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, designed to be consistent with predictions made by renewable resource, production, and finance theory, 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 importance of each of these effects. Simulation exercises reveal the extent to which commodity price volatility shocks significantly reduce forestry 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: N52, Q20 and Q32.

Introduction

There is a considerable body of evidence linking macroeconomic volatility to 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 more volatile changes in their terms of trade due to the combination of relatively concentrated industrial structures with unsophisticated domestic financial intermediation, and higher price volatility among resource intensive products relative to labour or capital intensive products. The correlations among these variables lead us to conclude that there may be a link between commodity price volatility, on the one hand, and long run macroeconomic performance, on the other. What the cross-section growth equation approach to comparative performance assessment cannot reveal are 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 investigate 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 describing the Canadian forestry sector's economic fundamentals 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 our case study 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 perhaps most importantly for our purposes, 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 an optimization problem describing how producers make renewable resource extraction and processing decisions. Resource theory typically assumes that producers choose production levels in an effort to maximize the stream of future profits earned off a renewable resource stock, subject to their available technology and a series of constraints specifying the determinants of reproducible and natural capital accumulation. To fully capture the impact of commodity price volatility, the four equations that comprise this standard resource modeling approach have been augmented with a multi-factor capital asset pricing model (CAPM) that describes the cost of acquiring investment funds on a domestic equity market. The full simulation model, therefore, consists of a system of equations that document the evolution through time of five key economic fundamentals characterizing the performance of the Canadian forestry sector: profits earned, the forestry firms' common share prices on the Toronto Stock Exchange (TSE), production levels, and the accumulation of reproducible and natural capital. The dynamic nature of the model stems from the forward looking investment demand equations. Each simulation is run by solving the model's five equations iteratively through 100 periods using the observed (or counterfactual) exogenous variables, and econometrically estimated parameters. The parameters for the model's system of equations have been estimated with an iterative least squares procedure and annual data spanning 1900-1999 drawn from the extraction, primary processing, and secondary processing firms that made up Canada's forestry sector.

The structure of the simulation model lends itself to the performance of a series of counterfactual experiments 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, their strength, economic and historical significance, and their cumulative impact on macroeconomic growth can be documented.

Our investigation begins by measuring the extent to which commodity price volatility affects long run performance in a diversified environment with sophisticated financial intermediation. To be more specific, the first question we ask is: "How much did commodity price volatility affect the performance of Canada's forestry sector during the twentieth century, even though Canada had a large, wealthy, industrially diversified economy with efficient, well-integrated financial markets?" To answer this question we use the observed exogenous variables when iteratively solving our simulation model's system of five equations through 100 periods following the imposition of a one standard deviation shock to the volatility of domestic forestry prices relative to the volatility of the gross domestic product (GDP) deflator. The resulting counterfactual long run growth rates for the model's endogenous variables are then measured and compared to their simulated means in the absence of any counterfactual shock. To complete the exercise, we link the industry specific effects to macroeconomic performance. We find that even in the presence of extensive diversification opportunities, the effects of an increase in commodity price volatility are large and statistically distinguishable from zero, particularly for the forestry sector's profits and the cost of their investment funds raised from external sources.

The process by which price volatility triggers industry performance effects is more carefully and fully documented in the second stage of the investigation. Having established that volatility matters, our next question is: "Why did commodity price volatility reduce the long run profitability of Canada's forestry sector?" To answer this question we use the model's exogenous variables fixed at their long run means when iteratively solving the system of equations. This allows us to derive a series of stable simulated endogenous variables that are also equal to their long run mean values. When we shock this system with a one standard deviation increase in the relative volatility of forestry prices, we can trace the timing and magnitude of the impact of this shock through changes in each of the simulated endogenous variables. Increasing commodity price volatility initially suppresses the incentive to accumulate reproducible and natural capital and substantially increases the cost of investment funds raised from external sources. The rising cost of investment funds reduces investment demand even further in subsequent periods, and the cumulative investment demand effects drive down production levels and drive up extraction costs, which both decrease profits, further inflating the cost of investment funds raised from formal equity markets. Another simple counterfactual experiment illustrates that the impact of a commodity price volatility shock is largely dependent on the sensitivity of the investment supply response rather than the investment demand response.

In the third stage of the investigation we study the role played by commodity price *crises* – periodic episodes of very high and rising volatility – in determining investment supply and demand responses. Having isolated the responsiveness of investment supply from external sources as a key channel linking commodity price volatility to performance, we conclude our case study with a final question: "Why was the supply of investment funds from the TSE so sensitive to price volatility?" The answer to this question lies in the observation that the forestry sector's equity prices moved much more abruptly during periods of crisis than they did during periods of calm. Rather than assuming that equity market participants' sensitivity to commodity price movements was fixed over the full 1900-1999 period, we re-estimate the simulation model's parameters allowing the impact of price volatility to vary between periods of calm and crisis in the investment supply equation. We find that the (conditional) correlation between the cost of externally supplied investment funds and commodity price movements was dramatically larger during three periods of exceptionally volatile forestry prices: 1900-1909, 1914-1945, and 1991-1999. In contrast, the sensitivity of reproducible and natural capital demand does not vary in a significant way between these periods of crisis and the intervening periods of calm. After parameterizing the model with the more insensitive investment supply responses derived in the absence of price volatility crises, the impact of a volatility shock is again traced through the model's endogenous variables. The cumulative impact of this shock on performance is considerably reduced, suggesting that equity market participants' responses to episodes of crisis play a key role in determining the economic consequences associated with commodity price volatility.

