordinated system of national pricing system.

important in the G-Cubed model because of the role of forward looking expectations in decision making and because financial markets provide support in investing for expected future gains. The other factor weighing on investment is the expected future slowdown of the global economy as a result of the near term carbon constraint where the overall reduction in economic activity reduces the expected return to capital. In some cases, countries that are most affected will have a more negative impact of expected returns and financial capital will flow from those economies to economies with less impacted expected returns. The flows of capital will shown up as an improvement in the current accounts of countries losing capital and a worsening in the current accounts of countries that are gaining foreign capital inflow. In Figures 5 and 6 The United States and Japan experience initially stronger investment where countries like Australia and other Annex B countries experience weaker investment. Global capital flows to the larger economies away from fossil fuel intensive economies. This effect was noted in McKibbin, Shackelton and Wilcoxen (1999). This makes the loss in GDP larger for the countries losing capital and smaller for the countries gaining capital. Note that the negative investment effects are larger for the developing economies.

The impact of the policies on the current account for each country is shown in Figures 10 and 11. As anticipated above, countries such as the United States experience a worsening in their current account as capital flows in whereas Australia experiences an improvement in the current account as capital flows out. Unfortunately all the developing regions experience capital outflows due to the return to capital falling in these economies.

One of the strengths of the G-Cubed model is that it is not an equilibrium model in the short run. Labour market rigidities, sticky prices and adjustment costs mean that it takes many decades for equilibrium to be restored after an economic shock. This is shown clearly in the results for employment shown in Figures 11 and 12. The results are deviations from a reference scenario trajectory in which economies were moving from various degrees of excess demand and excess supply of labour towards a long run steady state in which all workers are eventually employed, subject to permanent structural rigidities. In all economies the carbon constraint causes a fall in employment for the three decades shown in the graphs. Eventually wages will adjust downwards relative to producer prices to ensure all workers are eventually employed. The reason for the decline in employment at the national level is due to the slowdown in overall economic activity globally, and the stickiness of real wages in which the carbon price induced spike in consumer price leads to higher wage claims which reduce the demand for labour. Individual sectors that are carbon intensive lose jobs that are not quickly created by other expanding sectors because of the overall decline in economic activity and spike in real wages. In Australia the average employment loss over the first five years is 1 percent under the Garnaut 450 scenario and 0.5 percent under the Garnaut 550 scenario. The CPRS has a similar initial impact but after a decade employment returns close to reference scenario.

The results for inflation are shown in Figures 13 and 14. It is important to stress that inflation is partly driven by the carbon constraint but also by the reaction of monetary authorities in each economy in response to the changing economic conditions. The monetary rule in each economy differs. The behavior of each region’s central bank follows a region-specific Henderson-McKibbin-Taylor rule with a weight on output growth relative to trend, a weight on inflation relative to trend and a weight on exchange rate volatility.[8] The weights vary across countries with industrialized economies focusing on controlling inflation and output volatility, and developing countries placing a large weight on pegging the exchange rate to the US dollar. Thus inflation is controlled eventually by all monetary authorities with different short run responses depending on the relative weights on inflation versus output loss. The introduction of the Garnaut 450 scenario causes Australian inflation to spike by 0.4% and for the Garnaut-550 scenario to spike by 0.2% in the initial year of the policy. The CPRS

---

8 See Henderson and McKibbin (1993) and Taylor (1993).

scenarios have a slightly higher inflation spike of 0.7 percent and 0.5 percent for the 15 percent and 5 percent cuts. As with the other variables in the model, inflation tends to be volatile around a small range once the various country entry assumptions are taken into account.

As mentioned above, the change in the carbon price reduces the return to capital in the short run. Figures 15 and 16 show that this translates into a decline in real interest rates of between 0.2 percentage points and 4 percentage points for the Garnaut 450 scenario. The longer run change in real interest rates is directly related to the global changes in the return to capital. The short run changes are a combination of this effect and the change in the short term nominal interest rates set by the monetary authorities in each economy. The differences across economies reflect the expected changes in real exchange rates over time. As a highly greenhouse intensive economy, OPEC experiences a significant fall in real interest rates. This is followed by Australia. In the case of the CPRS scenarios the adjustment path is more volatile reflecting the volatility in other asset prices and economic activity. The overall trend is similar to the Garnaut scenarios.

Figures 17 and 18 contain the results for the share market valuations. This is the total value of all shares. Equity markets fall in all economies upon announcement of the policies with an additional step down when the policies are implemented. The fall in share markets in Australia is between 2 percent and 4 percent initially for the four scenarios. They then drift lower over time reflecting the permanent decline in economic growth relative to reference scenario. There is some volatility in prices in the CPRS scenarios as already outlined. The relatively small fall in share markets reflect the anticipation of the largest impact being up front but the long term changes in profitability is less affected

Finally results for the real effective exchange rates are shown in Figures 19 and 20. The real effective exchange rate is defined in such a way that a rise is an appreciation. As expected countries that are relatively fossil fuel intensive such as Australia and ROECD experience a fall in their real exchange rate although there are a wide range of differences. Partly this reflects the general equilibrium effects of the structure of production, aggregate production outcomes, and the responses of monetary authorities. The outcomes are relatively small because all countries are taking on carbon constraints. A single country taking action would experience a much larger change in its real exchange rate.

6 Summary and Conclusions

This report has focused on the short run to medium run impacts of the four scenarios for global emissions trading in a carbon constrained world. It is found that the very short run impacts are significant in the model used although over time adjustment is relatively smooth. These results are insightful not because of the specific sign of the outcomes but because they show a number of important points. Firstly arbitrary restrictions on the global carbon market and access to that market can generate volatility in carbon prices and asset prices generally. It is not obvious that there are gains to this volatility and thus a strong case can be made to build into policy a capacity to smooth this price volatility. Smoothing of the carbon price in the short run will not necessarily occur because this volatility depends on what actually occurs in future years across a wide range of economic realities. However the results for the scenarios in this report show that excessive short term price volatility can occur in which case it should be taken into account in the system design. Access to global carbon markets if possible, can reduce this problem as might complete banking and borrowing of permits if systems are well designed.

Secondly, developing countries have a significant impact on the price of carbon in industrialized economies.

Thirdly, by linking developing countries into a global carbon price regime, these countries incur adjustment costs which are not necessarily offset sufficiently by “fair” permit allocations such as those under the contraction and convergence allocations modeled.

Finally it is important to understand the short run aggregate effects of policy shifts such as an emission trading system that may deliver emissions reductions with a reasonable economic outcome on average over half a century but which needs to survive the initial years of dislocation and adjustment in order to be sustained. Due to technical problems this report has not modeled the impact of transitional policy measures but the report does demonstrate the importance of dealing with transitional issues in whatever policy framework is designed, independently of how good the policy may look in the longer run.

