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The Impact of Commodity Price Volatility on Resource Intensive Economies

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Abstract

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Commodity price volatility is bad for macroeconomic performance. Virtually all empirical studies that document this negative relationship rely on the estimation of aggregate growth equations using cross-section evidence drawn from the post-1970 era. This paper uses a simulation model based on the structure of a dynamic renewable resource model of optimal extraction to determine *why* commodity price volatility affects investment decisions, production levels, profitability, and ultimately long run growth. The Canadian forestry sector is used as a case study to assess the relative strength of each of these effects. Simulation exercises reveal that commodity price volatility shocks significantly reduce resource firms' equity prices and their demand for reproducible and natural capital. As a result of these changes in the firms' external financing costs and investment incentives, extraction costs rise, output levels and profits fall, and real GDP per capita growth slows.

JEL Classification: O13; Q23; Q32.

Keywords: Commodity price volatility; resource based growth; simulation modeling.

Introduction

There is a considerable body of empirical evidence confirming the presence of a link between macroeconomic volatility and poor macroeconomic performance. This evidence is almost exclusively based on the estimation of aggregate growth equations that use data drawn from a cross-section of countries during the post-1970 era. The parameters derived from these estimates reveal that nations with larger and more frequent changes in their income per capita growth rates tend to have lower growth rates. The use of aggregate data averaged over long time periods can also be used to identify movements in other economic fundamentals that are often chronologically coincident with macroeconomic volatility, and hence slower growth. Terms of trade shocks, for example, appear to be closely and positively correlated with macroeconomic volatility, and nations specializing in resource intensive activities tend to have relatively concentrated industrial structures, unsophisticated domestic financial intermediation, higher aggregate price volatility, and more volatile changes in their terms of trade. What the estimation of cross-section growth equations cannot reveal are the relative strength of the channels through which these correlations operate.

To explain *why* differences in commodity price volatility may be chronologically coincident with differences in long run macroeconomic performance, we must move from broad comparisons across many nations and long time periods to more detailed studies of specific nations, economic environments, and industries. Case studies can be valuable complements for much of the existing price volatility evidence because they can be used to "look inside the black box" and illuminate the economic relationships underlying the correlations identified with the highly aggregated, reduced form cross-country comparisons. The objective of this paper is to empirically document the strength of the channels through which commodity price volatility affects the fundamentals characterizing economic performance within a resource intensive industry, and long run macroeconomic performance within a resource intensive economy. To conduct this investigation a series of simulation exercises and counterfactual experiments have been performed using a dynamic industry model that captures the evolution of five key endogenous variables characterizing a resource sector's economic fundamentals. The data used in this model have been drawn from a case study of the forestry sector in Canada over the twentieth century.

Canadian forest, wood, and wood product producers have been chosen for detailed study due in part to practical considerations, such as the quality and availability of long, consistently defined data series for equity prices, profits, output levels, and natural and reproducible capital stocks. However, the Canadian economic environment turns out to be particularly desirable for the purposes of this paper because other factors that often confound the identification of a connection between commodity price volatility and performance in cross-section comparisons, including fundamental characteristics such as culture, institutions, endowments, market structure, and the sophistication of domestic financial intermediation, have been remarkably stable in Canada over the 1900-1999 period.

The dynamic simulation model used in this paper is based on a constrained optimization problem describing how producers make renewable resource extraction and processing decisions, and a multi-factor capital asset pricing model (CAPM) that describes the cost of acquiring investment funds on a domestic equity market. The dynamic nature of the model stems from the forward looking investment demand equations. The model's parameters have been econometrically estimated with an iterative least squares procedure and 100 years of annual data drawn from the extraction, primary processing, and secondary processing firms that made up Canada's forestry sector. The structure of the model lends itself to the performance of a series of simulation exercises that facilitate the identification of the channels through which commodity price volatility affects the economic fundamentals characterizing the development of the resource sector over the long run. Once these channels are identified, counterfactual experiments allow us to document their strength, economic significance, and their cumulative impact on macroeconomic growth.

During periods of particularly high and rising price volatility the cost of investment funds supplied by external sources rises sharply and the incentive to accumulate both reproducible and natural capital falls. These effects combine to drive down production levels and drive up extraction costs, which suppresses profits, further increasing investment costs and decreasing investment demand. The cumulative impact of commodity price volatility on industry performance is large and persistent, and even in our Canadian case study where financial intermediaries were sophisticated and integrated with international capital markets, diversification opportunities could not fully immunize the economy against these consequences.

Commodity Price Volatility and Macroeconomic Performance

Ever since Easterly, Kremer, Pritchett, and Summers (1993) pointed out that growth performance varies across time and countries far more than its key theoretical determinants – culture, institutions and endowments – there has been an ongoing effort to account for the "excess volatility" in growth. Many potential determinants have been proposed, but following Ramey and Ramey's (1995) identification of a strong negative relationship between unanticipated variation in real GDP per capita and average real GDP per capita growth rates, one of the standard control variables in cross-section growth equations has become macroeconomic volatility.[1]

Of course, macroeconomic volatility has many sources, including poor policy, ethno-linguistic fragmentation, military and political uncertainty, institutional discontinuities, or any other of a wide range of idiosyncratic and common market shocks. However, there appears to be growing acceptance that, at least among developing economies, resource intensity may be associated with more volatile movements in real exchange rates and terms of trade, which in turn tend to be closely chronologically coincident with unanticipated movements in real GDP per capita, and slower real GDP per capita growth.

Aghion, Bacchetta, Rancière, and Rogoff (2009), for example, document a strong link between currency volatility and macroeconomic volatility among contemporary nations with poorly developed financial institutions. Chen and Rogoff (2003) push this connection even further, showing that over the twentieth century resource price movements were associated with real exchange rate shocks even among wealthy, resource intensive economies, such as Australia and New Zealand (but not Canada). Blattman, Hwang, and Williamson (2007) estimate a significant connection linking terms of trade shocks and macroeconomic volatility among a sample of 35 "periphery" nations as early as the 1870-1939 period. Blattman *et al.* also report a significant correlation between movements in periphery nations' relative import and export prices and the extent to which they specialized in resource extraction and processing activities. The authors argue that specialization in resource intensive activities exacerbate terms of trade shocks because resource specialization is often associated with a lack of industrial diversification *and* because commodity prices are inherently more volatile than the prices of other goods and services that have more price sensitive supply responses.[2]

Confirmation of a correlation linking resource specialization and volatility in a contemporary context is provided by Koren and Tenreyro (2007), who use data drawn from a cross-section of developed and developing nations during the post-1980 era to decompose macroeconomic volatility. They show that (Pg. 245) "...poor countries are more volatile because they specialize in fewer and more volatile sectors...Quantitatively, roughly 50 percent of the differences in volatility between poor and rich countries can be accounted for...by differences in sectoral composition." Van der Ploeg and Poelhekke (2009) go further still, arguing that the large and growing body of evidence that documents a "resource curse" in which resource intensity leads to poor growth performance among less developed nations since 1970, can be overturned if growth equations include commodity price volatility as a control variable.[3] This result, taken together with the evidence presented by Lederman and Maloney (2007) showing that particularly high levels of export concentration among late twentieth century resource intensive economies is strongly negatively related to growth performance, suggests that there is a robust correlation connecting resource specialization and commodity price shocks to terms of trade and real exchange rate shocks, macroeconomic volatility, and eventually slower real GDP per capita growth.

Identifying a correlation between price volatility and macroeconomic performance does not explain *why* these variables tend to move together in a predictable way across nations or time. If we turn to a different literature, we find that development economists emphasize the role that increases in risk play in determining both public and private investment incentives – reducing overall investment and altering its composition in favour of lower risk projects.[4] These effects can slow the accumulation of publicly funded infrastructure, reproducible capital and human capital, which in turn can undermine long run macroeconomic performance.[5] Development theory, therefore, suggests that one of the channels through which inherent volatility and a lack of diversification opportunities can negatively affect growth is likely to be the link between risk and the incentive to engage in both investment demand and supply activities.