Based on the econometric estimation of the simulation model's parameters and the results from the counterfactual experiments and simulation exercises, we can articulate a much more complete description of exactly *why* commodity price volatility affects the economic fundamentals in a resource intensive industry, and hence macroeconomic performance in a resource intensive economy. During periods of particularly high price volatility the cost of investment funds from 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 performance can be large and persistent, and even in our Canadian case study where financial intermediaries have been sophisticated and well integrated, diversification opportunities cannot 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, which they were able to estimate with statistical confidence even after controlling for initial income levels, population growth, human capital, and reproducible capital accumulation, 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, cultural fragmentation, military and political uncertainty, institutional discontinuity, 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, variation in real exchange rates and terms of trade shocks tend to be closely chronologically coincident with unanticipated movements in real GDP per capita. 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, while Blattman, Hwang, and Williamson (2007) show that there may be an even more direct connection linking terms of trade shocks and macroeconomic volatility among "periphery" nations. This connection is not just a recent phenomenon, but can be identified among a sample of 35 countries as early as the 1870-1939 period.

The Blattman *et al.* paper is of even greater interest to us here because they not only quantify a strong correlation between terms of trade shocks and macroeconomic volatility, but they note that there has been a significant link connecting movements in the periphery nations' relative import and export prices and the extent to which they have specialized in resource extraction and processing activities. The authors argue that specialization in resource intensive activities exacerbates terms of trade shocks, contributes to macroeconomic volatility and ultimately slows income per capita growth, because it 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]

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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, and the offsetting effects of globalization – increased specialization and increased market integration – had little overall effect on relative price volatility.

Confirmation of a correlation between resource specialization and volatility in a more 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 seems consistent with the presence of a "resource curse" linking resource intensity and poor growth performance among less developed nations after 1970, can be overturned if macroeconomic growth equations include commodity price volatility among the set of control variables.[3] They report that as long as the volatility of commodity prices is appropriately taken into account, natural resource "dependence" appears to be positively related to growth. 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 fairly robust negative 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. Development theory, therefore, suggests that one of the channels through which inherent volatility and a lack of

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[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).

diversification opportunities can negatively affect growth is likely to be the link between risk and uncertainty and the incentive to engage in both investment demand and supply activities.

Modeling Resource Intensive Production

Virtually all of the volatility-growth literature uses evidence derived from aggregate data averaged over long time periods and broad cross-sections of countries to argue that specializing in resource intensive economic activities is typically associated with high levels of industrial concentration, and this lack of diversification, in conjunction with persistently volatile commodity prices, is often coincident with terms of trade and real exchange rate shocks, macroeconomic volatility, and poor macroeconomic performance. However, the correlations that underlie this argument do not necessarily help us to articulate exactly why commodity price movements affect growth rates. Development theory tells us that it might have something to do with investment decisions. Unfortunately, when we rely on empirical evidence that is averaged across time and international boundaries we encounter confounding and interdependent relationships that 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 assessed in the presence of careful controls for these confounding effects. These controls can be particularly challenging to construct across developing economies with wildly different environments, institutional structures, and access to international capital markets.

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 an individual nation and environment. It would also be helpful if the nation chosen for detailed study provided us with a long time series of high quality, consistently defined data, a stable cultural, institutional and endowment environment, and a domestic capital market that allows us to safely ignore any concerns we might have regarding discontinuities introduced by the presence of unsophisticated financial intermediation. Any case study intended to document a particular example of an industry and economy affected by commodity price volatility needs a theoretical foundation to guide the search for connections linking price movements to performance. Careful consideration of the predictions made by renewable resource, production, and finance theory can help us to construct an industry model that can be taken to the data to generate evidence that sheds light on the implicit and explicit conclusions drawn from the estimation of aggregate, cross-section growth equations.

A Canadian Case Study

Canada is an example of a wealthy, industrially diversified nation that has specialized in resource extraction and processing activities throughout its development process. 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.[5] Ninety-nine years later Canada's purchasing power adjusted real GDP per capita still ranked fourteenth in the world, manufacturing accounted for 16% of GDP, and 77% of the population lived in an urban centre. Despite the urban and industrial structure of the Canadian economy, resource intensity has also been persistently high throughout the twentieth century, with the forestry sector accounting for a significant fraction of aggregate input employment and output production.

During the early part of the century the production of lumber, wood, and wood products from old growth hardwood forests was geographically concentrated in south-eastern Ontario and south-western Quebec. The primary markets for Canadian forestry products at this time, as they had been throughout most of the nineteenth century, were in Britain – shipped through the port of Montreal – and the north-eastern United States –

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[5] 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.

shipped through Albany, NY.[6] 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] During the post-World War 2 era the production of timber, wood, and wood products shifted towards softwood lumber taken from Canada's Pacific coast, and the US became by far Canada's largest export market. By the 1990s the forestry sector still employed 2.5% of the Canadian workforce and 5% of the reproducible capital stock, while generating 4% of the aggregate income earned by Canadians.

These stylized facts illustrate the extent to which Canada successfully developed, diversified and grew through the twentieth century, while continuing to specialize in the intensive use of its resource endowments. This implies that the Canadian experience represents a very successful example of resource-based growth. However, what makes the Canadian environment particularly attractive for a study of the relationship between commodity price volatility and macroeconomic performance is the remarkable stability of the Canadian environment over the 1900-1999 period. Unlike many of the nations included in the broad cross-sections used to estimate aggregate growth equations, in a Canadian case study we need not concern ourselves with the possibility that episodes of cultural, geographic, or institutional discontinuity will confound our effort to map out the connections linking price volatility and performance over time. Canada experienced no dramatic and 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 physical environments after 1900, the connections linking volatility and performance do not appear to have been fundamentally affected by these transitions.[8]

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

[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] 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.