Figure 1: Carbon Prices from Garnaut 450 and 550 Scenario

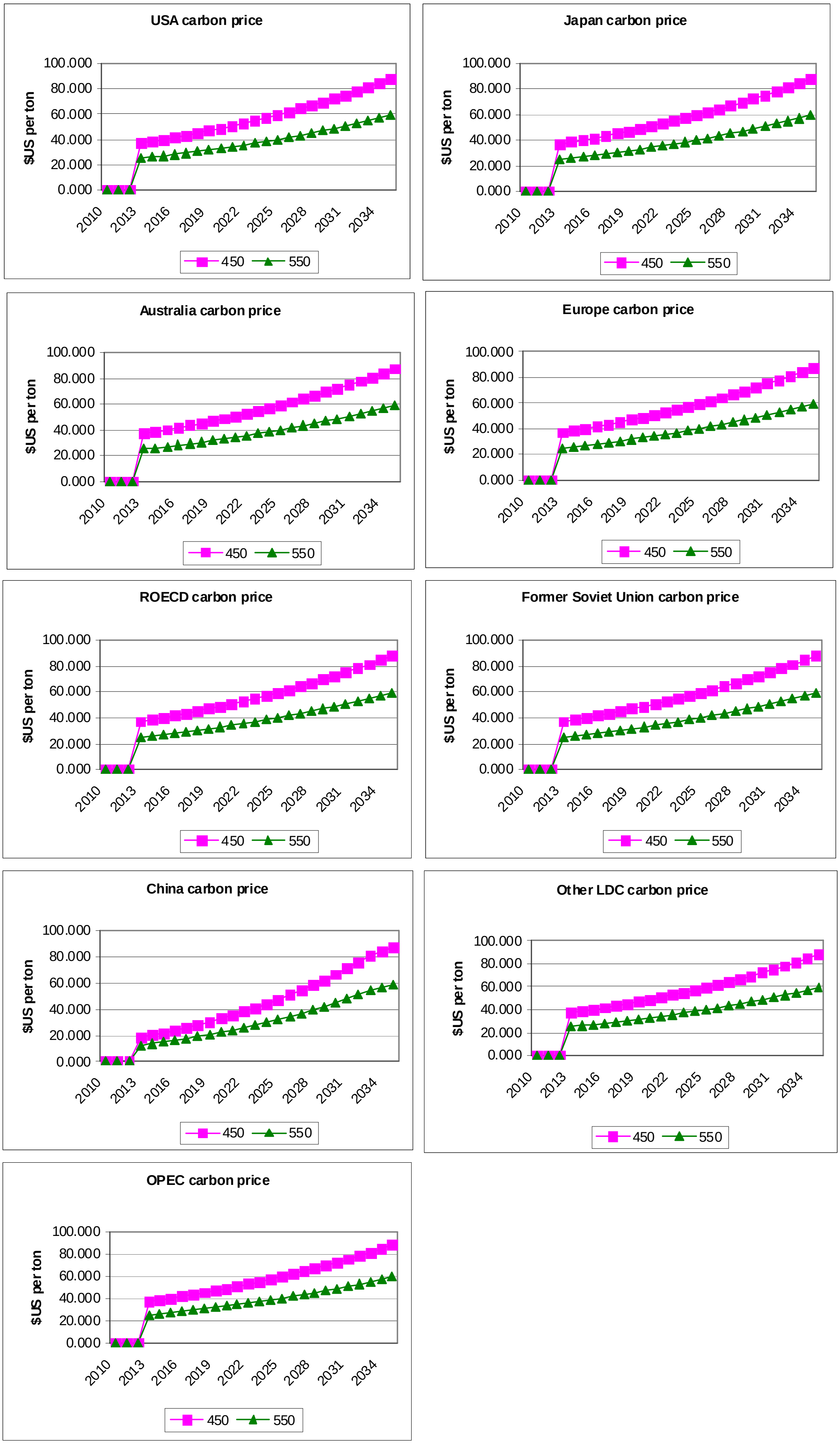


Figure 2: Carbon Prices from CPRS-5 and CPRS-15 Scenarios

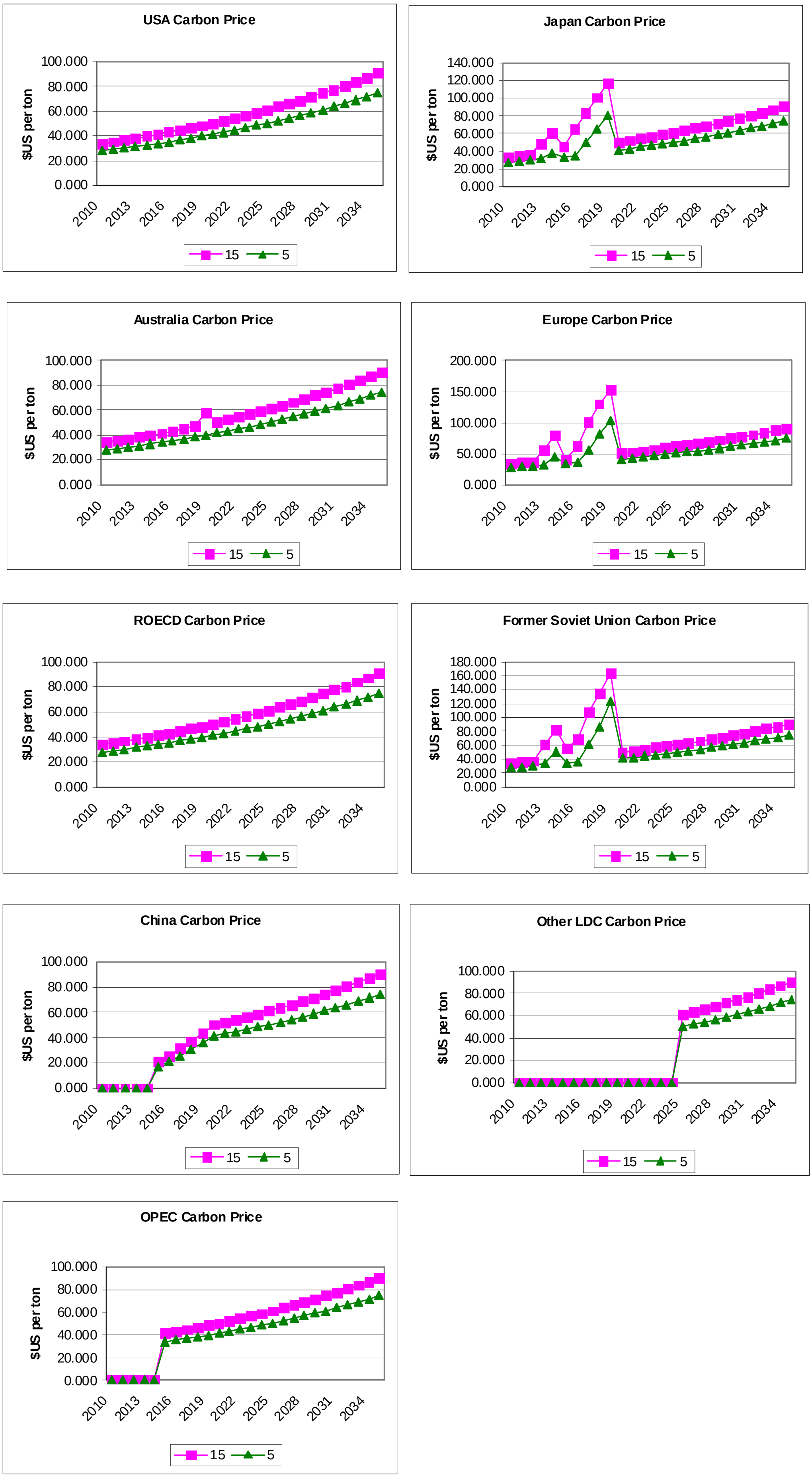


Figure 3: Consequences for Real GDP from Garnaut 450 and 550 Scenarios

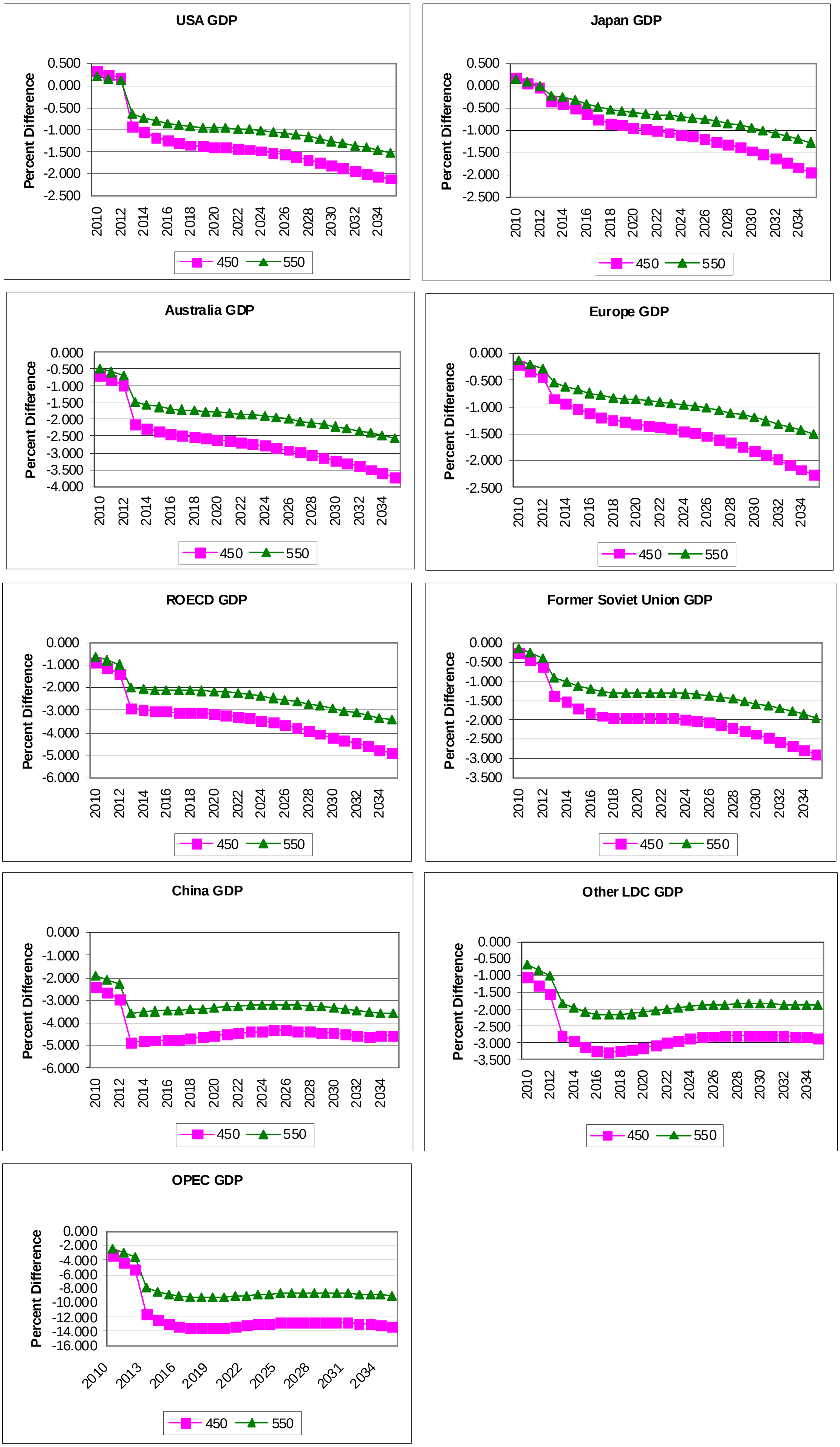


Figure 4: Consequences for Real GDP from CPRS-5 and CPRS-15 Scenarios