Modeling Resource Intensive Production

Virtually all of the volatility-growth literature relies on evidence derived from aggregate growth equations, estimated with cross-section data. Unfortunately, the use of reduced form econometric models and evidence that is averaged across time and space often introduces confounding and interdependent relationships that simultaneously affect the variation in other key performance determinants, such as culture, institutions, endowments and financial market sophistication. The proposed link between price volatility and investment demand and supply decisions can only be confidently documented in the presence of an explicit structural framework and careful controls for confounding effects. The theoretical structure and necessary controls can be particularly challenging to construct among developing economies that have wildly different economic and institutional environments, and varying access to international capital markets. Therefore, to identify specific channels through which volatility affects growth, and to quantify the strength of these channels, a useful complement to aggregate comparisons across many nations may be a more detailed study of a single, stable, well developed, and diversified economy.

A Canadian Case Study

At the turn of the twentieth century the Canadian economic environment had a substantial urban and industrial component. In 1901 over 35% of the Canadian population lived in an "incorporated urban centre", 22% of all economic activity originated in the manufacturing sector, and Canada's purchasing power adjusted real GDP per capita ranked fifth in the world, just ahead of Belgium and just behind New Zealand and Britain.[6] Ninety-nine years later Canada's purchasing power adjusted real GDP per capita still ranked fourteenth in the world, manufacturing accounted for 16% of the country's GDP, and 77% of the population lived in an urban centre. However, despite the urban and industrial structure of the twentieth century Canadian economy, production remained persistently resource intensive.

Chen and Rogoff (2003, Pg. 136) note that although, "...Canada has a large and...developed industrial base...it continues to rely on commodity products such as base metals, forestry products, and crude oil." The forestry sector in particular has accounted for a significant fraction of aggregate input employment and output production. On average between 1900-1910 the Canadian forestry sector exported over 34% of its gross output, employed 7% of the Canadian workforce and 8% of the aggregate reproducible capital stock, while generating 9% of Canada's GDP.[7] By the 1990s the forestry sector exported 26% of its gross output and 4% of the aggregate income earned by Canadians originated in extraction, primary processing and secondary processing forestry activities, while 2.5% of the Canadian workforce and 5% of the reproducible capital stock was still employed in the sector.[8]

These stylized facts illustrate the extent to which Canada successfully developed, diversified and grew through the twentieth century, while continuing to specialize in the exploitation of its forest endowment. As we would expect given the resource intensity of the Canadian economy and evidence from cross-section macro-growth equations, macroeconomic performance in Canada has not been immune from the effects of commodity price volatility. Between 1900-1999 changes in the volatility of domestic mineral, forestry, and energy prices relative to the GDP deflator were strongly and statistically significantly negatively correlated with real GDP per capita growth in Canada.[9] The Canadian forestry sector provides us with a particularly attractive case study for a detailed investigation of this relationship between commodity price volatility and macroeconomic performance because, unlike many of the nations included in the broad cross-sections used to estimate aggregate growth equations, we need not concern ourselves with the possibility that episodes of cultural, geographic, or institutional discontinuity may confound our effort to map out the connections linking price volatility and performance over time. Canada experienced no dramatic or permanent disruptions in its economic environment during the twentieth century, and although there is considerable qualitative evidence documenting the evolution of the forestry sector's technological, market access, policy, and biological environments after 1900, the connections linking volatility and performance do not appear to have been fundamentally affected by these smooth transitions.[10]

In addition to macroeconomic and sector specific environmental stability, Canadian financial markets were large, diversified, fairly competitive, and well integrated with US markets throughout the twentieth century.[11] After reviewing the characteristics of the Canadian and US banking sectors, life insurance sectors, equity markets, and bond markets between 1900-1990 Keay and Redish (2004) argue that although there were statistically identifiable differences, the structure of US and Canadian capital markets were similar in terms of their depth, diversity, and sophistication. The wide range of diversification opportunities open to participants on Canadian financial markets implies that hedging against commodity price volatility must have been feasible throughout the period of study. Any Canadian commodity price volatility effects must have been present *despite* easy access to diversification opportunities.

The stability of the economic environment and the efficiency of domestic financial markets suggests that the connections linking commodity price shocks to the economic fundamentals in our Canadian case study can not be attributed to unmeasured changes in other growth determinants or changes in the decision makers' ability to diversify. In short, the effect of commodity price volatility on macroeconomic performance should be both easier to isolate and less abrupt in an economic environment such as Canada's, relative to virtually all other twentieth century resource intensive economies. Estimates based on a Canadian case study, therefore, should be interpreted as a lower bound on the impact that commodity price volatility has on investment demand and supply decisions made by individuals in a large resource intensive industry and a resource intensive economy.

A Structural Framework Based on Resource and Finance Theory

To carefully document the channels through which price volatility affects performance we can adopt a more structural approach by relying on optimal resource extraction model and finance theory to provide guidance when specifying an empirical model. For our purposes we wish to construct a simulation model that describes the interdependence of industry profits, production decisions, investment decisions for both reproducible and natural capital, and the cost of acquiring investment funds. A slightly augmented dynamic renewable resource extraction model can capture all of these relationships in a series of fairly simple and empirically tractable simultaneous equations.

Virtually all theories of optimal resource extraction are based on an assumption that resource industries choose their production levels, and hence extraction patterns, to maximize the present value of the stream of expected industry profits into the indefinite future.[12] The decision makers within any resource industry face a series of constraints when seeking to maximize profits, including a technological constraint described by a standard production function, a reproducible capital accumulation constraint described by an investment demand function, and a natural capital accumulation constraint described by both investment demand determinants and biological determinants. To fully capture the impact of commodity price volatility, we also introduce an external investment supply constraint that depends on expected industry profits and uncertainty. We can depict the structure of the model in the following form:

Objective Function: $Max_{(K,B)} \int_0^T E(\Pi_t) e^{-rft} dt$

Definitions:
(i) Profit Function: $\Pi_t = P_t Q_t - C(A_t, K_t, B_t)$
(ii) Production Function: $Q_t = f(A_t, K_t, B_t)$

Constraints:
(i) Reproducible Capital: $\Delta K = h(P_t, \sigma_{Pt}, WK_t, WL_t, r_t, Q_t, \delta)$
(ii) Natural Capital: $\Delta B = g(P_t, \sigma_{Pt}, WK_t, WL_t, r_t, Q_t, temp_t, pcip_t, \mathbf{L}.B_t)$
(iii) Investment Supply: $r_t = m(rf_t, rm_t, \Delta E(\Pi_t), \sigma_{Pt})$

In the standard resource model, expected industry profits are discounted by a risk free interest rate (*rf*). The choice of optimal production levels (Q_t), and the resultant industry profits ($\prod_t$), hinge on the trade-off between extraction costs (*C(...)*) and output prices (P_t). Extraction costs are typically considered to be dependent on standard cost determinants, taken from production theory, and the size (or biomass) of the resource stock *in situ* (B_t).[13] Depletion of the *in situ* stock is expected to be positively related to extraction and processing costs. Among the standard determinants of extraction costs proposed by production theory we include total factor productivity (A_t) and capital intensity (K_t).[14] By including capital intensity independently, TFP may be interpreted narrowly as a proxy for technological change in the cost function. The technological environment faced by forestry firms is simply modeled as a production function in which output is determined by the productivity parameter (A_t), and a series of inputs (K_t, B_t). No returns to scale constraints are imposed on this technology. Labour in this model is assumed to be supplied elastically at an exogenously determined price.