In addition to underlying environmental stability, Canadian financial markets were large, diversified, fairly competitive, and well integrated with US markets throughout the twentieth century.[9] 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 indicates that hedging against commodity price volatility must have been feasible throughout the period of study. Any commodity price volatility effects captured by our case study 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 any connections we find linking commodity price shocks to the economic fundamentals in our Canadian case study will not be attributable to unmeasured changes in other growth determinants or changes in the decision makers' ability to diversify over the period of study. 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 price volatility may have on the investment and production decisions made by a large resource intensive industry in a resource intensive economy.

Predictions drawn from Resource, Production, and Finance Theory

When investigating the channels through which price volatility affects performance we must carefully consider the distinction between causation and correlation among the variables of interest. To emphasize this distinction, we can adopt a more structural approach to the empirical exercise by relying on optimal resource extraction, production, and finance theory to provide guidance when specifying an empirical model.

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[9] For considerably 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).

For our purposes we wish to employ 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 renewable 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 future stream of expected industry profits, or resource rents.[10] 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 characterize the impact of commodity price volatility, we also introduce an external investment supply constraint that depends on industry profits. We can depict this theoretical approach 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 (*Qt*), and the resultant industry profits (∏*t*), hinge on the trade-off between extraction costs (*C(...)*) and output prices (*Pt*). Extraction costs are typically considered to be dependent on standard cost determinants, taken from production theory, and the size of the resource stock (or

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

biomass) *in situ* (B_t).[11] 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).[12] 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).[13] 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 ($pcip_t$).[14]

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[11] 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.

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

[13] The investment demand function for reproducible capital is based on the application of *Sheppard's Lemma* to a standard, well defined cost function, as described in Varian (1992) Chapter 5.

[14] 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).

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 share prices imply a reduction in the cost of raising investment funds from external capital markets for the forestry 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 investment supply from all external sources.[15]

To capture the endogenous nature of the equity market performance of forestry firms participating on the TSE, we can use a multi-factor capital asset pricing model (CAPM).[16] 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.[17] 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*. In its most basic form the CAPM approach to understanding the evolution of equity prices on formal stock exchanges 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

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[15] 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.

[16] 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.

[17] For similar U.S. and British examples see El-Sharif, Brown, Burton, Nixon, and Russell (2005) or Jones and Kaul (1996).

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.[18] 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.[19]

Commodity price volatility appears in the model's three constraints – the reproducible capital accumulation function, the natural capital accumulation function, and the multi-factor CAPM function. However, because the endogenous variables described by these constraints are also determinants of the 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 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 optimal transition paths and the steady state for the model's state and control variables. These first order conditions would include a set of equations

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

[19] 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.

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.[20] 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 that are 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 Canada's forestry sector, and we can then look to the 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 the theory 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 for the equations that characterize the evolution of the resource sector's endogenous variables. 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, production and finance theory. We make five minor changes to the

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[20] 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.

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 endogenous and exogenous variables from the model 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 forest products 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 wildly 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.[21] 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[22]

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

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[21] 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 (annual % Δ) in forestry real output relative to aggregate real output between period *t-1* and *t*. A detailed definition for all of the variables included in Equations (1) - (5) is included in the Data Appendix. 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.

[22] 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 $n=1$.

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 timber stock variables in Equations (1) and (2), affecting subsequent production decisions and profitability.

The cumulative impact of price volatility in the resource sector may affect national labor or capital markets if workers and investment funds are not elastically supplied in the domestic economic environment, and there may be externalities linking resource extraction and processing to the other more labor and capital intensive industries in the economy. However, even if we ignore these possible spillovers, the generation of economic profits alone, which result from the use of a fixed factor of production, directly contributes to the wealth of the aggregate economy.[23] This implies that as a lower bound estimate of the strength of the possible link between commodity price movements and macroeconomic performance, we can measure the extent to which income per capita growth might be affected by changes in industry profitability triggered by price volatility shocks. Therefore, after choosing parameters for Equations (1) - (5) and testing the fully specified model's ability to simulate the observed endogenous variables, volatility-profitability-growth connections can be probed with a series of simulation exercises and counterfactual experiments.

The parameters for the simulation model have been chosen on the basis of an econometric estimation of Equations (1) - (5), using data from the Canadian forestry sector covering the years 1900-1999. Identification of Canada's forestry industries follows the NAICS definitions used by Natural Resources Canada in 2004.[24] The decision to use contemporary industrial categories necessitated the reconstruction of

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[23] For a more detailed discussion of the direct and indirect impact that resource intensive industries may have on macroeconomic performance see Keay (2007) Pg. 24.

[24] The composition of the industries used in this study is described in Keay (2009) Figure 1.

industries from more disaggregate data for much of the early part of the century. There were particularly dramatic reorganizations of industry categories by the Dominion Bureau of Statistics and Statistics Canada in 1926, 1948 and 1982. Prior to the existence of the Dominion Bureau of Statistics, which began operations in 1926, much of the quantity, value, and price data used in this study were only available from decennial *Canadian Census Reports* and periodic publications by the Department of Forestry, the *Government of Canada Sessional Papers*, and *Canadian Statistical Year Books*. For the series which had no annual data published outside of census years (1901, 1911, and 1921) interpolation was based on the methodological approach employed by Urquhart (1993) in his reconstruction of late nineteenth and early twentieth century Canadian GDP.