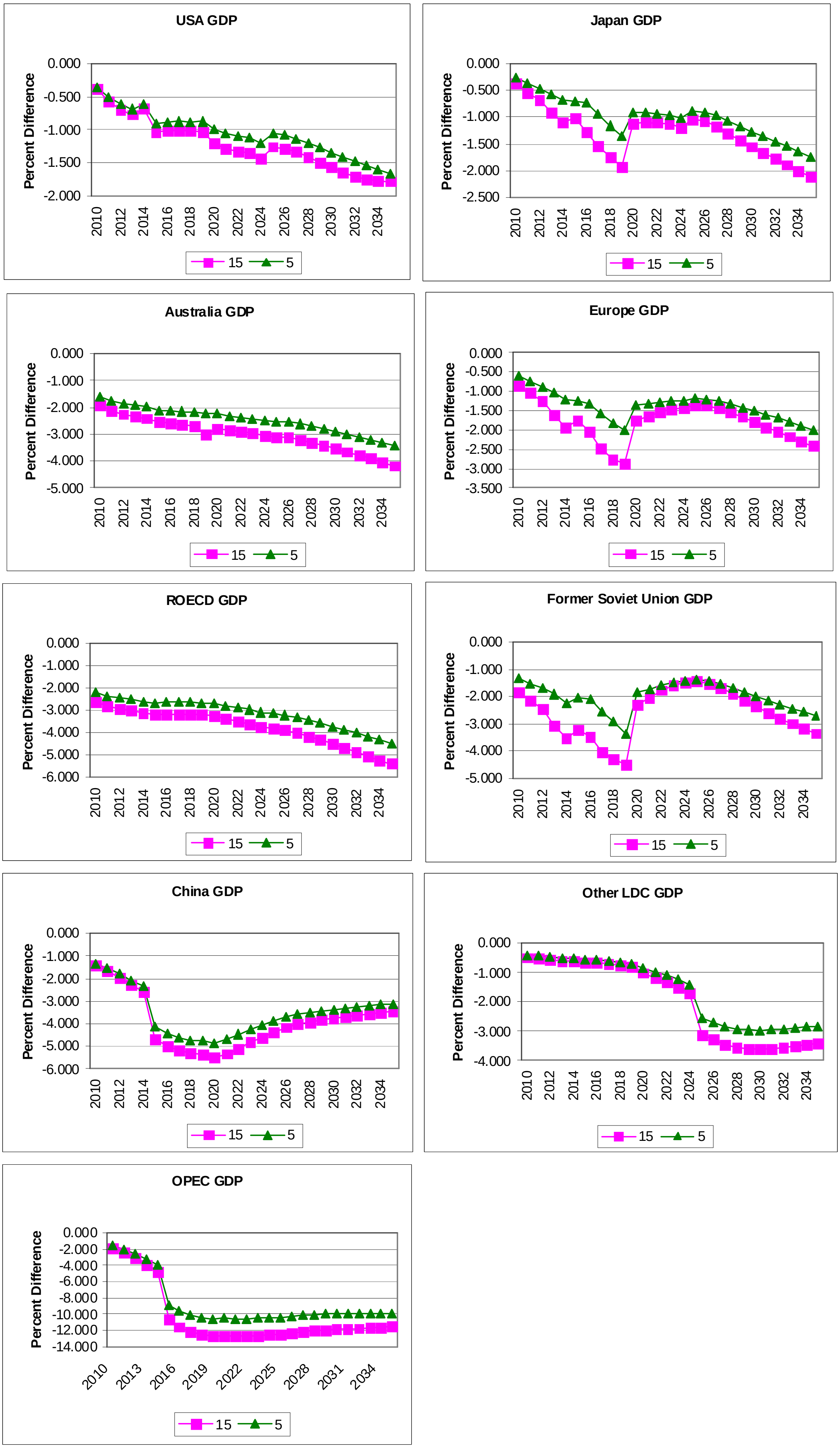


Figure 5: Consequences for Real GNP from Garnaut 450 and 550 Scenarios

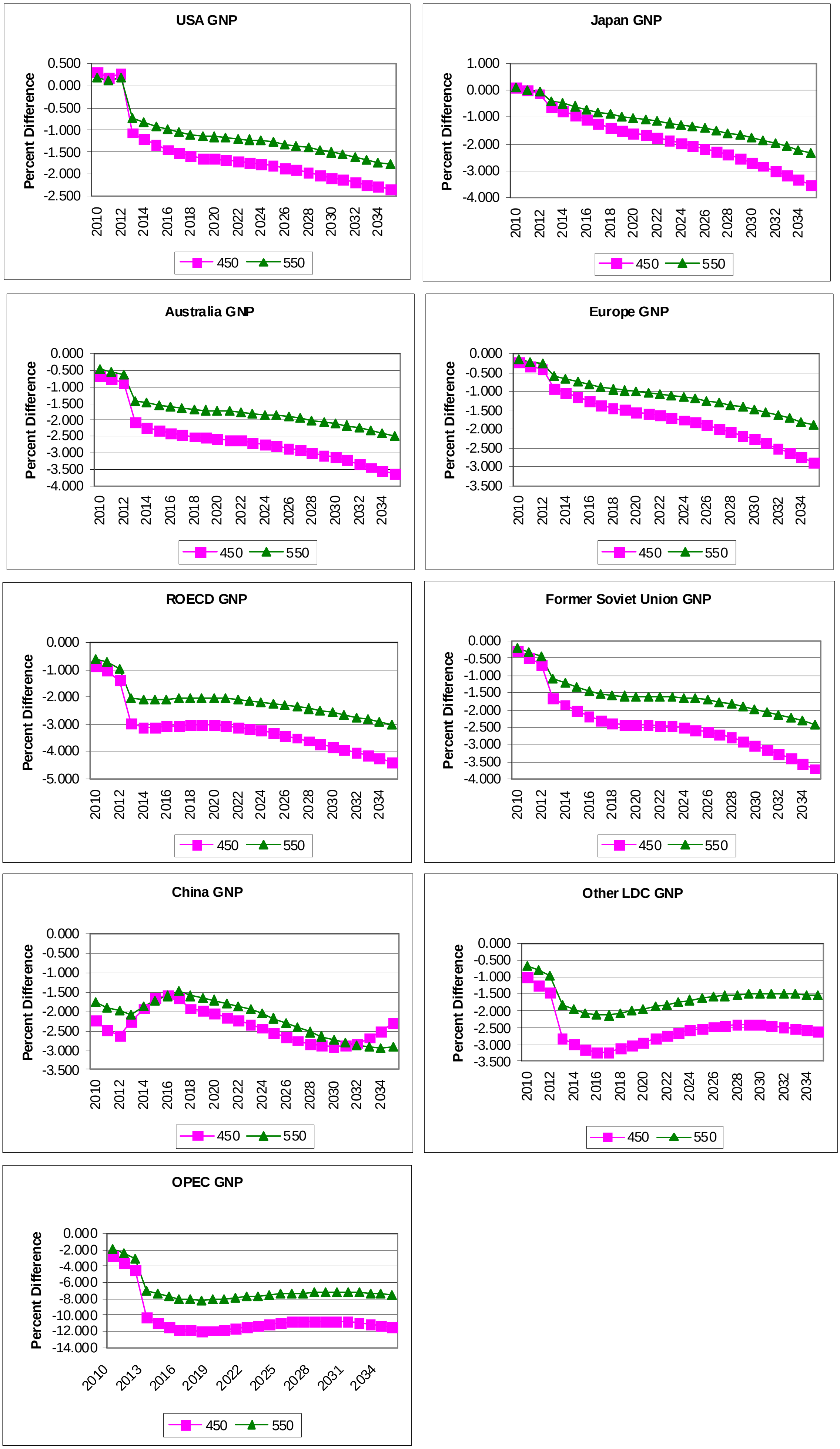


Figure 6: Consequences for Real GNP from CPRS-5 and CPRS-15 Scenarios

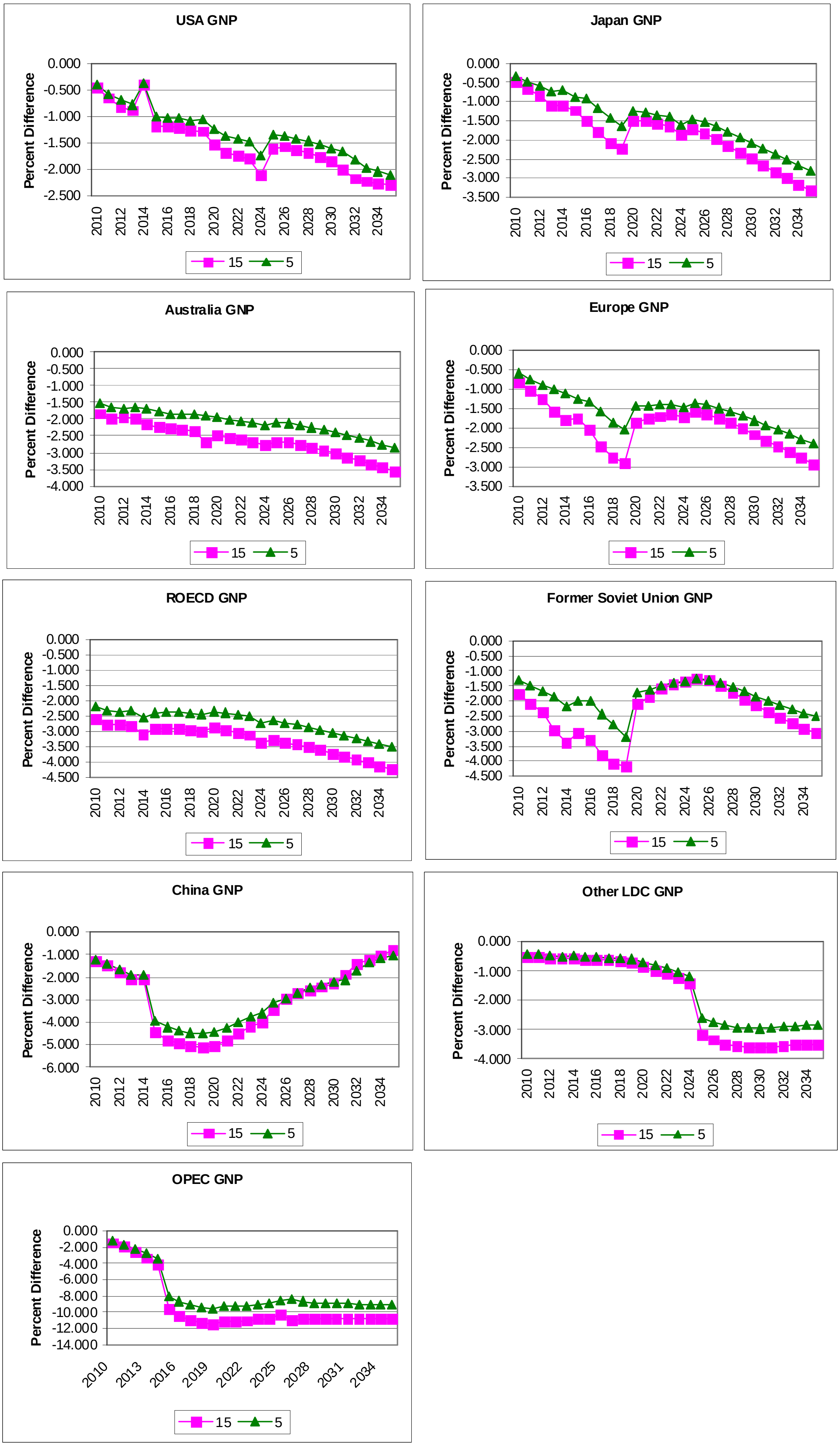


Figure 7: Consequences for Private Investment from Garnaut 450 and 550 Scenarios