To link the economic fundamentals that characterize the forestry sector's production, cost, and profit functions to the determinants of investment demand and supply, three constraints are imposed on the resource industry's decision makers. First an investment demand, or reproducible capital accumulation function assumes that the desire to accumulate machinery and equipment for next period (ΔK) will be determined by a fixed depreciation rate (δ), the industry's output prices in the current period, uncertainty (volatility) in these output prices (σ_{Pt}), output levels in this period, exogenously determined wage rates for labour (WL_t), an exogenously determined average user cost for capital (WK_t), and an endogenously determined cost for investment funds raised on the domestic equity market (r_t).[15] The investment demand function for natural capital assumes that the firms' financial incentives to augment resource stock levels for next period (ΔB) will vary with the same determinants as those included in the reproducible capital accumulation function, but these incentives will operate in concert with biological determinants of natural growth rates, including past extraction rates (Q_t), a series of lagged stock levels ($\mathbf{L}.B_t$), deviations from trend temperature ($temp_t$), and deviations from trend precipitation levels ($pcip_t$).[16]

The final constraint imposed in the model is an investment supply function that endogenously determines the cost of acquiring investment funds from the domestic equity market. Given their capital intensity, it is not surprising to find that throughout the twentieth century forestry firms were actively engaged in raising funds from the largest formal equity market in Canada – the Toronto Stock Exchange. Although it is not possible to provide exact annual figures for the earliest years, on average between 1900-1910 forestry firms accounted for approximately 8% of the total capitalized value of all the firms listed on the TSE. By the last decade of the century, forestry firms' share of the composite market had fallen to just over 1.7%. Equity market performance is a key endogenous variable in the model because increases in the firms' share prices imply a reduction in the cost of raising investment funds from external capital markets for these firms. If we assume that the firms treat investment supply sources as close substitutes (capital is fungible), then rising share prices may be considered representative of a more general increase in the supply of investment funds from all external sources.[17]

To capture the endogenous nature of the equity market performance of forestry firms we can use a multi-factor capital asset pricing model (CAPM).[18] In its most basic form the CAPM is founded on the notion that the expected rate of return on an equity portfolio should be dependent on only the risk free rate of return (rf_t) and the market average rate of return (rm_t). If we restrict ourselves to only these two determinants of share prices, then we are implicitly assuming either quadratic preferences among all traders, or normally distributed returns for all risky assets. Relaxing these assumptions allows us to consider the possibility that decision makers use information about additional factors to assess equity market values, including the present value of the stream of profits the firms expect to earn into the indefinite future.[19] In a multi-factor CAPM, therefore, we might reasonably propose that sector specific equity market returns should depend not only on the risk free rate of return and the composite market rate of return, but on unanticipated changes in industry profits ($\Delta E(\prod t)$) and the formation of expectations regarding the path of future profits. Price volatility (σ_{Pt}) will be used in the multi-factor CAPM investment supply function as a measure of uncertainty in the formation of investor's expectations.[20]

Commodity price volatility appears in all three of the model's constraints – the reproducible capital accumulation function, the natural capital accumulation function, and the multi-factor CAPM function. However, because the investment demand and supply variables described by these constraints are also determinants of the model's other endogenous variables, the cumulative effect of price volatility on the objective function defies any simplistic or unconditional characterization. An empirical investigation is necessary to identify the direction, strength, and persistence of the direct and indirect effects of price volatility on the resource industry's economic fundamentals.

The dynamic solution to this optimal extraction problem can be specified if we make assumptions about functional forms and calibration, then derive a set of first order conditions that characterize transition paths and the steady state for the model's state and control variables. These first order conditions would include a set of equations describing the demand and supply conditions that determine the optimal time paths for natural and reproducible capital, an equation that describes the optimal production decision at each point in time, and a *portfolio balance* equation that describes the optimal trade-off between current extraction (earning a return on financial capital) and delayed extraction (earning a biological return from natural growth and a financial return from appreciation in the value of the stock *in situ*). The difficulty with this approach lies in making the theoretical solution to the problem empirically tractable. In particular, the portfolio balance equation requires an estimate of the time path of shadow prices (marginal resource rents) for the forestry stock. These figures are not only currently unavailable, they are probably impossible to calculate with confidence over the long run.[21] We do, however, have information on aggregate economic profits for the forestry sector in Canada between 1900-1999. Therefore, rather than deriving the optimal transition paths characterized by the first order conditions, we can assume that the underlying structure of the model reflects the objectives and constraints faced by decision makers in a resource intensive industry, and we can then look to the Canadian data to tell us about the direction and strength of the relationships implied by this structure. The evidence, therefore, will tell us about the time paths actually taken by the endogenous variables, and these time paths will allow us to trace out the channels linking price volatility to profits, output, and investment.

Calibration by Estimation

To use a theoretical model of optimal resource extraction as a guide for the specification of a dynamic industry simulation model, we must provide some additional structure and choose appropriate parameters. Rather than simply selecting parameters based on our reading of the qualitative or (very limited) quantitative literature on Canadian forestry, we calibrate our simulation model with parameters drawn from an econometric estimation of a system of five equations based on the objective function and constraints implied by resource and finance theory. We must make a few minor changes to the variables specified in the theoretical exposition to make the empirical estimation tractable. First, our interest in the performance of the Canadian forestry sector relative to the aggregate economy leads us to measure all of the model's endogenous and exogenous variables relative to similarly defined national aggregates. Second, our desire to focus on the impact of commodity price volatility on growth, and a need to ensure stationarity in the data, leads us to measure all variables as log-differences over time. Third, because such a large proportion of Canadian forestry production has traditionally been exported – primarily to the United States – it seems reasonable to expect Canadian forestry producers to consider both domestic output prices and the Canada-US exchange rate (cux_t) when assessing the trade-off between revenues and extraction costs in the profit function. Finally, we explicitly include employment in the production function (L_t), and based on an assumption that depreciation rates do not vary dramatically across sectors, we drop depreciation from the reproducible capital accumulation function. Following these adjustments to the optimal extraction problem, and to maintain continuity in notation, the model's lower case variables are now defined as log-differences in the sector specific values relative to the aggregate national values.[22] The five equations that make up our estimation and simulation models take the form:

Equation (1): Profit Function

$$\pi_t = \alpha 0 + \alpha 1\ a_t + \alpha 2\ q_t + \alpha 3\ k_t + \alpha 4\ b_t + \alpha 5\ p_t + \alpha 6\ cux_t$$

Equation (2): Production Function

$$q_t = \beta 0 + \beta 1\ a_t + \beta 2\ k_t + \beta 3\ l_t + \beta 4\ b_t$$

Equation (3): Reproducible Capital Accumulation Function

$$k_{t+1} = \gamma 0 + \gamma 1\ (r_t - rf_t) + \gamma 2\ p_t + \gamma 3\ \sigma_{pt} + \gamma 4\ wk_t + \gamma 5\ wl_t + \gamma 6\ q_t$$

Equation (4): Natural Capital Accumulation Function[23]

$$b_{t+1} = \eta 0 + \eta 1\ (r_t - rf_t) + \eta 2\ p_t + \eta 3\ \sigma_{pt} + \eta 4\ wk_t + \eta 5\ wl_t + \eta 6\ q_t + \eta 7\ temp_t + \eta 8\ pcip_t + \Sigma_0^n\ \eta_{9+i}\ b_{t-i}$$

Equation (5): Investment Supply Function (CAPM)

$$(r_t - rf_t) = \lambda 0 + \lambda 1\ (rm_t - rf_t) + \lambda 2\ \pi_t + \lambda 3 \sigma_{pt}$$

With Equations (3), (4) and (5) we can identify the direct impact of commodity price volatility on decision makers' incentive to invest in reproducible and natural capital, and on the cost of investment funds raised through the domestic equity market. Because of the dynamic structure of the simulation model – embodied in the forward looking reproducible and natural capital accumulation functions – we can also identify indirect effects of commodity price volatility that accumulate over time. The initial investment effects "trickle down" through the capital intensity and biomass variables in Equations (1) and (2), affecting subsequent production decisions and profitability.