Before estimating Equations (1) - (5), the time series properties of the data were explored using Phillips-Perron unit root tests.[25] It was not surprising to find that the series were often non-stationary when measured in levels. However, because we are interested in relative rates of change over time, the stationarity of the log differences in the relative performance indicators and their determinants is more relevant than the stationarity of each series in level terms. Non-stationarity can be rejected with at least 99% confidence for all of the log differenced series employed in Equations (1) - (5).[26]

To implement an estimation strategy regression residuals must be added to each of the equations in our simulation model. 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 corrects the standard errors for each parameter estimate to account for correlation among the error terms across equations. This approach produces parameter estimates equivalent to those derived from maximum likelihood estimation. Diagnostic tests have been performed on the residuals (and parameter estimates) from Equations (1) - (5) to ensure that the standard assumptions hold.[27]

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[25] A complete set of econometric results is available from the author.

[26] Despite the fact that almost all variables are I(1), we cannot find any statistical evidence of a long run, stable, cointegrating relationship among the equity price premia, resource rents, or price volatility series when measured in levels.

[27] The diagnostic tests that have been performed include tests for heteroskedasticity, autocorrelation, the presence of statistical outliers, parameter stability for the price volatility variables, and a Hausman test for

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 the volatility of forestry prices relative to 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.[28] 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 output 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 output 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 96.9% 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.

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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. In equation by equation estimation (where necessary) robust or Newey-West standard errors have been used and outliers dropped to ensure the presence of normally distributed errors.

[28] 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.

Model Diagnostics

Before engaging in a detailed discussion of the exercises and experiments that reveal the channels through which commodity price volatility affects a resource intensive industry's economic fundamentals, and hence macroeconomic performance, we must first establish the ability of the underlying simulation model to replicate the observed endogenous variables. 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 have then compared the distribution of each of the simulated variables to the distribution of each of the observed endogenous variables. For simplicity we confine our attention to the first two moments of these distributions.

Table 2: Comparing Simulated and Observed Endogenous Variables

	π_t	q_t	k_{t+1}	b_{t+1}	$(r_t - rf_t)$
Observed:					
Mean	-0.0098	-0.0126	0.0035	0.0042	-0.0135
Std Dev	0.2255	0.0963	0.0858	0.0552	0.2845
Simulated:					
Mean	-0.0097	-0.0128	0.0036	0.0043	-0.0145
(P-value)	(0.993)	(0.977)	(0.978)	(0.984)	(0.960)
Std Dev	0.1642	0.0754	0.0389	0.0174	0.1961

Note: Data series definitions are provided in the Data Appendix. Means are calculated over 100 periods (1900-1999). P-values reflect the results from a test of the null hypothesis that the simulated means are equal to observed means.

Over 100 periods the simulation model is able to fit the observed variables quite well, with the mean simulated endogenous variables differing from the observed endogenous variables by less than 7.4% in every case. From Table 2 we can see that even for the CAPM and reproducible capital demand functions, which generated simulated values that deviated the farthest from the observed variables on average, the absolute differences in growth rates are small and statistically insignificant. Changes in the simulated share price premium, for example, differ from changes in the observed share price premium by only 0.1 percentage points. However, we can also see that the simulation model is unable to capture the full extent of the volatility in the observed endogenous variables. The ratio of the standard deviation of the simulated series relative to the observed series varies from a high of 78.4% for the production function to a low of 31.6% for the timber stocks. The simulated series still manage to capture periods of relatively high and low growth rates, but the variation within each series is consistently muted in the model.[29] Much of the missing volatility can be attributed to the poor statistical fit in the estimation of the natural capital demand function. If we use the observed timber stock series in the simulation model, the remaining four simulated variables come much closer to replicating the volatility in the observed series. Because we are interested in long run average rates of change, it is reassuring to note that an inability to generate appropriately volatile simulated variables does not interfere with the model's ability to generate appropriate long run means.

Measuring the Impact of Commodity Price Volatility

The objective of the empirical investigation described in this paper 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 three dimensions. First, we measure the size of the impact that a counterfactual increase in commodity price volatility would have had on long run performance in a stable, diverse and financially sophisticated economic environment such as Canada's. Having identified a measureable impact on the resource industries' economic fundamentals, we then seek to test the sensitivity of the investment supply and demand responses to a commodity price volatility shock. Finally, 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 very high and rising price volatility – in provoking these particularly elastic investment supply responses is probed.

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[29] The unconditional correlation between the observed and simulated endogenous variables ranges from 0.653 for π_t to 0.222 for b_{t+1}.

Does Commodity Price Volatility affect Performance in the Presence of Sophisticated Financial Intermediaries?

With our fully calibrated simulation model we can conduct a counterfactual experiment in which we measure the impact of a shock to commodity price volatility on the economic fundamentals that characterize the performance of the twentieth century Canadian forestry sector. In conjunction with some admittedly restrictive assumptions, the results from this experiment can be used to estimate a lower bound on the long run macroeconomic effect of the counterfactual increase in commodity price volatility. To be more specific, in our first counterfactual experiment (Counterfactual # 1) we use the simulation model described by Equations (1) - (5) with the observed exogenous variables and the econometrically estimated parameters reported in Table 1. By iteratively solving the model's five equations over 100 periods we generate a series of simulated endogenous variables, and we can calculate long run average annual growth rates for each of these variables. We then shock the model by increasing the volatility of forest prices relative to the volatility of the GDP deflator by one standard deviation, and we measure the changes in long run growth for each of the forest sector's economic fundamentals in response to this shock.[30]

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 the p-values that reflect the results from a series of tests establishing the statistical significance of the measured differences among these average growth rates. We can see that the one standard deviation increase in relative price volatility imposed under Counterfactual # 1 would have driven 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 would have declined by just under one and a quarter percentage points, changes in reproducible capital intensity in the forest sector relative to the aggregate economy would have fallen by one percentage point, and the rate of growth of the natural

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[30] The counterfactual price volatility shock 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.

capital stock would have fallen by just over one half of a percentage point. The forestry sector's share prices appear to have been particularly sensitive to price volatility – they would have fallen by nearly six and a half percentage points in response to the counterfactual volatility shock. With the exception of the growth rate of forestry output, all of these counterfactual effects were not only statistically distinguishable from zero with at least 90% confidence, but they represent changes from the fundamentals' pre-shock growth rates in excess of 100%.[31] 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. Of course, while this experiment reveals much about the impact of commodity price volatility on a resource intensive industry, it does not tell us how important these industry specific performance effects might have been for Canadian macroeconomic performance during the twentieth century.

