Summary

This thesis examines the optimal macroeconomic policy response to the uncertainty associated with natural resource revenues and the uncertainty associated with climate change. Both areas lie outside the realm of day-to-day household behaviour and require explicit government intervention, which is subject to fundamental normative assumptions affecting the valuation of costs and benefits occurring in an uncertain future. If a decision maker is prudent, that is, less risk averse at higher income levels, uncertainty about future income leads to additional saving and postponing of consumption.

For natural resource uncertainty, prudent policy takes the form of additional (precautionary) saving of resource revenues, often in a sovereign wealth fund. The investments in such a fund must be optimally allocated in the face of uncertainty in the financial markets, taking heed of their correlation with the value of underground assets. For climate uncertainty, prudent policy generally leads to a higher optimal carbon tax, reflecting a higher social cost of emitting carbon. Yet, the effects of economic and climatic uncertainty are distinct and require a careful consideration of the risk-aversion implicit in the climate model and the climate damage function.

Starting from a continuous-time, time-separable, dynamic stochastic welfare optimisation framework, this thesis uses perturbation methods to develop leading-order estimates of the effect of these two types of uncertainty in combination with risk aversion and prudence. Its objectives are two-fold: improve our understanding of the mechanisms through which uncertainty acts and provide order-of-magnitude estimates of the effects and thus be able to assess their importance within the broader context of macroeconomic policy.

Chapter 2 Precautionary saving for resource price uncertainty

Chapter 2 examines the role of precautionary saving in the optimal management of natural resource windfalls. It addresses the question how resource-rich countries should allocate the temporary and highly volatile income they receive from extracting natural resources. This income, sometimes referred to as windfall in-

come because of its temporary nature, can be either consumed, invested or saved. Generally, three types of funds may necessary to manage an oil windfall: intergenerational, liquidity, and investment funds. Precautionary saving for resource price uncertainty drives the size of the liquidity fund, and the optimal liquidity fund is larger if the windfall lasts longer and oil price volatility, prudence, and the GDP share of oil rents are high and productivity growth is low. The theoretical insights obtained in this chapter are applied to the windfalls of Norway, Iraq, and Ghana. The optimal size of Ghana's liquidity fund is tiny even with high prudence. Norway's liquidity fund is larger than Ghana's. Iraq's liquidity fund is colossal relative to its intergenerational fund. Only with capital scarcity, should part of the windfall be used for investing to invest. For developing economies such as Ghana, where public capital is scarce and debt burdens are high, paying off sovereign debt and investing in public capital may be more important driving forces than precautionary saving.

Chapter 3 Case study: resource revenues in Alberta

Through a case study of the Canadian province Alberta, Chapter 3 examines the policy implications of an uncertain natural resource windfall for government finances in particular. Based on an equivalent welfare-based intertemporal stochastic optimization model to Chapter 2, Chapter 3 estimates the size of the optimal intergenerational and liquidity funds and the corresponding resource dividend available to the Albertan government. To leading order, this dividend should be a constant fraction of total above- and below-ground wealth, complemented by additional precautionary savings at initial times to build up a small liquidity fund to cope with oil price volatility. Finally, the effect of the 2014 plunge in oil prices on our estimates is examined.

Chapter 4 Asset allocation and extraction for resource SWFs

Chapter 4 considers the important source of uncertainty ignored in Chapters 2 and 3: the asset return uncertainty of the sovereign wealth fund in which the proceeds from natural resource extraction are invested. One of the most important developments in international finance and resource economics in the past twenty years is the rapid and widespread emergence of the $6 trillion sovereign wealth fund industry, many of which are derived from natural resource rents. Oil exporters typically ignore below-ground assets when allocating these funds, and ignore above-ground assets when extracting oil. This chapter presents a unified stylized framework for considering both. Subsoil oil should alter a fund's portfolio through additional leverage and hedging. First-best spending should be a share of total wealth, and any unhedgeable volatility must be managed by precautionary savings. An optimally chosen financial portfolio will reduce the aggregate level of uncertainty to which the economy is exposed, by choosing assets that offset oil price risk. If such

a portfolio is unavailable, additional precautionary saving may be required. If oil prices are pro-cyclical, oil should be extracted faster than the Hotelling rule to generate a risk premium on oil wealth. Finally, this chapter discusses how its analysis could improve the management of Norway's fund in practice.

Chapter 5 The risk-adjusted carbon price

Moving onto climate uncertainty, Chapter 5 examines the effect of uncertainty on estimates of the social cost of carbon and thence the optimal carbon tax. The existing and popular model of the economy and climate change by Golosov et al. (2014) has logarithmic preferences and damages proportional to the carbon stock in which case the certainty-equivalent carbon price is optimal. This chapter allows for different aversions to risk and intertemporal fluctuations, convex damages, uncertainties in economic growth, atmospheric carbon, climate sensitivity and damages, correlated risks, and distributions that are skewed in the longer run to capture climate feedbacks. This chapter thus derives a non-certainty-equivalent rule for the carbon price, which incorporates precautionary, risk-insurance and risk-exposure, and climate-beta effects to deal with future economic and climatic risks. This is achieved in the context of a stylized integrated assessment model based on an endogenous growth model. A combination of different perturbation methods is used to develop simplified rules for the social cost of carbon and its dependence on four categories of uncertainty: shocks to the carbon cycle, uncertain climate sensitivity and damage function estimates and, finally, the uncertain evolution of total factor productivity. Quantitative estimates of the risk-adjusted carbon price are obtained after calibration of the model.