The parameters for the simulation model have been chosen on the basis of an econometric estimation of Equations (1) - (5), using annual data from the Canadian forestry sector covering the years 1900-1999, and adding regression residuals to each equation.[24] Because we assume that the decision makers within the Canadian forestry sector made investment and production decisions simultaneously, we have estimated the system of five equations using an iterative seemingly unrelated regressor technique that generates results equivalent to maximum likelihood estimation.[25] This technique corrects the standard errors reported for each parameter estimate to account for correlation across the error terms from each equation. Diagnostic tests have been performed on the residuals (and parameter estimates) from Equations (1) - (5) to ensure that the standard assumptions hold.[26]

Insert Table 1

In Table 1 we report the parameter estimates (and their p-values) that make up the fully calibrated simulation model. From this table we can see that changes in the volatility of forestry prices relative to the volatility of the GDP deflator directly affected the incentive to invest in both reproducible and natural capital in a manner consistent with our theoretical predictions, but these effects appear small and statistically insignificant when estimated over the full 1900-1999 period.[27] To be more specific, the point estimates on σ_{pt} in Equation (3) and (4) indicate that, holding all else constant, a 1% increase in the relative volatility of forestry prices was associated with a 0.022% decrease in the intensity of reproducible capital use among the forestry industries relative to the aggregate economy, and a 0.018% decrease in the accumulation of *in situ* timber volumes. In contrast, the forestry firms' share prices appear to have been much more sensitive to commodity price fluctuations. Even after controlling for movements in the composite market price index and unanticipated changes in forest sector profitability, the CAPM equation indicates that a 1% increase in the volatility of forestry prices relative to the GDP deflator (a proxy for uncertainty in expectations formation) was associated with a 0.383% decrease in the forestry firms' share prices, and this effect can be statistically distinguished from zero with 97% confidence. Of course the cost of raising investment funds on the domestic equity market also has a subsequent (and statistically significant) effect on the incentive to accumulate reproducible and natural capital, which in turn affects production levels, extraction costs, and profits. This indirect impact on production and profit levels then affects the incentive to accumulate capital in later periods, and the cycle repeats. There is, therefore, a substantial degree of persistence implied by the size and significance of the interactions among the endogenous variables that are documented in Table 1.

Measuring the Impact of Commodity Price Volatility

The objective of our empirical investigation is to document the strength of the channels through which commodity price volatility affects economic performance within a resource intensive industry and a resource intensive economy. In pursuit of this objective we use our fully calibrated simulation model to assess the nature of the volatility-performance relationship along four dimensions.[28] First, we trace the transmission of a price volatility shock through each of the five endogenous variables in our model. We then focus more narrowly on the relative sensitivity of the investment supply and investment demand responses. In light of our conclusion that investment supply responses to volatility shocks tend to be more sensitive than investment demand responses, the role played by episodes of crisis – characterized by high and rising price volatility – in provoking these particularly elastic investment supply responses is probed. Finally, having traced out the effects of price volatility on the resource industries' economic fundamentals, we then seek to place these results in their appropriate economic context by measuring the size of the impact that a counterfactual increase in commodity price volatility would have had on long run growth performance in a stable and financially sophisticated economic environment such as Canada's.

<u>Linking Commodity Price Volatility to Performance</u>

To fully characterize the channels through which a commodity price volatility shock diffuses through the economic fundamentals that describe performance in a resource intensive industry, we must simplify the exposition as much as possible, abstracting from reality to assess the initial impact of a shock as well as its subsequent, more indirect effects. The approach we adopt relies on the dynamic structure of our simulation model to show us how price volatility "trickles down" through the resource sector's profits, production levels, reproducible and natural capital investment demands, and the cost of their investment funds. Using Equations (1) - (5) with the Canadian forestry sector's exogenous variables *fixed* at their long run average values, we iteratively solve the model's five simultaneous equations to generate a series of stable simulated endogenous variables that are equal to their long run average values. We then shock the model with a one standard deviation increase in the volatility of forest prices relative to the volatility of the GDP deflator, and measure the changes in the simulated endogenous variables that occur in response to this shock.[29]

In Table 2 we report the observed long run average rates of change for each of the sector's endogenous variables, and the period-over-period percentage point changes in each of the five simulated endogenous variables beginning at the date of the shock and continuing through five post-shock periods.[30] The final line under *Simulation # 1* in Table 2 reports the cumulative, post-shock effect of a one standard deviation increase in relative commodity price volatility for each of the endogenous variables. Figure 1 depicts the cumulative effects of the volatility shock that are reported in Table 2. The chronological patterns that are apparent from Table 2 and Figure 1 not only indicate which of the model's endogenous variables are most sensitive to the initial volatility shock, but they also reveal how persistent the effects are for each of the economic fundamentals, and they indicate the absolute size of the cumulative post-shock effects for each variable.

Insert Table 2

From Table 2 we can see that the forestry firms' simulated equity prices drop sharply in response to an increase in output price volatility, and although investment demand for both reproducible and natural capital also falls, reductions in investment demand at $t = 0$ only affect the annual percentage changes in timber stocks and reproducible capital intensity at $t = 1$. The downward pressure on equity prices immediately following the shock reflects upward pressure on the cost of investment funds for forestry firms, and as a result, investment demand in subsequent periods will be further depressed. The reductions in reproducible capital intensity and natural capital stocks following the suppression of investment demand have a negative effect on production levels, reducing them by 0.86 percentage points in the first period following the shock, while simultaneously increasing extraction costs. Both of these effects have a negative influence on the growth rate of economic profits relative to GDP – the model predicts a 1.94 percentage point reduction in the growth rate of industry profits in response to the combination of falling output levels and rising extraction costs in the first period following the price volatility shock.

Insert Figure 1

The persistent, cumulative effects of the price volatility shock are a result of the connections linking the initial investment demand and supply effects to production levels and profitability, which in turn affect the forward looking investment decisions in subsequent periods. The investment supply equation in the simulation model indicates that unexpected changes in the profitability of the forestry sector are negatively correlated with changes in the cost of investment funds raised on the Toronto Stock Exchange, and the investment demand functions indicate that changes in forestry profits and production levels are positively correlated to natural and reproducible capital accumulation. These subsequent, indirect effects cycle through the model, dissipating slowly over the five periods following the shock. In total the cumulative, post-shock effects of a one standard deviation increase in relative price volatility include a 257% reduction in the rate of growth of forestry profits relative to GDP, a 89% reduction in the rate of growth of forestry output relative to aggregate output, a 63% reduction in the rate of growth of reproducible capital intensity among the forestry industries relative to the aggregate economy (this is in addition to a 200% reduction in immediate response to the shock), a 14% reduction in the rate of growth of the timber stock (this is in addition to a 110% reduction in immediate response to the shock), and a 103% reduction in the rate of growth of forestry firms' equity prices (this is in addition to a 335% reduction in immediate response to the shock).

Consistent with the predictions made by resource, finance and development theory, the shock's persistence in the simulation exercise is driven by the indirect effect that volatility has on the sector's profits, and hence, investment incentives. What is not obvious from the theory, but we can see quite clearly from the simulation exercise, is that the impact of volatility on the incentive to invest in the forestry sector is not uniform across both sides of the capital market. Although investment demand decisions are somewhat responsive, the supply of investment funds through the formal equity market appears to be dramatically more sensitive to commodity price movements. An assessment of the significance of the relative responsiveness of investment supply and demand decisions is necessary to put the differential cumulative effects of a volatility shock that are documented in Table 2 and Figure 1 into their appropriate comparative context. A simple modification of our first simulation exercise allows us to measure the extent to which investment supply responses alone can account for the cumulative effects that we documented in *Simulation # 1*.

In a second simulation exercise we again shock the model with a one standard deviation increase in relative commodity price volatility, but this time we use a new set of econometrically estimated parameters derived from a constrained version of Equations (1) - (5). More specifically, the parameters used in *Simulation # 2* have been estimated after restricting both investment demand functions' price volatility responses to be zero: in Equation (3) $\gamma 3 = 0$, and in Equation (4) $\eta 3 = 0$. These restrictions imply that the only channel through which commodity price volatility can directly affect the sector's economic fundamentals in this exercise is the investment supply response captured by the CAPM equation.

In Table 2 we report the cumulative effects of this shock on the simulated endogenous variables that have been derived from the constrained model. In Figure 2 we depict the response of the model's key profitability variable with (under *Simulation # 1*) and without (under *Simulation # 2*) a direct and immediate investment demand response. We can see that the forestry sector's economic fundamentals respond to an increase in relative price volatility in much the same way with or without direct investment demand effects. The connection between the shock and the incentive to accumulate reproducible and natural capital is lagged and muted in *Simulation # 2* relative to our first, unconstrained simulation, but the impact of an increase in price volatility on the long run growth rates of the forestry sector's fundamentals is quantitatively similar and statistically indistinguishable in the two exercises.