To complete the link connecting price volatility to macroeconomic performance we adopt a general equilibrium approach that is very similar to that employed by Chambers and Gordon (1966) when they estimated the net contribution made by western wheat production to Canadian economic performance in 1911. By assuming perfectly elastic labor and capital supplies within the agricultural sector and assuming away any externalities spilling over from agriculture into other less resource intensive activities, Chambers and Gordon showed that the net impact of the "wheat boom" on real Canadian GDP per capita could be fully captured by measuring the returns paid to the fixed factor in production – in their case study, prairie land rents. Lewis (1975) has shown that loosening Chambers and Gordon's assumptions regarding perfectly elastic labor and capital supplies can have a significant effect on the net impact of resource intensive production, 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. However, despite these caveats, we maintain Chambers and Gordon's simplifying assumptions in an effort to establish a lower bound on the macroeconomic effects of forestry price volatility. Chambers and Gordon's approach implies that the key endogenous variable from our simulation model is the growth rate of

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[31] Even for the growth rate of forestry output, the difference between the counterfactual and simulated long run means was statistically significant with 89% confidence.

the forestry sector's economic profits relative to GDP (π_t). Forestry generates economic profits because extraction and processing activities earn a return off the fixed factor of production – trees. Therefore, if we accept that the profits earned by the forest sector contribute directly to income per capita, and GDP growth is a weighted average of sectoral growth rates (including forestry), then Counterfactual # 1's 2.7 percentage point reduction in the average rate of change of forestry profits relative to GDP (from -0.97% to -3.66%) would lead to a reduction in the average annual growth rate of forestry profits from 6.1% to 3.3%, and a reduction in forestry profits' share of GDP from 3.7% to 1.9%. As a result of these changes, the counterfactual average annual real GDP per capita growth rate would fall from 2.01% to 1.98%.[32]

This does not seem like a very large counterfactual "hit" to macroeconomic performance. The small reduction in real GDP per capita growth simply illustrates *Harberger's Law*, which tells us that a fraction multiplied by a fraction is a smaller fraction. In this case, even a fairly substantial reduction in the rate of growth of forestry profits in response to a counterfactual increase in price volatility does not have much effect on the aggregate economy because the forestry sector (more specifically, forestry profits) do not comprise that large a fraction of total economic activity. We must keep in mind, of course, that these growth rate effects are not one time discontinuities in performance, but long run reductions that accumulate over 100 periods in the simulation exercise. If the rate of change in the relative volatility of Canadian forestry prices had been one standard deviation higher than we actually observed between 1900-1999, then the slower real GDP per capita growth predicted by our counterfactual experiment (in conjunction with Chambers and Gordon's general equilibrium model) implies that the average Canadian would have been approximately $800 poorer than they actually were during the last decade of the twentieth century.

This estimate 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

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

not represent a large fraction of aggregate economic activity, and aside from three episodes of dramatic volatility, its output prices were fairly stable (at least relative to many international commodity price series). 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 dramatic.

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	-0.0097	-0.0131	0.0036	0.0040	-0.0142	
Counterfactual # 1 % Δ (CF # 1 P-value)	-0.0366 (0.097)	-0.0246 (0.109)	-0.0062 (0.015)	-0.0008 (0.002)	-0.0787 (0.002)	0.0198 (0.948)
Counterfactual # 2 % Δ (CF # 2 P-value)	-0.0261 (0.558)	-0.0201 (0.597)	-0.0024 (0.340)	0.0016 (0.240)	-0.0710 (0.677)	0.0199 (0.964)
Counterfactual # 3 % Δ (CF # 3 P-value)	-0.0167 (0.591)	-0.0165 (0.558)	0.0000 (0.308)	0.0020 (0.084)	-0.0261 (0.526)	0.0200 (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 test of the null hypothesis that the CF # 1 means are equal 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 test of the null hypothesis that the CF # 2 means are equal 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 test of the null hypothesis that the CF # 3 means are equal to simulated means. P-values for *GDP/Capita* reflect the results from a test of the null hypothesis that the counterfactual means are equal to observed mean.

The Role Played by Investment Supply in the Diffusion of Commodity Price Shocks

To measure the cumulative impact of a shock to commodity price volatility on the long run performance of a resource intensive industry and a resource intensive economy, we used the observed exogenous variables in our simulation model. Explicitly mapping out the channels through which a counterfactual shock diffuses through the model requires an assessment of the timing and sensitivity of each of the endogenous variables' responses to the increase in price volatility. To accomplish this 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. In contrast to Counterfactual # 1, the approach we adopt for the second stage of our investigation does not describe anything like the historical reality experienced by the Canadian forestry sector, but instead we rely on the dynamic structure of the model to show us how price volatility "trickles down" through the resource sector's economic fundamentals.