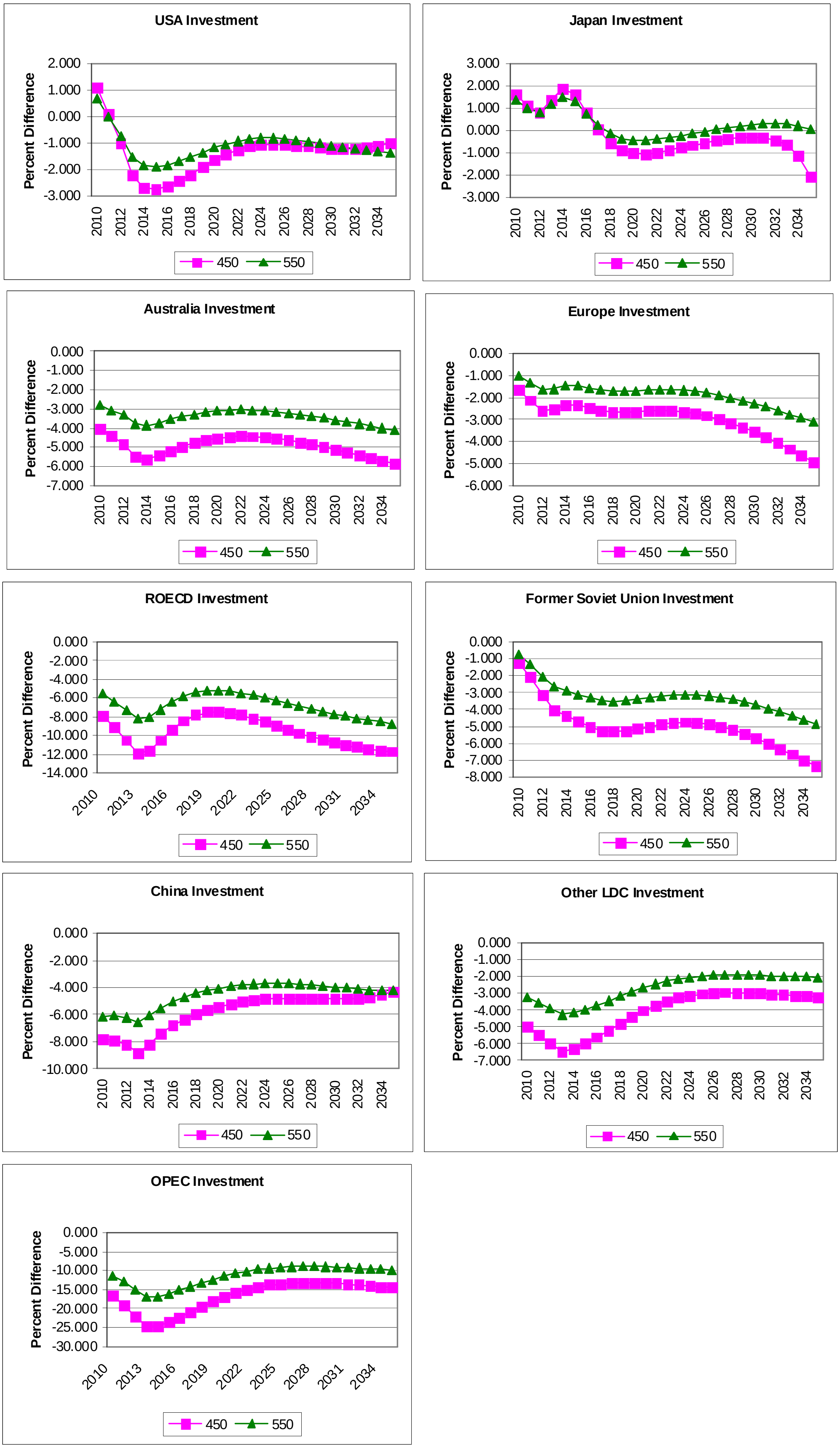


Figure 8: Consequences for Private Investment from CPRS-5 and CPRS-15 Scenarios

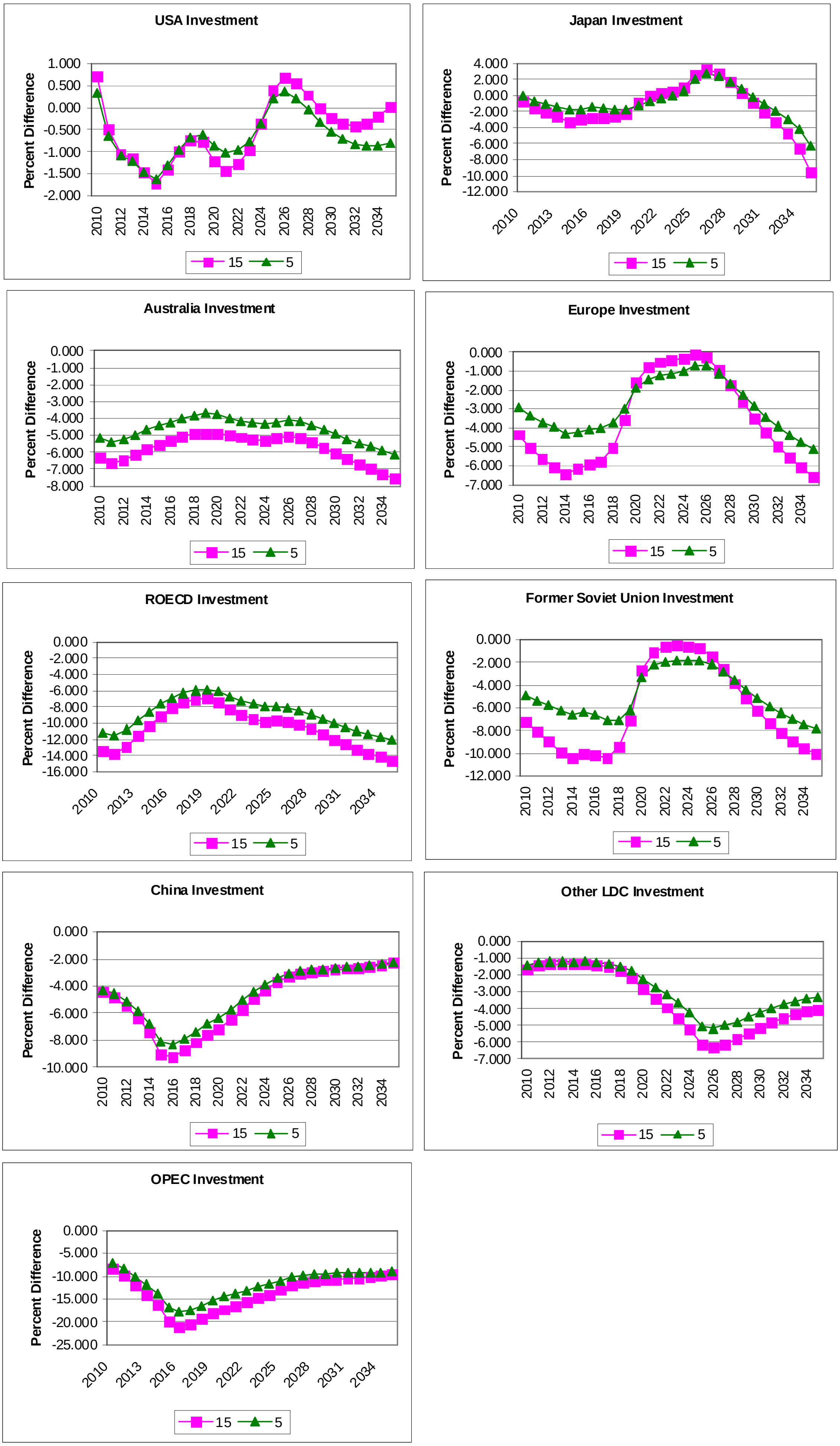


Figure 9: Consequences for Current Account from Garnaut 450 and 550 Scenarios

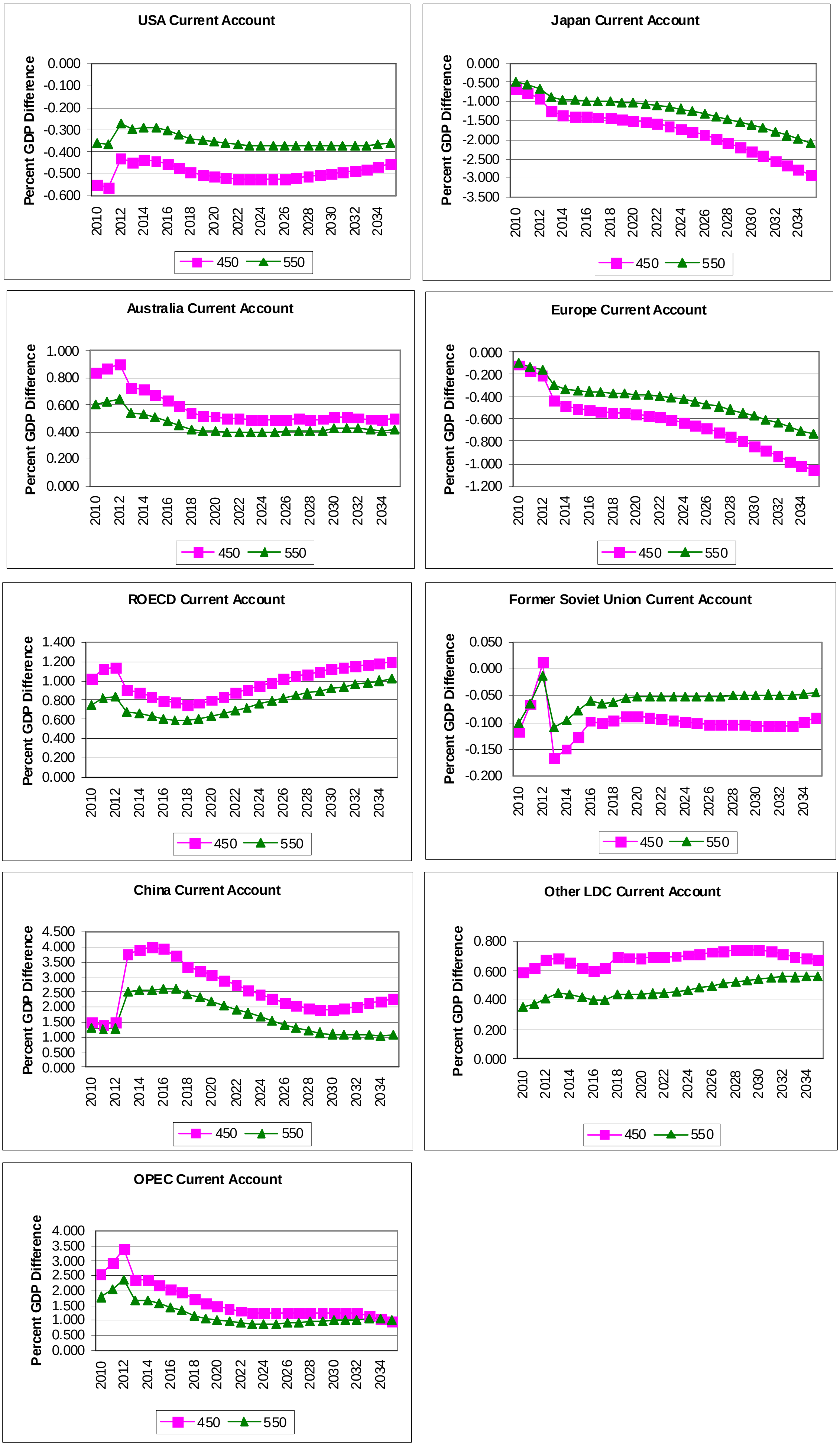


Figure 10: Consequences for Current Account from CPRS-5 and CPRS-15vScenarios