Natural capital stocks experience the largest change in their response to a volatility shock when investment demand effects are constrained to be zero (a 42% reduction in *Simulation # 2* relative to *Simulation # 1*), but the measured change in the b_t variable's long run growth rate is still less than one quarter of one percentage point: from *-0.0052* under *Simulation # 1* to *-0.0030* under *Simulation # 2*. The change in the responsiveness of the model's other endogenous variables range from a 0.8 percentage point drop in the growth of forestry profits relative to GDP: from *-0.025* under *Simulation # 1* to *-0.017* under *Simulation # 2*; to a *0.3* percentage point drop in the growth of reproducible capital intensity: from *-0.009* under *Simulation # 1* to *-0.006* under Simulation # 2. The similarity in the results from these two exercises suggest that the sensitivity of external investment supplies are largely responsible for the impact that commodity price volatility has on the performance of resource intensive industries. Even with direct investment demand responses removed from the model, a one standard deviation increase in relative price volatility still substantially reduces the long run growth performance of the sector's economic fundamentals.

Insert Figure 2

Clearly, equity market participants did not like volatile forestry prices. Investors' responses to increases in output price volatility drove down forestry firms' equity prices, thereby increasing the cost of the firms' investment funds, suppressing their incentive to accumulate reproducible and natural capital, reducing their production levels and increasing their extraction costs, all of which ultimately undermined profitability. Given the central role played by the relationship between price movements and investment supply decisions in explaining why commodity price volatility may be correlated with poor resource industry performance, a more detailed characterization of this relationship seems warranted.

Figure 3 depicts the relative volatility of Canadian forestry prices and an index of Canadian forestry sector equity prices relative to the Toronto Stock Exchange composite market index over the twentieth century. These series have been smoothed using a

Hodrick-Prescott filter. The negative (unconditional) correlation between the two variables is starkly apparent during the first decade of the century, the interwar period, and the last decade of the century, when steep reductions in the equity price series coincide with steep increases in the price volatility series. Periods with lower price volatility or falling price volatility appear to have equity price movements that, while still negatively correlated, are more muted, and the transitions between peaks and troughs do not appear to be as chronologically coincident during episodes of calm.

Insert Figure 3

These impressions, based on a visual inspection of the smoothed relative volatility and equity price series, are consistent with more statistically rigorous investigation. For the investment supply equation in our simulation model, covariance ratio tests, Cook's distance tests, and Welsch's distance tests identify observations with disproportionate statistical influence in parameter estimation during the first eight years of our sample period, the 1920s and 1930s, and the last 10 years of our sample period. A rolling regression with a 30 year estimation window indicates that the parameter estimate on commodity price volatility in the investment supply equation ($\lambda 3$ in Equation (5)) is unstable during the earliest years of our sample period, the interwar years, and the last years of the period. More specifically, the parameter estimate on price volatility in the CAPM equation is considerably larger (more negative) during these years.[31]

Our visual inspection of Figure 3 and the results from diagnostic testing on the investment supply equation suggest that during the twentieth century the responsiveness of Canadian equity market participants to commodity price volatility has been particularly acute during episodes of "crisis". Periods of high and rapidly increasing relative price volatility have a disproportionate influence on our estimate of the sensitivity of external investment supply decisions. When we re-estimate the system of five equations that make up our simulation model, allowing for a differential price volatility response in the investment supply equation during periods of crisis and calm, we find that years with high and rising commodity price volatility have been associated with a significantly more negative equity price response. During the years 1901-1909, 1921-1937, and 1991-1999 the parameter estimate on σ_{pt} in Equation (5) is *-0.8146* (p-value = *0.002*).[32] Over the full sample period the parameter estimate on σ_{pt} in Equation

(5) is *-0.3832* (p-value = *0.031*), and during the episodes of calm (1910-1920 and 1938-1990) the parameter estimate on σ_{pt} drops to *-0.0269* (p-value = *0.906*).[33]

To determine the extent to which these differential investment supply responses matter, we can again revisit our first simulation exercise. In *Simulation # 3* we parameterize our simulation model using only the investment supply response estimated during episodes of calm - low or falling relative price volatility. As we did in our first simulation, we allow the investment demand response in the reproducible and natural capital accumulation equations to be determined over the full sample period, and we run the post-shock simulation using the mean exogenous variables from the full sample period, which includes sharply rising price volatility during the episodes of crisis.[34] We then measure the change in the endogenous variables' long run growth rates in response to a one standard deviation increase in the relative volatility of commodity prices. The cumulative results from *Simulation # 3* are reported in Table 2, and Figure 2 depicts the response of the model's key profitability variable over 10 post-shock simulation periods when the investment supply response is determined during episodes of calm.

We can see that the channels through which volatility affects industry performance are similar, and the forestry sector's economic fundamentals are harmed even if equity market participants' responses to commodity price volatility shocks are not derived during crises. However, the strength of these effects is much reduced during periods of low or falling price volatility, and size of the cumulative performance effects is dramatically smaller. Under *Simulation # 3* the impact of a one standard deviation increase in commodity price volatility drops to a 0.67 percentage point reduction in forestry firms' equity prices (a decline of more than 89% over the measured response in *Simulation # 1*), a 1.3 percentage point reduction in the growth rate of profits relative to GDP, less than one half of a percentage point decline in both output and reproducible capital intensity, and just over one quarter of a percentage point reduction in the forestry sector's rate of natural capital accumulation. These results illustrate the extent to which the negative consequences associated with commodity price volatility for resource industry performance, at least in our twentieth century Canadian case study, depend critically on the sensitivity of those individuals who supply resource intensive producers with investment funds on formal, external capital markets during periods of crisis.

Are These Responses Economically Relevant?

Our simulation exercises illustrate that the strength of the connection between commodity price volatility shocks and a resource intensive industry's economic fundamentals is primarily determined by the sensitivity of investment supply responses during episodes of crisis. However, because these exercises employ the model's exogenous variables set at their long run means, they can not illustrate the size of these effects in an economically meaningful context. To provide this context we use our simulation model with the *observed* exogenous variables over the years 1900-1999 to conduct three counterfactual experiments, which parallel the simulation exercises described above. In conjunction with some admittedly restrictive assumptions, the results from the experiments can be extended to estimate a lower bound on the long run macroeconomic consequences of an increase in Canadian forestry price volatility.

In the first counterfactual experiment we iteratively solve the model's five equations over 100 periods to generate a series of simulated endogenous variables that closely track the observed endogenous variables. We then shock the model by increasing the relative volatility of forestry prices by one standard deviation, and we measure the changes in long run growth rates for each of the forestry sector's economic fundamentals in response to this shock.

Insert Table 3

Table 3 reports observed, simulated and counterfactual long run average annual log-differences in the Canadian forestry sector's economic fundamentals, and real GDP per capita, calculated over 100 periods. Table 3 also includes results from a series of tests establishing the statistical significance of the measured differences among these average growth rates. We can see that a one standard deviation increase in relative price volatility imposed under *Counterfactual # 1* drives down the long run growth rate of forestry profits relative to GDP by more than two and two third percentage points, the growth rate of forestry output relative to aggregate output declines by just over one percentage point, changes in reproducible capital intensity in the forest sector relative to the aggregate economy fall by just less than one percentage point, and the rate of growth of the natural capital stock falls by a half percentage point. Consistent with the simulation results, the forestry sector's share prices fall by nearly six percentage points in response to a counterfactual volatility shock. All of these counterfactual changes are statistically distinguishable from zero with at least 90% confidence. Keeping in mind that the figures reported in Table 3 reflect very long run rates of change, the resultant level effects accumulated over 100 periods would be large indeed.

Under *Counterfactual # 2*, like our second simulation exercise, the model is again hit with a one standard deviation increase in relative commodity price volatility, but the reproducible and natural capital investment demand responses are constrained to be insensitive to the direct and immediate effects of this shock. From Table 3 we can see that the long run growth rate effects of this shock on the resource sector's fundamentals are very similar, and statistically indistinguishable, from the *Counterfactual # 1* effects in which the investment demand responses are unconstrained.

Similarly, under *Counterfactual # 3*, which parallels our third simulation exercise, a one standard deviation increase in relative commodity price volatility with investment supply responses determined during periods of low or falling commodity price volatility, results in much smaller long run growth rate effects. The counterfactual reduction in the average annual percentage change in forestry profits relative to GDP, for example, only falls by 0.62 percentage points under *Counterfactual # 3*, and none of the counterfactual reductions in the fundamentals' growth rates are statistically distinguishable from zero.