To be more specific, we track the direct and indirect effects that price volatility has on a resource industry's profits, production levels, reproducible and natural capital investment demands, and the cost of their investment funds raised on domestic equity markets, by using our simulation model with the Canadian forestry sector's exogenous variables averaged over the full 1900-1999 period. After iteratively solving the model we generate a series of simulated endogenous variables that are equal to their long run average values in each period. 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 endogenous variables that occur in response to this shock. In Table 4 we report the period over period percentage change in each of the five simulated endogenous variables beginning at the date of the shock and continuing for seven post-shock periods.[33] The final line in Table 4 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 simply depicts the initial and cumulative effects of the volatility shock reported in Table 4, after normalizing the pre-shock growth rates to create an index equal to 1.00 prior to the shock date. The chronological patterns that are apparent from Table 4 and Figure 1 not only indicate which of the model's endogenous variables are most sensitive to price volatility, 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.

Table 4: Cumulative Effects of 1 Standard Deviation Shock to Price Volatility (% Deviation from Previous Period)

	π_t	q_t	k_{t+1}	b_{t+1}	$(r_t - rf_t)$
t = 0	0.0000	0.0000	0.0000	0.0000	-3.0989
t = +1	-2.2676	-0.7549	-1.9051	-1.0236	-0.8264

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

t = +2	-0.5786	-0.1981	-0.5120	-0.1219	-0.2109
t = +3	-0.1441	-0.0503	-0.1320	-0.0065	-0.0525
t = +4	-0.0370	-0.0128	-0.0331	-0.0061	-0.0135
t = +5	-0.0095	-0.0033	-0.0085	-0.0017	-0.0035
t = +6	-0.0022	-0.0008	-0.0022	0.0005	-0.0008
t = +7	-0.0005	-0.0002	-0.0005	0.0004	-0.0002
Cumulative Post-Shock	-3.0297	-1.0202	-0.6883	-0.1353	-0.2814

Note: One standard deviation shock applied to model at t = 0. Cumulative post-shocks effects: Σ t = +1 → t = +7 for π, q, and $(r - rf)$; Σ t = +2 → t = +7 for k and b.

From Table 4 we can see that the forestry firms' share price premia drop sharply in response to an increase in output price volatility, and investment demand for both reproducible and natural capital also fall, although 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 76% 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 227% 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.

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 CAPM 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 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 decisions. These indirect effects, therefore, cycle through the model, dissipating only slowly over the six or seven periods following the shock. In total the indirect (post-shock) effects of a one standard deviation increase in relative price volatility include a 303% reduction in the rate of growth of forestry profits relative to GDP, a 102% reduction in the rate of growth of forestry output relative to aggregate output, a 69% 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 direct 191% 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 direct 102% reduction in immediate response to the shock), and a 28% reduction in the rate of growth of forestry firms' equity prices (this is in addition to a direct 310% reduction in immediate response to the shock).

Insert Figure 1

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 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 unanticipated output price movements. An assessment of the economic 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 4 and Figure 1 into their appropriate context. A simple modification of our first counterfactual experiment allows us to measure the extent to which investment supply responses alone may account for the cumulative long run growth effects that result from a one standard deviation increase in the volatility of forestry prices relative to the volatility of the GDP deflator.

In Counterfactual # 2 we again shock our simulation 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, parameters used in Counterfactual # 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 affect the sector's economic fundamentals in Counterfactual # 2 is the investment supply response captured by the CAPM equation. The results from this experiment are again reported in Table 3.

The forestry sector's economic fundamentals respond to a counterfactual 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 Counterfactual # 2 relative to Counterfactual # 1, 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 experiments. Although *in situ* timber volumes experience the largest proportional reduction in their response to a volatility shock when investment demand effects are constrained to be zero (a 46% reduction), the measured change in the b_t variable's long run growth rate is still less than one quarter of one percentage point – from *-0.0050* under Counterfactual # 1 to *-0.0027* under Counterfactual # 2 – and we cannot reject the hypothesis that these responses are identical with any standard level of statistical confidence. The change in the responsiveness of the model's other endogenous variables range from a one percentage point drop in the growth of forestry profits relative to GDP – from *-0.0269* under Counterfactual # 1 to *-0.0164* under CF # 2 – to a 0.38 percentage point drop in the growth of reproducible capital intensity – from -0.0098 under Counterfactual # 1 to -0.0060 under Counterfactual # 2. The results from these experiments suggest that external investment supply responses are largely responsible for the effect that commodity price volatility has on the performance of resource intensive industries. Even with 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.

Investment Supply Responses during Episodes of Crisis

During the twentieth century, participants on Canada's largest formal equity market did not like high and sharply rising volatility in forestry prices. Investors' responses to episodes of severe volatility drove down forestry firms' equity prices, thereby increasing the cost of their 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 and macroeconomic performance, a more detailed characterization of this relationship in our case study seems warranted.

Figure 2 depicts two data series used in our case study: the volatility of Canadian forestry prices relative to the volatility of the GDP deflator between 1900-1999, and an index of Canadian forestry sector equity prices relative to the TSE composite market index. These series have been smoothed using a Hodrick-Prescott filter, and only the non-stationary components of the filtered series are included in the figure in an effort to emphasize the negative (unconditional) correlation between the two variables. What is particularly noticeable in Figure 2 are the steep reductions in the equity price series that coincide with steep increases in the price volatility series during the first decade of the century, the interwar period, and the last decade of the century. 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 2

These impressions, based on a visual inspection of the smoothed relative volatility and equity price series, are consistent with more statistically rigorous investigation. Covariance ratio tests, Cook distance tests, and Welsch distance tests identify observations with disproportionate statistical influence in parameter estimation. For the CAPM investment supply equation in our simulation model, these tests confirm that significant outliers can be found during the first eight years of our sample period, the years between the start of World War 1 and the end of World War 2, and the last 10 years of our sample period. A rolling regression with a 30 year estimation window indicates that the parameter estimate on σ_{pt} 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.[34]