Figure 11: Consequences for Employment from Garnaut 450 and 550 Scenarios

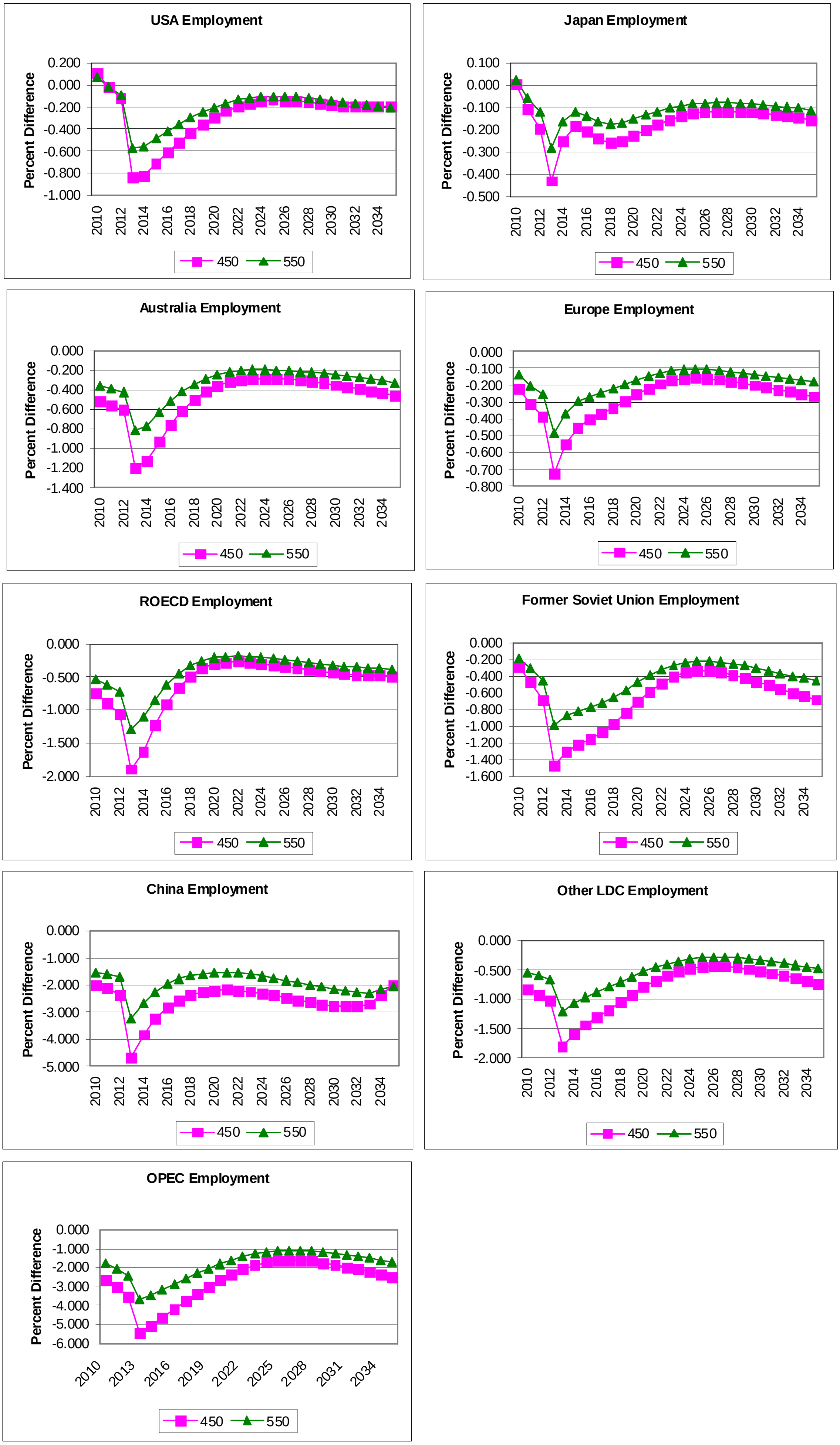


Figure 12: Consequences for Employment from CPRS-5 and CPRS-15vScenarios

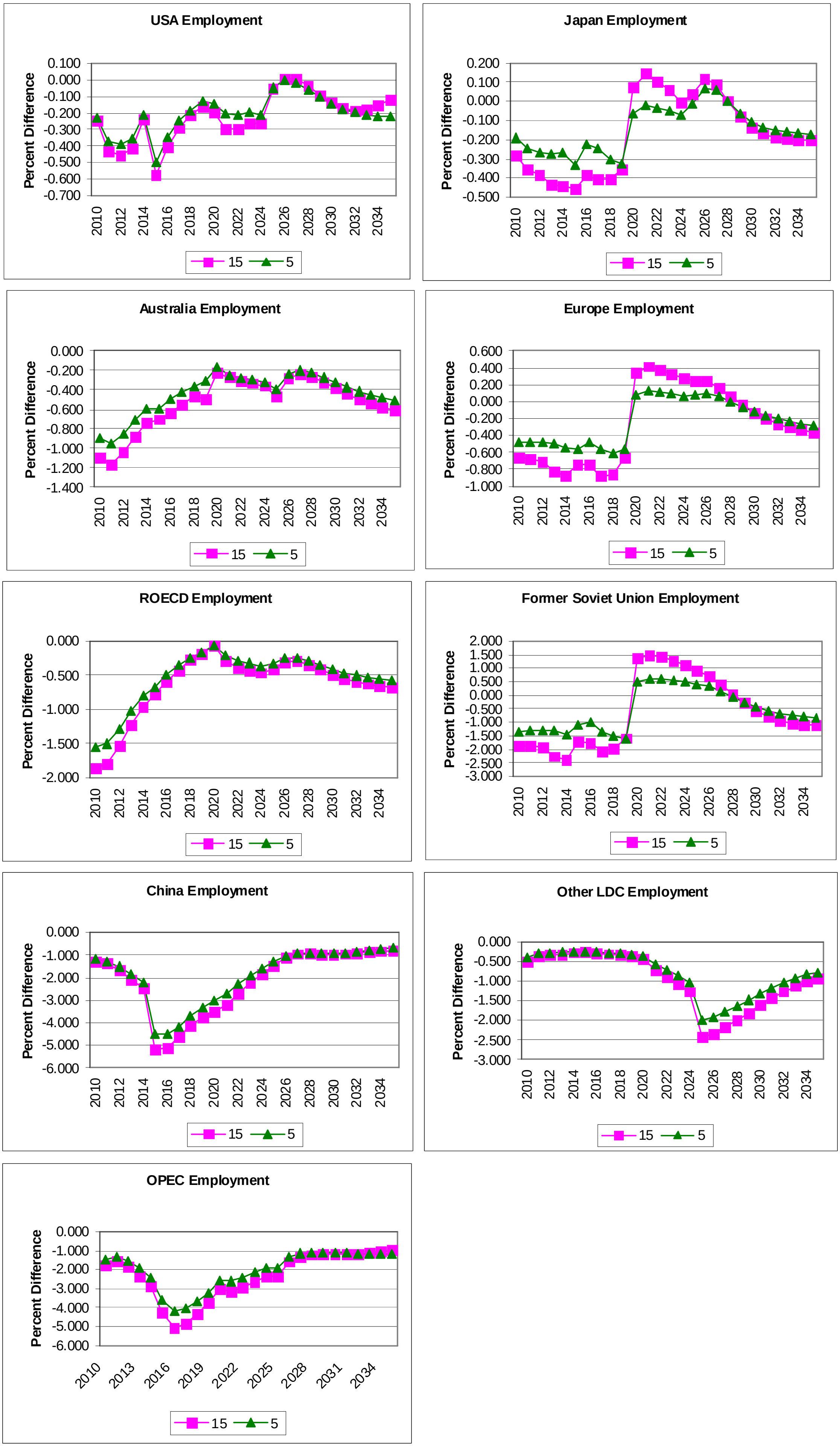


Figure 13: Consequences for Inflation from Garnaut 450 and 550 Scenarios