Although these counterfactual experiments reveal much about the impact of commodity price volatility on a resource intensive industry, they do not tell us how important these industry specific performance effects might have been for aggregate macroeconomic performance. To complete the link connecting price volatility to macroeconomic performance we adopt a simplified, static general equilibrium extension to our estimated counterfactual industry effects.[35] By assuming perfectly elastic labor and capital supplies and assuming away any externalities spilling over from the capture of resource rents into other less resource intensive activities, the connection between a resource sector's fundamentals and aggregate macroeconomic performance can be fully captured by measuring changes in the returns paid to the fixed factor in production – in our case study, forestry profits.[36]

If we accept that the profits earned by the forestry sector (π_t) contribute directly to income per capita, and GDP growth is a weighted average of sectoral growth rates (including forestry), then *Counterfactual # 1*'s 2.4 percentage point reduction in the average rate of change of forestry profits relative to GDP (from -0.98% to -3.33%) would imply a reduction in the average annual growth rate of forestry profits from 6.1% to 3.7%, and a reduction in forestry profits' share of GDP from 3.7% to 1.7%. As a result of these changes, the counterfactual average annual real GDP per capita growth rate would fall from 2.01% to 1.98%.[37] This counterfactual impact on macroeconomic growth performance is virtually identical in the absence of direct investment demand effects (*Counterfactual # 2*) and with investment supply responses determined during periods of calm (*Counterfactual # 3*).

These estimates do not seem to imply a very large counterfactual "hit" to macroeconomic performance. Even a substantial reduction in the rate of growth of the resource sector's profits in response to a counterfactual increase in price volatility does not have much effect on the aggregate economy when the sector (more specifically, resource rents) do not comprise a large fraction of total economic activity.[38] Of course, these estimates of the macroeconomic impact of commodity price volatility should be viewed as a lower bound. During the twentieth century Canada had a large, wealthy, diversified economy with sophisticated and well integrated financial markets. The Canadian forestry sector was important to the domestic economy, but it was never as large as the mining sector nor the energy sector (particularly after 1970), its profits did not represent a large fraction of aggregate economic activity, and aside from three episodes of high and rising volatility, its output prices were fairly stable (at least relative to many international commodity price series).[39] All of these factors contribute to the notion that *any* commodity price volatility effect in the twentieth century Canadian environment should be surprising, and the size of the industry and macroeconomic implications we identify suggests that in virtually all other sectors and nations the performance effects would likely be considerably more consequential.

Conclusions

Commodity price volatility is bad for macroeconomic performance. Evidence from aggregate cross-section growth equations confirms that since the 1970s economies that were more specialized in resource intensive economic activities have had more volatile macroeconomic environments and slower macroeconomic growth rates. In this paper a dynamic simulation model based on predictions made by renewable resource and finance theory has been used in conjunction with evidence drawn from the Canadian forestry sector over the period 1900-1999 to document exactly *why* price volatility affects the economic fundamentals characterizing a resource intensive industry, and hence macroeconomic performance in a resource intensive economy. In our case study, over the twentieth century, increases in the volatility of forestry prices were associated with reductions in the incentive to invest in both reproducible and natural capital, and reductions in forestry firms' equity prices. The initial, direct investment demand effects exerted downward pressure on production levels and profits, while the declining equity prices represented a negative investment supply effect – increasing the cost of investment funds raised from external sources, and therefore, further reducing investment demand in subsequent periods. In our simulation model, price volatility had a substantial and persistent effect on the resource sector's economic fundamentals, with external investment supply responses being particularly sensitive. The sensitivity of individuals participating on formal equity markets to commodity price volatility was considerably more acute during episodes of high and rising volatility. Even with a set of assumptions designed to minimize the measured macroeconomic effect of slower growth within the resource sector, our calculations suggest that real GDP per capita growth would have been suppressed in response to commodity price volatility and the cumulative growth effects would have had a significant impact on income levels by the end of our sample period.

These findings imply that commodity price volatility affects resource industry performance through investment supply and, to a lesser extent, investment demand decisions, and resource industry performance affects macroeconomic performance through the generation of resource rents. We can also conclude that price volatility cannot be fully sterilized, even in the presence of large, diversified, sophisticated, and well integrated domestic financial intermediaries. The more specialized an economy is in resource intensive activities, the more volatile their commodity prices are, the more sensitive their investment supply responses are, and the more important resource rents are to the aggregate economy, the stronger the connection will be linking price volatility to poor growth performance.

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Tables and Figures

Table 1: Simulation Model's Econometrically Estimated Parameters

	Profit Function: π_t	Production Function: q_t	Reproducible Capital Demand: k_{t+1}	Natural Capital Demand: b_{t+1}	Investment Supply Function: $(r_t - rf_t)$
π_t					**0.5492**
					(0.000)
q_t	**2.0828**		0.0778	-0.0104	
	(0.000)		(0.484)	(0.883)	
k_t	0.0744	**1.1828**			
	(0.702)	(0.000)			
b_t	0.2165	0.0782		**0.2022**	
	(0.256)	(0.320)		(0.041)	
$(r_t - rf_t)$			**0.0960**	**0.0541**	
			(0.005)	(0.017)	
a_t	**0.9067**	**0.9852**			
	(0.000)	(0.000)			
p_t	**3.2925**		**0.3143**	0.0503	
	(0.000)		(0.089)	(0.670)	
cux_t	0.2034				
	(0.422)				
l_t		**0.6444**			
		(0.000)			
wk_t			**-0.0836**	-0.0173	
			(0.001)	(0.274)	
wl_t			0.0134	0.1317	
			(0.928)	(0.173)	
σ_{pt}			-0.0223	-0.0182	**-0.3833**
			(0.791)	(0.731)	(0.031)
$temp_t$				0.2332	
				(0.544)	
$pcip_t$				-0.0622	
				(0.368)	
$(rm_t - rf_t)$					**0.9089**
					(0.000)
b_{t-1}				**-0.2262**	
				(0.023)	
constant	0.0060	-0.0049	0.0028	0.0048	0.0080
	(0.590)	(0.258)	(0.740)	(0.354)	(0.721)
R^2	0.7752	0.8129	0.1212	0.1728	0.4016
χ^2	0.000	0.000	0.001	0.027	0.000

Note: Equation structure, estimation procedure and data series definitions are provided in text. P-values are specified in parentheses and statistically significant parameter estimates are reported in bold font. χ^2 represents the probability that all explanatory variables are jointly statistically insignificant.

Table 2: Cumulative Effects of 1 Standard Deviation Shock to Price Volatility (% Deviation from Previous Period)

	π_t	q_t	k_{t+1}	b_{t+1}	$(r_t - rf_t)$
Observed	-0.0098	-0.0126	0.0035	0.0042	-0.0135
Simulation # 1:					
t = 0	0.0000	0.0000	0.0000	0.0000	-0.0452
t = +1	-0.0194	-0.0086	-0.0070	-0.0046	-0.0107
t = +2	-0.0044	-0.0020	-0.0017	-0.0004	-0.0024
t = +3	-0.0010	-0.0005	-0.0004	-0.0001	-0.0006
t = +4	-0.0003	-0.0001	-0.0001	-0.0001	-0.0001
t = +5	-0.0001	-0.0000	-0.0000	-0.0000	-0.0001
Cumulative	-0.0252	-0.0112	-0.0092	-0.0052	-0.0591
Simulation # 2: Cumulative	-0.0167	-0.0075	-0.0061	-0.0030	-0.0558
Simulation # 3: Cumulative	-0.0128	-0.0056	-0.0045	-0.0028	-0.0067

Note: Observed: Average annual % Δ, 1900-1999. Simulation # 1: One standard deviation shock applied to model at t = 0. Cumulative post-shock effects: Σ t = 0 → t = +5. Simulation # 2: One standard deviation shock applied to model at t = 0 with no investment demand response. Simulation # 3: One standard deviation shock applied to model at t = 0 with investment supply response determined during calm.