Our visual inspection of Figure 2 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 long run, average 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 response to price volatility 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, 1914-1945, and 1991-1999 the parameter estimate on σ_{pt} in Equation (5) is -*0.5734* (p-value = *0.013*).[35] 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 (1910-1913 and 1946-1990) the parameter estimate on σ_{pt} drops to -*0.1300* (p-value = *0.617*).[36]

To put these figures into a more meaningful economic and historical context, we can again revisit our first counterfactual experiment. In Counterfactual # 3 we re-parameterize our simulation model using only the investment supply response estimated during episodes of low or falling relative price volatility. As we did in Counterfactual # 1, 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 observed exogenous variables from the full sample

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[34] 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 generally do not find any significant differences in the σ_{pt} parameter estimates during periods of crisis versus calm.

[35] 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.

[36] 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 94.6% confidence.

period, which include sharply rising price volatility during the episodes of crisis.[37] We then measure the change in the endogenous variables' long run growth rates in response to a one standard deviation increase in the volatility of forestry prices relative to the volatility of the GDP deflator. The results from Counterfactual # 3 are reported in Table 3.

Again we can see that even if equity market participant's responses to commodity price volatility shocks are derived during periods of calm, the channels through which volatility affects industry performance are similar, and the long run growth performance of the forestry sector's economic fundamentals is harmed. However, the strength of these channels is much reduced during periods of low or falling price volatility, and size of the cumulative performance effects is dramatically smaller. Under Counterfactual # 3 only the long run growth rate of *in situ* timber volumes can still be statistically distinguished from the no shock simulated means. If investment supply responses are determined exclusively during episodes of calm, even with no restrictions placed on investment demand responses and the full range of observed price volatility is imposed on the endogenous variables in the experiment, the impact of a one standard deviation increase in commodity price volatility drops to as little as a one percentage point reduction in forestry firms' equity prices, a 0.7 percentage point reduction in the growth rate of profits relative to GDP, a one third of one percentage point decline in both output and reproducible capital intensity, and less than a 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 (and macroeconomic 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.

Conclusions

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[37] 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.

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, production, 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. Over the twentieth century, increases in the volatility of output prices for forestry products were associated with reductions in the incentive to invest in both reproducible and natural capital, and reductions in equity prices for forestry firms trading on the Toronto Stock Exchange. The initial, direct investment demand effects exerted downward pressure on production levels and profits, while the declining share 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. Price volatility had a substantial and persistent effect on the Canadian forest 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 Canadian GDP per capita growth would have been suppressed in response to commodity price volatility and the cumulative growth effects would have had a large impact on income levels by the end of the twentieth century.

These findings indicate 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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Data Appendix

The endogenous variables in the simulation model include:

- π_t = % Δ forestry resource rents (measured as value added less the opportunity cost of labor and the opportunity cost of capital)[38] divided by GDP.
- q_t = % Δ real output of forestry sector (measured as value added deflated by an industry specific output price index) divided by aggregate Canadian real output.
- k_t = % Δ reproducible capital intensity of forestry sector (measured as value added less wages and salaries paid to labor divided by value added)[39] divided by aggregate Canadian reproducible capital intensity.
- b_t = % Δ stock of natural capital in forest sector (measured as timber volume *in situ*).[40]
- $(r_t - rf_t)$ = % Δ forestry common share prices (measured as the *TSE Annual Review's* forestry and paper products share price index) less a risk free rate of return (measured as Government of Canada long term bond yields).[41]

The exogenous variables in the simulation model include:

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[38] I assume that the opportunity cost of labor is total employment multiplied by the average annual labor income earned in non-resource intensive manufacturing. I assume that the opportunity cost of capital is the nominal value of net fixed capital times Moody's AAA industrial bond yields. Total resource rents may be disaggregated into rents paid to government, labor, and capital owners. As a sensitivity test, all results have been derived using only rents paid to capital owners as an alternate rent measure. The key qualitative conclusions are unaffected by the choice of rent measure. If I use this approach to calculate total economic profits earned by the Canadian manufacturing sector over the twentieth century (which includes some resource processing firms), I find that on average their profits were less than one third of those enjoyed by the resource intensive producers. Note that I have not calculated marginal scarcity rents (or shadow prices) for the forestry sector. Scarcity rents have an impact on extraction decisions, but they do not directly determine aggregate profitability. For a detailed discussion of the derivation of scarcity rents in a Canadian context see Livernois, Thille and Zhang (2006) or Young (1992).

[39] As a sensitivity test, all results have been derived using fixed capital per worker ratios as an alternate capital intensity measure. The key qualitative conclusions are unaffected by the choice of capital measure.

[40] Note that valuing the timber stock would require the estimation of scarcity rents or shadow prices for all forest stands. No estimates of the value of aggregate natural capital exist for Canada for the first 80 years of the twentieth century.

[41] Unfortunately the TSE forestry and paper products price index is only reported from 1914-1999. Between 1900-1914 the weighted average of annual high-low quotations in the *TSE Annual Review* for forestry and paper firms is used, with firm weights derived from capitalized values calculated in 1900 and 1910. Information on Canadian government bond yields for the earliest part of the twentieth century is scarce. I have used the series compiled by McInnis (2006).