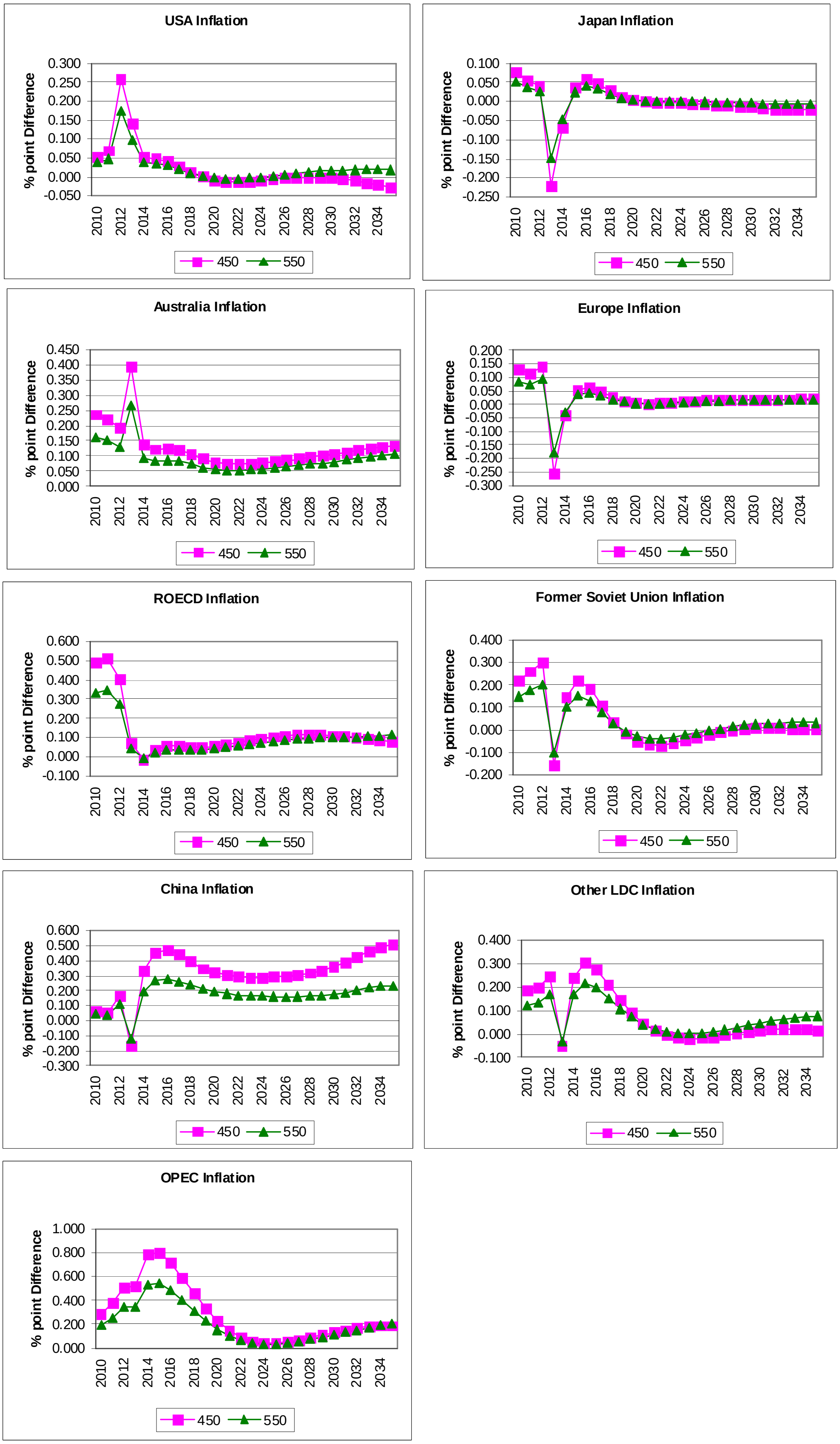


Figure 14: Consequences for Inflation from CPRS-5 and CPRS-15vScenarios

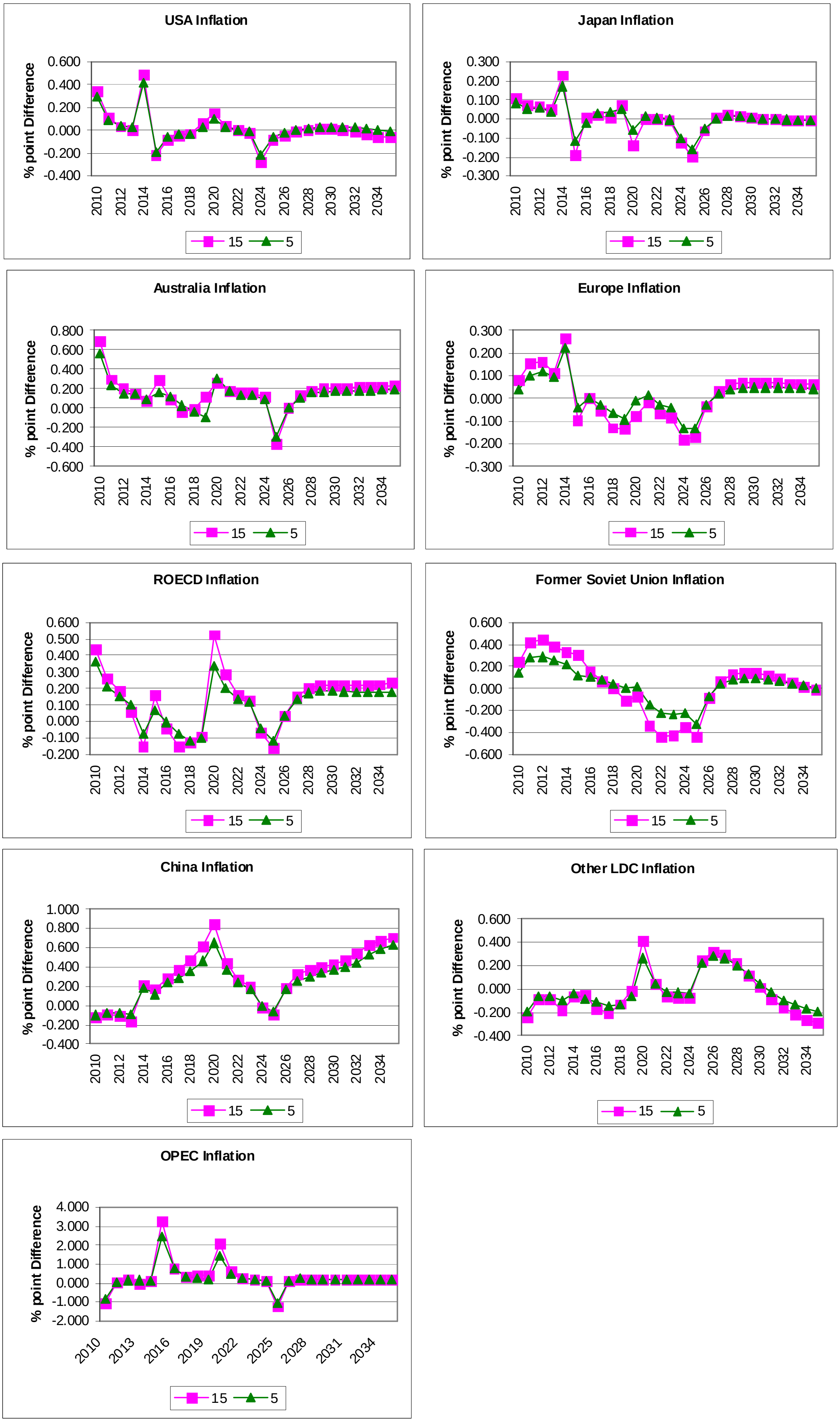


Figure 15: Consequences for Real Interest Rates from Garnaut 450 and 550 Scenarios

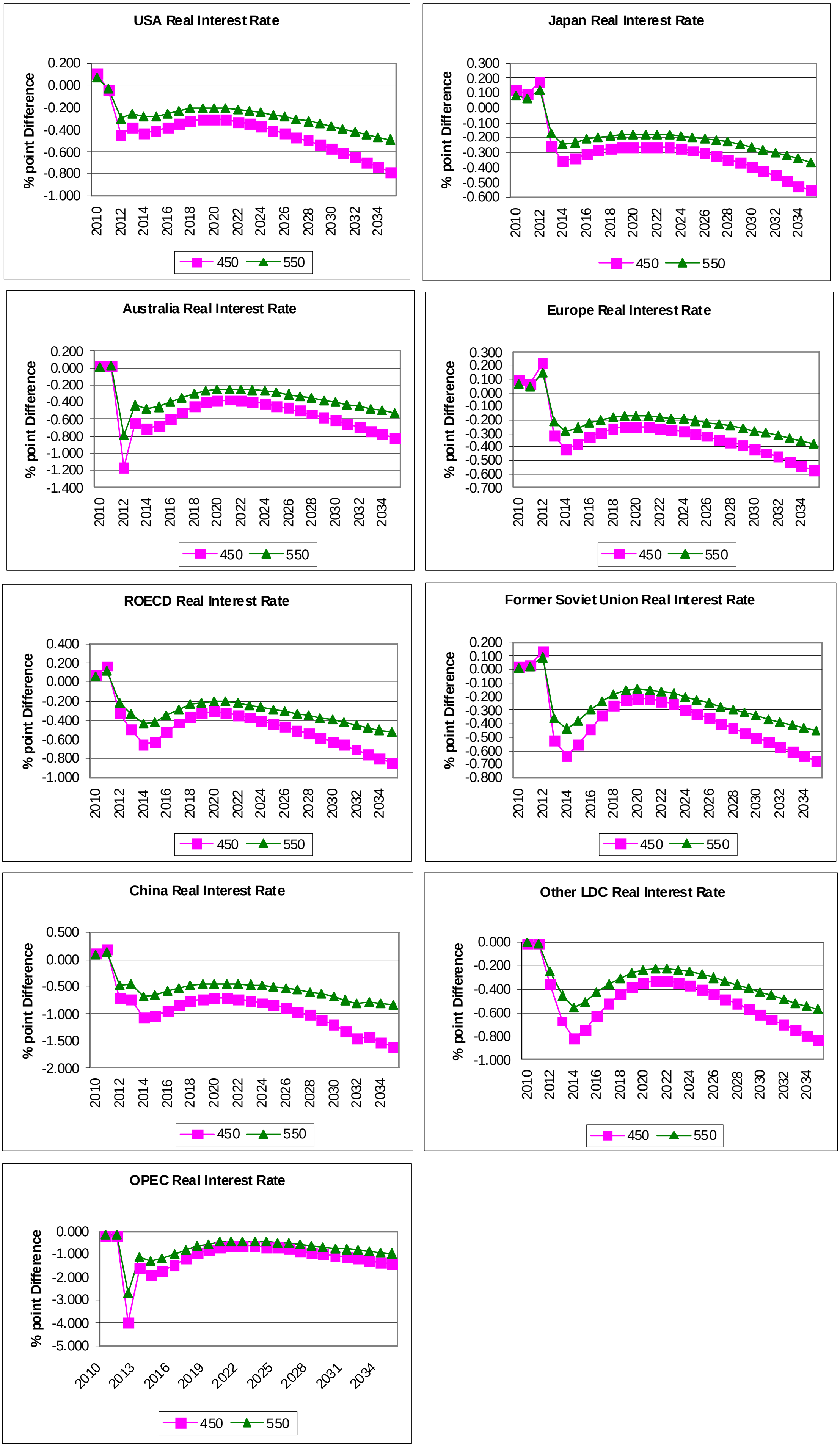


Figure 16: Consequences for Real Interest Rates from CPRS-5 and CPRS-15vScenarios