Table 3: Results from Counterfactual Experiments

	π_t	q_t	k_{t+1}	b_{t+1}	$(r_t - rf_t)$	*GDP/Capita*
Observed % Δ	-0.0098	-0.0126	0.0035	0.0042	-0.0135	0.0201
Simulated % Δ	-0.0098	-0.0128	0.0036	0.0041	-0.0148	
Counterfactual # 1 % Δ	-0.0333	-0.0233	-0.0052	-0.0004	-0.0729	0.0198
(CF # 1 P-value)	(0.069)	(0.075)	(0.012)	(0.001)	(0.002)	(0.948)
Counterfactual # 2 % Δ	-0.0320	-0.0229	-0.0058	0.0015	-0.0737	0.0198
(CF # 2 P-value)	(0.996)	(0.988)	(0.803)	(0.400)	(0.959)	(0.964)
Counterfactual # 3 % Δ	-0.0160	-0.0155	0.0012	0.0029	-0.0037	0.0200
(CF # 3 P-value)	(0.321)	(0.332)	(0.242)	(0.118)	(0.701)	(0.981)

Note: Average annual % changes calculated over 100 periods. Counterfactual # 1 shocks simulation model with a one standard deviation increase in relative price volatility. CF # 1 p-values reflect the results from a single tailed t-test of the null hypothesis that the CF # 1 means are equivalent to simulated means. Counterfactual # 2 shocks simulation model with a one standard deviation increase in relative price volatility, constraining investment demand sensitivity to be 0. CF # 2 p-values reflect the results from a 2 tailed t-test of the null hypothesis that the CF # 2 means are equivalent to CF # 1 means. Counterfactual # 3 shocks simulation model with a one standard deviation increase in relative price volatility, using investment supply sensitivity estimated during periods of low or falling price volatility. CF # 3 p-values reflect the results from a single tailed t-test of the null hypothesis that the CF # 3 means are equivalent to simulated means. P-values for *GDP/Capita* reflect the results from a 2 tailed t-test of the null hypothesis that the counterfactual means are equivalent to the observed means.

Figure 1: Cumulative Effect of Price Volatility Shock

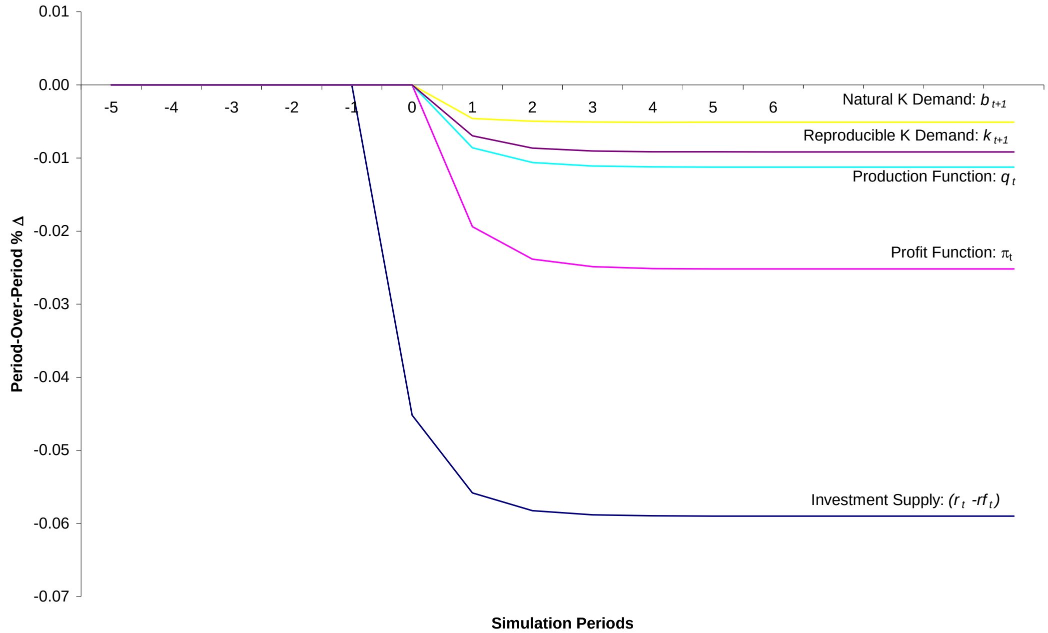

Figure 2: Cumulative Effect of Price Volatility Shock on Profit Function (Π_t)

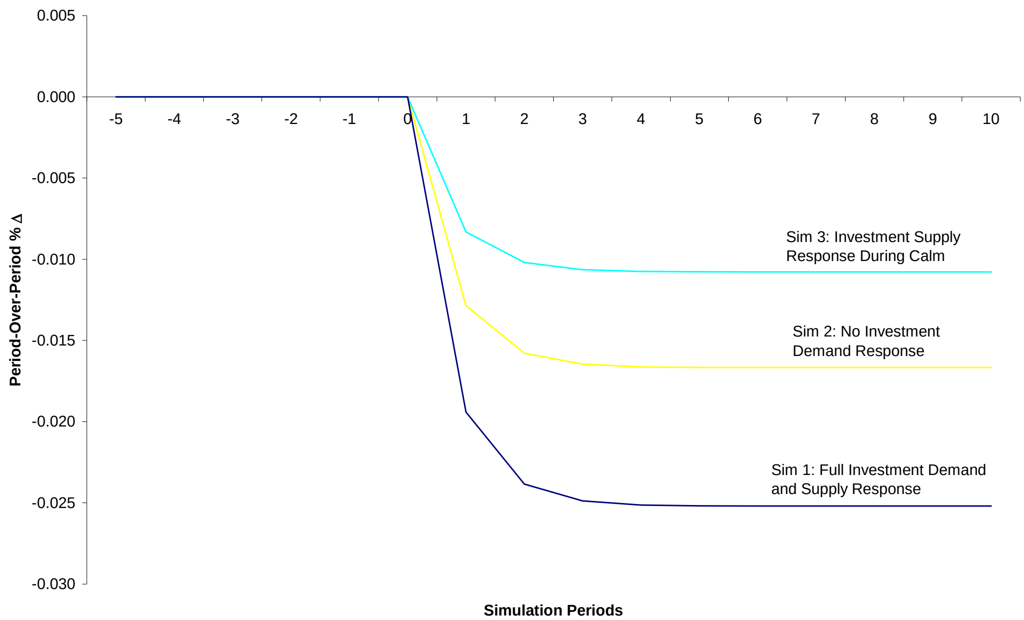

Figure 3: Forestry Equity Price / TSE Composite and Forestry Price Volatility / GDP Deflator Volatility

Endnotes

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[1] For an example see Acemoglu, Johnson, Robinson and Thaicharoen (2003) and the lengthy list of papers they reference on pages 55-56.

[2] Jacks, O'Rourke, and Williamson (2009) use a combination of monthly and annual data for the United States, Britain, the Netherlands and Denmark over a very long time period (1720-1950), in conjunction with IMF and UNCTAD data for the late twentieth century, to show that commodity prices have been persistently more volatile than industrial product prices.

[3] For a review of some of the key evidence that has followed Sachs and Warner's (2001) initial articulation of the "resource curse" see Auty (2001) or Brunnschweiler and Bulte (2008).

[4] For a theoretical and empirical illustration of the risk-investment relationship in less developed countries see Fafchamps (2003) or Dercon (2004).

[5] Bhattacharyya and Williamson (2009) use Australia as a case study to illustrate the importance of diversification and appropriate public policy and investment responses in mitigating the negative consequences of commodity price volatility.

[6] Income, industrial structure and urban population numbers have been derived from Urquhart (1993, Table 1.1 and 1.6) and *Historical Statistics of Canada* (1965, Series A18). The 1901 income per capita ranking is reported in Prados (2000, Table 9) and the 1999 income per capita ranking has been taken from the Penn World Tables.

[7] Canadian exports were never more than a small fraction of US sales, but the correlation between changes in Canadian and US forest product prices between 1900-1999 was 0.745. This indicates that even though Canadian forest producers were important players on international markets, they remained price takers.

[8] Many histories of the Canadian forestry sector have been written that chronicle its economic and technological development. For some examples see Lower (1933), Nelles (1974), Dick (1982), or Marchak (1983).

[9] Volatility is measured as the standard deviation of price indexes over the previous 15 years. Between 1900-1999 a 1% increase in relative commodity price volatility in Canada was associated with a 0.097% reduction in real GDP per capita growth rates. This correlation is statistically distinguishable from zero with 94% confidence.