- a_t = % Δ forestry TFP (measured as a Tornqvist weighted average of partial factor productivities, with value added used as the output measure and average income shares used as weights) divided by aggregate Canadian TFP.
- p_t = % Δ forestry output price index divided by GDP deflator.
- cux_t = % Δ annual average Canada-US official exchange rate.
- l_t = % Δ total employment in forestry divided by aggregate Canadian labor force.
- wk_t = % Δ user cost of reproducible capital for forestry (measured as value added less wages and salaries paid to labour divided by real gross reproducible fixed capital employed) divided by aggregate Canadian user cost of reproducible capital.
- wl_t = % Δ index of hourly wages in forest and wood products industries divided by aggregate Canadian hourly wage index.
- $temp_t$ = deviations from linear trend in average annual North American air temperature (measured across monitoring stations in contiguous US).
- $pcip_t$ = deviations from linear trend in average annual volume of North American precipitation (measured across monitoring stations in contiguous US).
- $(rm_t - rf_t)$ = % Δ composite market common share price index (measured as the *TSE Annual Review's* composite share price index) less a risk free rate of return.[42]
- σ_{pt} = % Δ standard deviation in forestry output price index over previous 15 years divided by standard deviation in GDP deflator over previous 15 years.[43]

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[42] Between 1956-1999 a TSE 300 composite index is available. From 1935-1956 a full market composite index has been used. From 1914-1935 the full market index must be adjusted to account for changes in the mining index. From 1900-1914 Rosenbluth's (2005) reconstructed composite index, adjusted to account for changes in the mining index, has been used.

[43] 15 years has been chosen as the period over which standard deviations have been calculated in an effort to span business cycles in both the forestry sector and the aggregate economy. Comparing volatility in manufacturing prices, export prices, and the GDP deflator indicates that the inclusion of non-tradables does not substantially mute volatility in the denominator. A wide range of alternate price volatility measures have been used in sensitivity testing, including longer and shorter periods over which standard deviations have been calculated, dummy variables for episodes of particularly high and low price volatility, US forestry prices as a proxy for international prices, manufacturing and export prices instead of the GDP deflator, and deviations from linear, quadratic and HP filtered trends. Although statistical power can be affected by the choice of volatility measure, investment supply and demand are consistently suppressed during times of high price volatility.

Table A1: Summary Statistics for Endogenous and Exogenous Variables

	Average Annual % Δ	Standard Deviation
Endogenous Variables:		
π_t	-0.0098	0.2255
q_t	-0.0126	0.0963
k_{t+1}	0.0035	0.0858
b_{t+1}	0.0042	0.0552
$(r_t - rf_t)$	-0.0135	0.2845
Exogenous Variables:		
a_t	-0.0054	0.0858
p_t	0.0040	0.0653
cux_t	0.0040	0.0346
l_t	-0.0109	0.1088
wk_t	-0.0300	0.4591
wl_t	0.0008	0.0578
$temp_t$	-0.0003	0.0146
$pcip_t$	-0.0034	0.0762
$(rm_t - rf_t)$	-0.0156	0.1705
σ_{pt}	0.0087	0.1179

Note: Annual average % Δ calculated over the 1900-1999 period. Standard deviation calculated as: $\sigma = [\Sigma^n (x_i - \mu)^2 / (n-1)]^{½}$. The means represent differences in growth rates, with negative values – for example, resource rents, real output, or share prices – indicating that the aggregate economy grew faster than the forestry sector over the twentieth century, and positive values – for example, reproducible capital intensity, natural capital stocks, or price volatility – indicating more rapid forestry sector growth.

Tables and Figures

Table 1: Econometrically Estimated Parameters for Simulation Model

	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.

Figure 1: Cumulative Effect of Price Volatility Shock

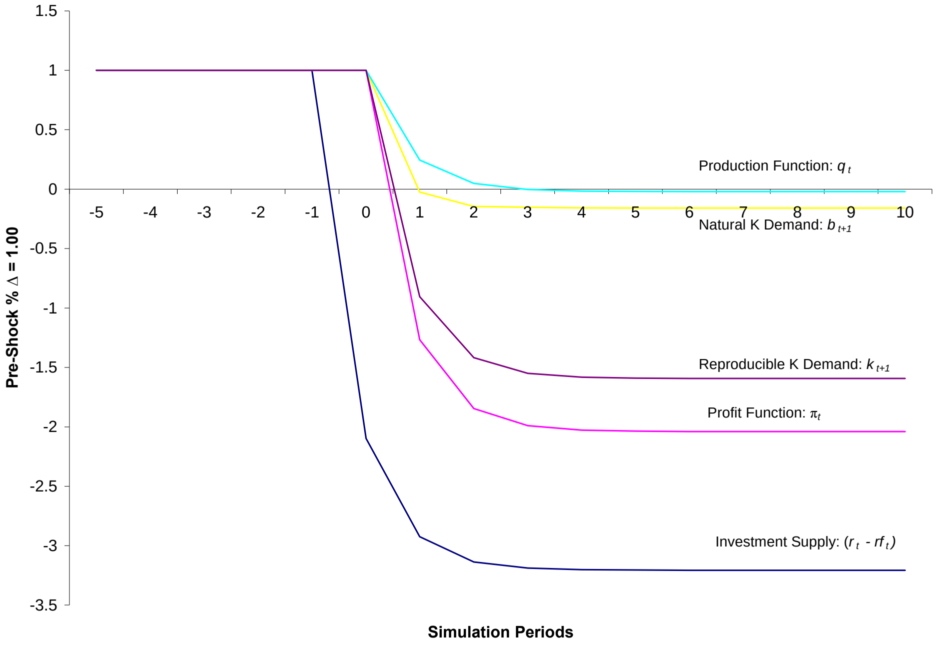

Figure 2: Forestry Equity Price / TSE Composite and Forestry Price Volatility / GDP Deflator Volatility