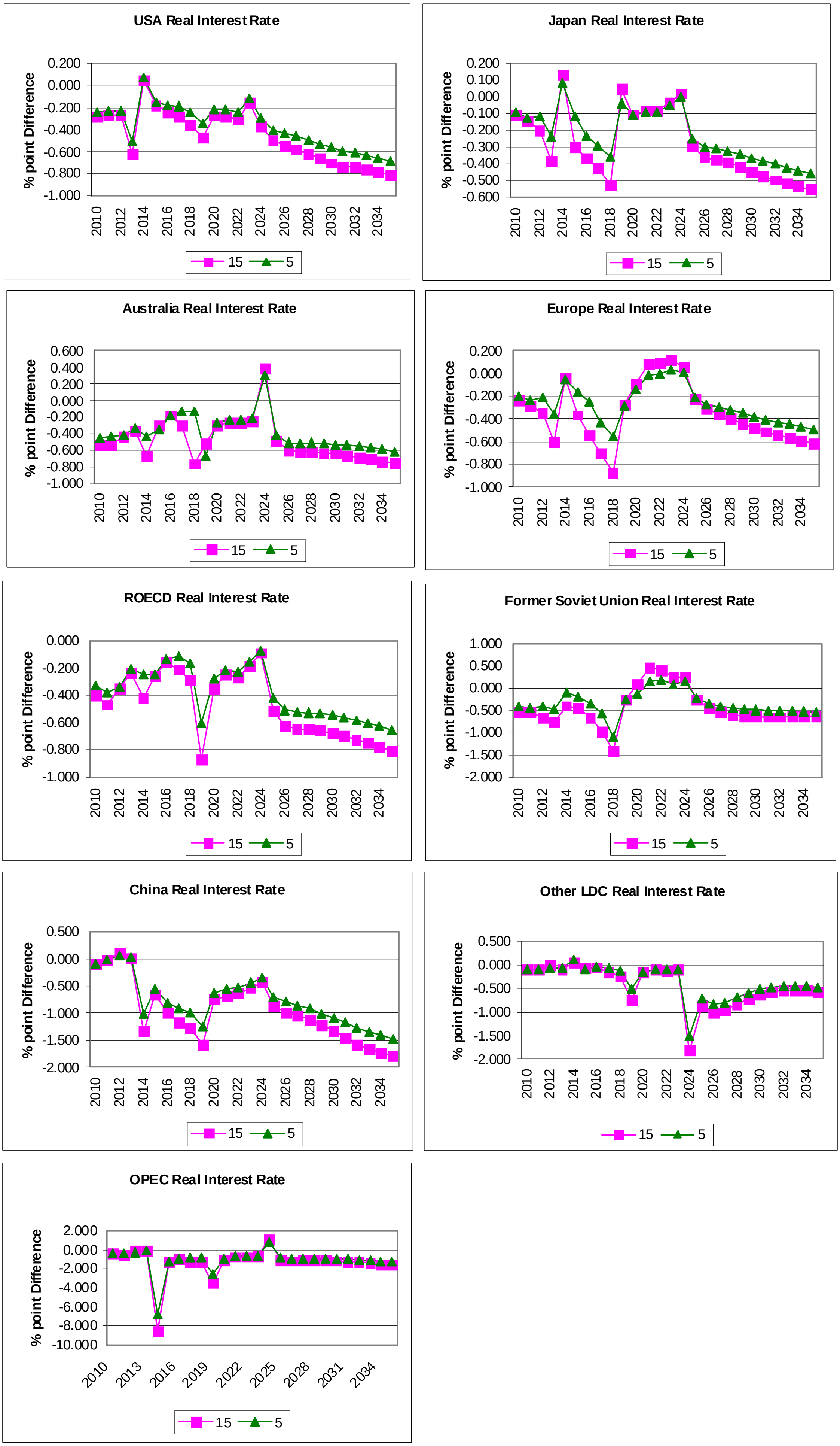


Figure 17: Consequences for Share Market Value from Garnaut 450 and 550 Scenarios

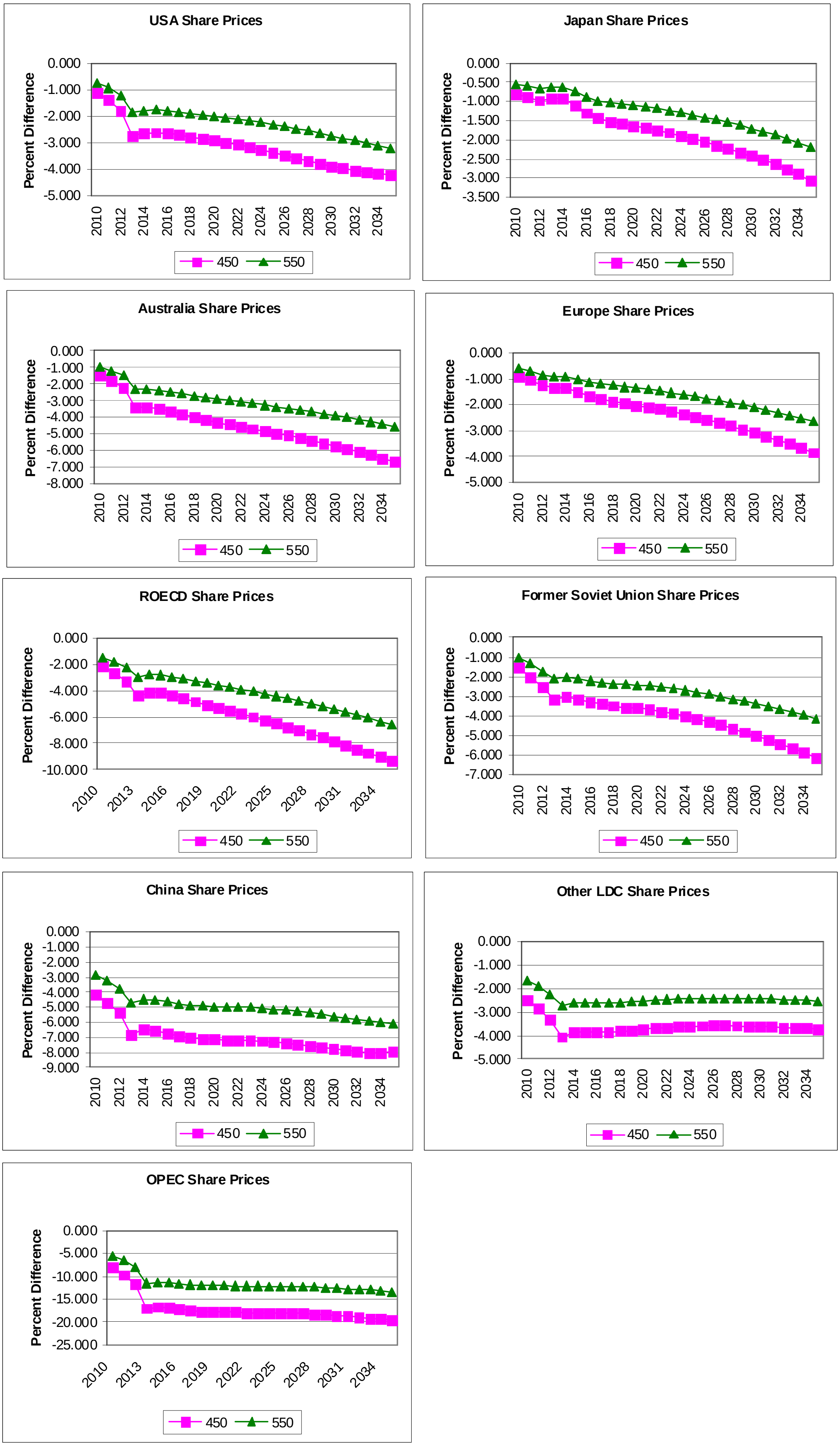


Figure 18: Consequences for Share Market Value from CPRS-5 and CPRS-15vScenarios

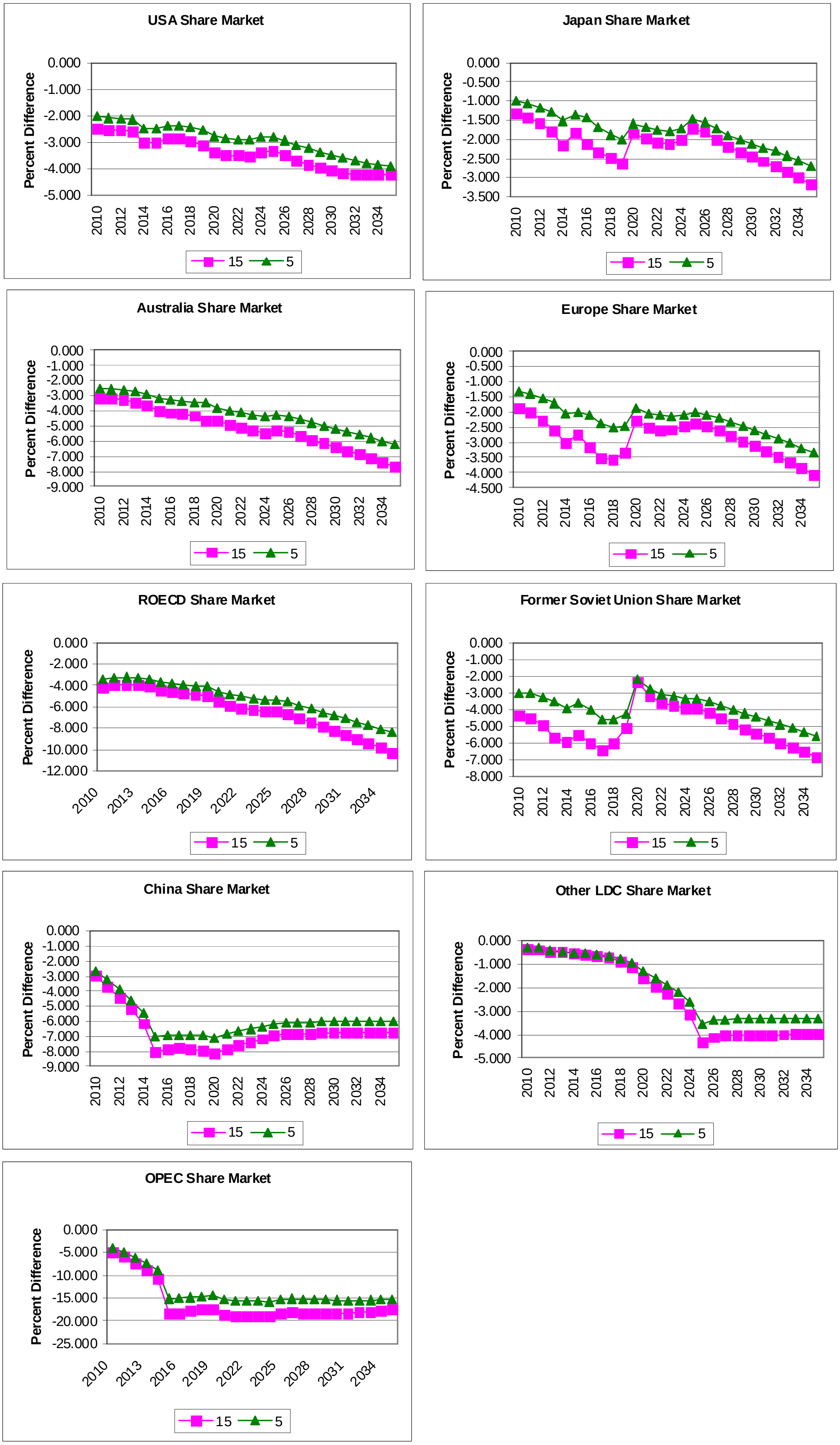
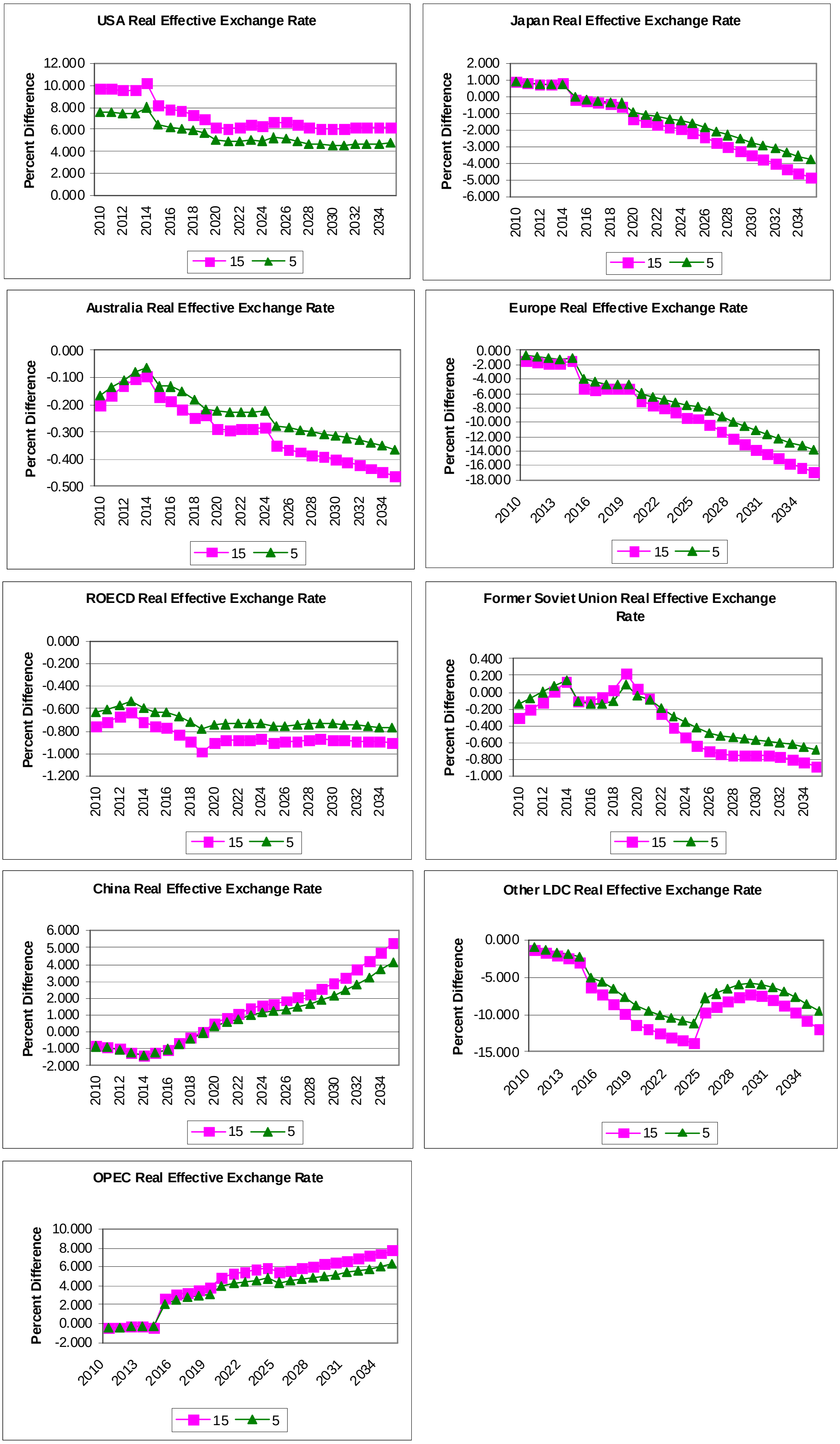