[10] See Inwood and Stengos (1995), Evans and Quigley (1995), or Serletis (1992) for results from formal tests for discontinuities in Canadian growth. The history of the economic environment specific to the Canadian forestry sector is described in detail by Drushka (1995) or Marchak (1983). The claim of stable volatility-performance links is supported by statistical testing for parameter stability and outlying observations. More detail is provided below.

[11] For more detailed discussions of the structure and characteristics of the twentieth century Canadian capital market see Bliss (1987), Rudin (1982), or Taylor and Baskerville (1994).

[12] For a standard depiction of this dynamic approach to modeling optimal extraction see Neher (1990) Chapter 17, or Hartwick and Olewiler (1998) Chapter 10.

[13] For a detailed discussion of the standard cost determinants and their inclusion in resource extraction models see Varian (1992) Chapter 5 and Neher (1990) Chapter 6.

[14] Input prices are not included as extraction cost determinants because resource theories typically assume that firms' optimize over production levels, rather than input quantities.

[15] The investment demand function for reproducible capital is based on the application of *Sheppard's Lemma* to a standard, well defined cost function.

[16] There is a vast literature on natural capital accumulation functions (biological growth functions) for forest resources. For surveys of this literature see Pearse (1990) or Statistics Canada (1993).

[17] Ideally we would like to consider the cost of funds raised from both equity and bond markets, but industry specific information about bond issues and yields is unavailable for the pre-1970 period.

[18] The theoretical foundation for the multi-factor CAPM approach was first articulated in Ross' (1976) arbitrage pricing theory. Cragg and Malkiel (1982) provide a survey of empirical CAPM applications. Sadorsky (2001), and Sadorsky and Henriques (2001) have used the multi-factor CAPM approach to model the late twentieth century equity market performance of Canadian energy and forestry industries, respectively. For similar U.S. and British examples see El-Sharif, Brown, Burton, Nixon, and Russell (2005) or Jones and Kaul (1996). Slade and Thille (1997) use evidence from Canadian copper mines to empirically test the structural implications of a more formal theoretical model that explicitly links a multi-factor CAPM equation to the resource rent patterns implied by the *Hotelling Rule*.

[19] For an example using "discounted cash flow" valuation techniques applied to natural resource industries see Perman, Ma, McGilvray, and Common (2003), Pg. 366-67.

[20] In an efficient, competitive equity market, anticipated changes in profitability should already be fully reflected in equity prices. This implies that changes in equity market performance should be related to deviations from expected profitability rather than aggregate changes in the profits. Although there are an infinite number of ways to model expectations (or deviations from expectations), in the simulation model used in this paper we simply assume that investors on the TSE expected changes in forestry profits to be determined by last years' profits. This implies that all of the annual change in forest profits may be considered unanticipated. As a sensitivity test the model has been calibrated under two alternate assumptions – investors may have used industry profits over the last three years or the last five years to form their expectations about changes in current profits. These assumptions imply that unanticipated changes in profits may be measured by using the residuals from a preliminary estimation equation in which current profits are regressed against a constant, a linear time trend (to allow for changes in information gathering and processing technology over time) and past profits. The qualitative conclusions regarding price volatility are unaffected by our assumptions regarding the anticipation of expected profits, but the solutions for the simulation model are simplified by the use of the more basic "consecutive year" expectations formation assumption.

[21] Young (1992) discusses in detail the challenges associated with the derivation of marginal resource rents for an unbalanced sample of 14 Canadian copper mining firms between 1956-1992.

[22] For example, Q_t – the implicit choice variable in the optimal extraction problem – is defined as the real output of the Canadian forestry sector in period t. q_t in the production function described by Equation (2) is defined as the log-difference in forestry real output

relative to aggregate real output between period *t-1* and *t*. A detailed description of sources and series construction for all variables can be accessed at: http://qed.econ.queensu.ca/faculty/keayi/datalinks/dataapp3.pdf.

[23] The number of lagged stock terms in the natural capital accumulation function has been determined by minimizing the *Akaike Information Criteria*. In our preferred specification *n=1*.

[24] Identification of Canada's forestry industries follows the NAICS definitions used by Natural Resources Canada in 2004. See Keay (2009, Figure 1) for more detail on industry composition.

[25] Before estimation the time series properties of the data were explored using Phillips-Perron unit root tests. Non-stationarity can be rejected with at least 99% confidence for all of the log differenced series employed in Equations (1) - (5). A complete set of econometric results is available from the author.

[26] The diagnostic tests that have been performed include tests for the presence of statistical outliers, parameter stability for the price volatility variables, and a Hausman test for the exogeneity of capital intensity in the profit equation. The endogeneity of capital intensity has been singled out for further testing because the direction of causation may be reversed from what is implied in Equation (1). Specifically, more profitable producers may have greater access to informal capital sources such as retained earnings, which in turn may facilitate more rapid capital accumulation.

[27] There is no obvious historical sub-period during which both reproducible and natural capital are significantly negatively correlated to price volatility (holding all else constant). However, during the 1920s and 1930s reproducible capital is strongly negatively related to volatility and the strongest connection between volatility and timber

stocks appears to be during the 1970s and 1980s. Share prices are consistently negatively correlated to output price volatility through virtually all sub-periods.

[28] Model diagnostics have been performed. We have used the parameter estimates reported in Table 1 with the observed exogenous variables describing the Canadian forestry sector to iteratively solve the system of five equations for each of the endogenous variables over 100 simulation periods. We then compared the distribution of each of the simulated variables to the distribution of each of the observed endogenous variables. The simulation model fits the observed variables quite well, with the mean simulated endogenous variables differing from the observed endogenous variables by less than ten percent in every case. Absolute differences in mean growth rates are small and statistically insignificant. However, the simulation model is unable to capture the full extent of the volatility in the observed endogenous variables. An inability to generate appropriately volatile simulated variables does not interfere with the model's ability to generate appropriate long run means.

[29] The price volatility shock imposed in the simulations increases the long run average annual percentage change in the volatility of forestry prices relative to the volatility of the average price level by 0.118. To put this figure into context, between 1991-1999 the observed average annual percentage change in the volatility of forestry prices relative to the volatility of the average price level was 0.163.

[30] For all five of the endogenous variables the change in the cumulative effect of the shock dissipates within five periods. We define "dissipation" to mean a period-over-period change in each variable of less than 1% of its pre-shock level.

[31] Outlier tests and parameter stability tests on the reproducible and natural capital accumulation equations are far more ambiguous about the statistical influence of the episodes of high and rising price volatility. If we allow for differential price volatility

effects in these equations, we do not find any significant differences in the σ_{pt} parameter estimates during periods of crisis versus calm.

[32] The average annual rate of change in the volatility of forestry prices relative to the GDP deflator during the three episodes of crisis identified in the text was 0.034. During the full sample the average annual rate of change in relative price volatility was 0.009, while during the two periods of calm the rate of change in relative price volatility fell to -0.017.

[33] The parameter estimate on σ_{pt} in Equation (5) derived during episodes of crisis can be statistically distinguished from the estimate derived during episodes of calm with 98% confidence.

[34] The parameter estimates on σ_{pt} in Equation (3) and (4) derived during episodes of crisis cannot be statistically distinguished from the estimates derived during episodes of calm with any standard level of confidence.

[35] This approach was developed for use in a resource modeling context by Chambers and Gordon (1966).

[36] Lewis (1975) has shown that loosening the assumptions regarding perfectly elastic labor and capital supplies can have a significant effect on the net impact of rent capture, and Keay (2007) has shown that over the twentieth century spillovers linking resource industries to more capital or labor intensive activities had a substantial impact on macroeconomic performance.

[37] This difference in long run growth rates is statistically indistinguishable from zero with 94% confidence.

[38] These effects are not one time level discontinuities, but long run reductions in growth rates that accumulate over 100 periods. The slower real GDP per capita growth predicted by our counterfactual experiment implies that the average Canadian would have been approximately $800 poorer than they actually were during the last decade of the twentieth century.

[39] If we assume that the volatility effects in forestry are representative of mining and energy, and we use the estimate of the value of indirect spillovers from resource shocks to other non-resource intensive sectors from Keay (2007, Pg. 26-27), then even the Canadian lower bound real GDP per capita counterfactual growth rate would drop to 1.88% - a reduction from the observed trend growth rate of nearly 8%.