Figure 19: Real Effective Exchange Rates from Garnaut 450 and 550 Scenarios

Figure 20: Real Effective Exchange Rates from CPRS-5 and CPRS-15vScenarios



References

Aldy, J. and R. Stavins (eds) (2007), *Architectures for Agreement: Addressing Global Climate Change in the Post-Kyoto World*, Cambridge University Press, pp185-208.

Australian Treasury (2008) *Australia's Low Pollution Future: The Economics of Climate Change Mitigation* 30 October 2008. Commonwealth of Australia.

Bagnoli, P. McKibbin W. and P. Wilcoxen (1996) "Future Projections and Structural Change" in N, Nakicenovic, W. Nordhaus, R. Richels and F. Toth (ed) *Climate Change: Integrating Economics and Policy*, CP 96-1 , Vienna: International Institute for Applied Systems Analysis, 181-206.

Barrett, S (2008). "A Portfolio System of Climate Treaties." Discussion Paper 08-13, Cambridge, Mass.: Harvard Project on International Climate Agreements, October 2008.

Blanchard O. and S. Fischer (1989) *Lectures on Macroeconomics* MIT Press, Cambridge MA.

Blanford, G, Richels, R and T. Rutherford (2008). "Revised Emissions Growth Projections for China: Why Post-Kyoto Climate Policy Must Look East." Discussion Paper 08-06, Cambridge, Mass.: Harvard Project on International Climate Agreements, September 2008.

Garnaut, R. (2008). *Garnaut Climate Change Review Final Report*, Cambridge University Press, Port Melbourne.

Harvard Project on International Climate Agreements (2008) http://belfercenter.ksg.harvard.edu/project/56/harvard_project_on_international_climate_agreements.html?page_id=209

Henderson, D.W., and W. McKibbin (1993), "A Comparison of Some Basic Monetary Policy Regimes for Open Economies: Implications of Different Degrees of Instrument Adjustment and Wage Persistence," *Carnegie-Rochester Conference Series on Public Policy*,39, pp 221-317.

Intergovernmental Panel on Climate Change (2007) Climate Change 2007: Synthesis Report, Cambridge University Press, Cambridge.

International Monetary Fund (2008), World Economic Outlook, April.

Jaffe, J. and R. Stavins.(2008) "Linkage of Tradable Permit Systems in International Climate Policy Architecture." Discussion Paper 08-07, Cambridge, Mass.: Harvard Project on International Climate Agreements, September 2008

McKibbin, W., Morris, A. and P. Wilcoxen (2008) “Expecting the Unexpected: Macroeconomic Volatility and Climate Policy”, Discussion Paper 08-16, Cambridge, Mass.: Harvard Project on International Climate Agreements, November 2008 also CAMA working paper 35/2008, The Australian National University http://www.cama.anu.edu.au/Working%20Papers/Papers/2008/McKibbin_Morris_Wilcoxen_352008.pdf;

McKibbin W. D. Pearce and A. Stegman (2007) “Long Term Projections of Carbon Emissions” *International Journal of Forecasting*, vol 23, pp637-653

McKibbin W. , Shackleton R. and P. Wilcoxen (1999) “What to Expect from an International System of Tradeable Permits for Carbon Emissions” *Resource and Energy Economics*, volume 21, 3, pp 319-346.

McKibbin W.J. and D. Vines (2000) “Modeling Reality: The Need for Both Intertemporal Optimization and Stickiness in Models for Policymaking” *Oxford Review of Economic Policy* vol 16, no 4.

McKibbin W. and P. Wilcoxen (1997), “A Better Way to Slow Global Climate Change” *Brookings Policy Brief* no 17, June, The Brookings Institution, Washington D.C. .

McKibbin W. and P. Wilcoxen (1998) “The Theoretical and Empirical Structure of the G-Cubed Model” *Economic Modelling* , 16, 1, pp 123-148

McKibbin, W. J. and P. J. Wilcoxen (2002a), *Climate Change Policy After Kyoto: A Blueprint for a Realistic Approach*, Washington: The Brookings Institution.

McKibbin, W. J. and P. J. Wilcoxen (2002b), “The Role of Economics in Climate Change Policy,” *Journal of Economic Perspectives*, 16(2), pp.107-130.

McKibbin W. and P. Wilcoxen (2007) “A Credible Foundation for Long Term International Cooperation on Climate Change” in Joseph Aldy and Robert Stavins (eds), *Architectures for Agreement: Addressing Global Climate Change in the Post-Kyoto World*, Cambridge University Press, pp185-208.

McKibbin W.J. and P. Wilcoxen (2008) "Building on Kyoto: Towards a Realistic Global Climate Change Agreement", Lowy Institute Working Paper in International Economics and CAMA working paper 13/2008; http://www.cama.anu.edu.au/Working%20Papers/Papers/2008/McKibbin_Wilcoxen_132008.pdf

Obstfeld M. and K. Rogoff (1996*) Foundations of International Macroeconomics* MIT Press, Cambridge MA.

Pearce D. and W. McKibbin (2007) "Two issues in Carbon Pricing: Timing and Competitiveness" Lowy Institute Working Paper in International Economics no 1.07.

Pizer, W.A. (1997), "Prices vs. Quantities Revisited: The Case of Climate Change," Resources for the Future Discussion Paper 98-02, Washington: Resources for the Future.

Roberts, M. J., and A. M. Spence (1976), "Effluent Charges and Licenses under Uncertainty," *Journal of Public Economics*, 5, 193-208.

Stern, N. (2006), *Stern Review: Report on the Economics of Climate Change*. Cambridge University Press, UK.

Taylor, J. B. (1993), Discretion Versus Policy Rules in Practice. Carnegie-Rochester *Carnegie-Rochester Conference Series on Public Policy* 39, 195-214.

Weitzman, M. L. (1974), "Prices vs. Quantities," *Review of Economic Studies*, 41, 477-91.

Weyant, John (ed.) (1999), "The Costs of the Kyoto Protocol: A Multi-model Evaluation," *The Energy Journal*, Special Issue.

Appendix A; New Treasury Equations:

This appendix should be read in conjunction with the model documentation for version GGGV83E which contains the naming conventions as well as all equations in the model. Please see:

http://www.msgpl.com.au/g3versions.htm

Table A1: New Treasury Equations

```
goods_e: CON = delta_eH * CNPE *
exp( PRCE - PRY - ln(1+cc_ch4G*TCARCH4) )^sigma_eH;

EMME = 1000*( sum( goods, cc_ch4*OUG ) + sum( goods, cc_ch4G*CON ) +
                                           sum( goods, cc_ch4W*OUG ) );
EMNO = 1000*( sum( goods, cc_n2o*OUG ) + sum( goods, cc_n2oW*OUG ) );
EMNC = 1000*( sum( goods, cc_ncc*OUG ) );

EMTC = EMNC + EMIS ;

EMTCEQ = EMTC + EMME + EMNO ;

PRD = ln( sum(sectors, makeinv*(exp(PRP)))
 + carcoef*TCAR + (cc_ch4 + cc_ch4W)*TCARCH4 + (cc_n2o + cc_n2oW)*TCARNO
 + cc_ncc*TCARNC + btucoef*TBFD );

PRCE = cd_eH*sum( goods_e,
delta_eH*(ln(1+cc_ch4G(goods_e)*TCARCH4)+PRY(goods_e)) )
   + (1-cd_eH)*ln( sum(goods_e,
delta_eH*(ln(1+cc_ch4G(goods_e)*TCARCH4)+exp(PRY(goods_e)))^(1-sigma_eH))
            ) / (1-sigma_eH*(1-cd_eH)) ;

dest: TAXE = sum( goods, (carcoef*TCAR + (cc_ch4 + cc_ch4W)*TCARCH4 +
                                           (cc_n2o + cc_n2oW)*TCARNO
+cc_ncc*TCARNC + btucoef*TBFD)*OUG +
                                           (cc_ch4G *TCARCH4)*CON+
              (carcoef*TCEX + btucoef*TBFX)*EXQ +
                                     (carcoef*TCAI + btucoef*TBFI)*IMQ );

TCARCH4 = TCAR;
TCARNO = TCAR;
TCARNC = TCAR;
```