Output Value Risk for Commodity Producers: the Uncertain Benefits of Diversification

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Abstract

Commodity price volatility has long been recognized as a main risk for commodity producers' welfare and has led to diversification efforts. Less noticed has been the importance of commodity correlations, and their increase after 2006, in the risk faced by producers. To assess their impact, we perform an empirical analysis of the market value of commodity producers' output. In a sample of 56 countries producing 26 commodities we find that diversification and correlations strongly explain

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output value volatility. Between 1987 and 2006, producers effectively specialized in a single commodity had an average output value volatility of 27.0% while producers of three or more commodities had a 12.7% volatility. In this period average correlation was 8% and diversification was very effective. In the 2007-2012 period, correlations averaged 26% and output volatilities for specialized and diversified commodities were 30.4% and 19.5% respectively, thus reducing the benefit of diversification at a time of macroeconomic distress. In 2013-2016, output volatilities reverted to levels close to those in 1987-2006 as commodities decorrelated again. Our findings should be relevant to policy makers embarking in diversification efforts and in the analysis of macroeconomic risk of commodity producers.

Keywords: Natural resources; volatility; specialization; co-movement; diversification

JEL codes: F40, O13; Q02; E30.

1. Introduction

Commodity price volatility has long been recognized as a main risk for commodity producers' welfare. This has led, in turn, to deliberate diversification efforts in terms of enlarging the set of commodities produced locally or developing manufacturing and service sectors.[1] [2] [3]. In addition, diversification occurs sometimes involuntarily through the discovery of a previously unknown natural resource such as the recent discovery of one of the largest shale oil and gas fields in Argentina [4]. However, little attention has been paid to the potential impact of commodity correlations, which measure the propensity of prices of commodities such as corn and copper to move in tandem, on the risk faced by commodity producers. This article explores the risk represented by the volatility of commodity output value for 56 commodity producing countries between 1987 and 2016, taking into account the changing impact of commodity correlations. For these countries, commodity output value is a significant fraction of GDP and it is strongly correlated with exports. Hence, variability in commodity output value is economically significant. We are motivated by two observations. First, the recent decade has witnessed a large increase in commodity return correlations. Commodity price percentage changes (monthly returns), which exhibited pairwise correlations close to 8% on average between 1987 and 2006, became much more correlated between 2007 and 2012, when pairwise correlations for returns in agricultural, mineral, energy and soft commodities were on average close to 26%. The increase in co-movement during the 2007-2012 period has been associated in the literature with growing world demand for commodities and global economic activity. This period also witnessed a strong increase in speculative activity although its impact

[1] African Economies Need Deeper Diversification and Better Policies. The World Bank, Africa's Pulse, October 2016.

[2] Algeria Seeks to Diversify, Reshape Economy as Oil Revenues Decline. IMF Survey, May 19th, 2016.

[3] Saudi Arabia Approves Plan to Diversify Economy. "...plan to diversify its economy away from oil production to other industries, including mining." The Wall Street Journal, June 6th, 2016.

[4] Patagonian shale raises hopes and fears. Financial Times, June 7th, 2015.

on co-movement has found uneven support. In this article, rather than exploring the causes of higher correlations, we aim to quantify the consequences of such a stronger co-movement. Second, commodity producers differ strongly in their degree of diversification. For example, 90% of Russia's commodity output value during the 2007-2016 period was due to oil. By contrast, commodity output value from Brazil was 38% from oil, 18% from iron ore, 14% from soybeans, and it also included significant components in corn, sugar, orange juice and others. Motivated by these two observations we bring a portfolio perspective to the risk faced by commodity producers and perform an empirical exploration of the volatility of commodity output value for the cross section of commodity producers and across time. We ask the following questions. First, a portfolio perspective suggests that diversified commodity producers should have experienced lower volatility than specialized producers. How significant was this effect? Second, a portfolio perspective also suggests that the observed increase in commodity correlations between 2007 and 2012 should have narrowed the difference in risk between diversified and specialized producers. What was the magnitude of this effect? Third, is there a simple relationship between the output volatility of a commodity producer, its degree of diversification, and overall commodity market conditions?

We explore these issues empirically on a sample of 56 countries for which the ratio of commodity output value to GDP exceeds 5%. Our sample includes mostly developing countries but also a few developed economies such as Australia, Canada and Norway. For each country we construct measures of national diversification based on the relative contribution of 26 agricultural, mineral, soft and energy commodities to the dollar value of national commodity output. We also compute, for each country, the historical time series of commodity output value using local physical output and contemporaneous global market prices, and the historical time series of commodity exports. We verify that, at 55% on average, national output value returns were strongly correlated with commodity export returns in our sample period. Then, we proceed to explore the interplay between commodity market dynamics, diversification, and output value risk. Our main findings are as follows.

First, between 1987 and 2006, specialized commodity producers defined as those countries significantly engaged in the production of a single commodity, experienced a 27.0% average volatility of output value from price changes. By contrast, producers that were diversified in three or more commodities, faced an average volatility of 12.7%. Hence, the risk faced by specialized producers was more than twice as large as that of diversified producers. This is economically significant because commodity output contributes a significant fraction of GDP and exports for the countries in our sample. Average pairwise commodity correlation during this period was close to 8%. Second, the gap in volatility between specialized and diversified producers narrowed in 2007-2012 to 10.9%, primarily driven by an increase of the risk faced by diversified producers to 19.5%. The volatility for specialized producers varied slightly (in relative terms) to 30.4%. This reduction in the benefits of diversification occurred at a time of global macroeconomics distress and followed directly from higher pairwise commodity correlations, averaging 26% between 2007 and 2012. Finally, in 2013-2016, volatilities for specialized and diversified producers reverted to 29.3% and 13.5% as commodities decorrelated again to 10.0%. The sizeable variation in commodity output volatility for diversified producers should therefore be taken into account by policy makers in their design of diversification efforts. Third, we find that a theoretical relationship between specialization and output variance holds approximately in the cross-section and across time, with parameters solely determined by the overall level of commodity volatility and average commodity correlation. This formula is very similar to that used by Giovanni and Levchenko (2009) for the aggregate variance of manufacturing sectors.

In our analysis we focus on the volatility of national output value which, to keep a parsimonious approach, we compute as the sum of the market value of produced metals, minerals, soft and agricultural commodities. We recognize, however, that there might be significant differences in the ownership of the revenues accrued in the production of different commodities. Agricultural and soft commodities are typically produced by locally owned farms. Oil production is often shared by multinational firms and by government sponsored firms. Minerals in developing countries are predominantly produced by multinationals. In this case, an alternative measure of output value could be computed based on taxes or other benefits accrued locally from mining activity (Otto et al. (2009); Söderholm and Svahn (2015)). This approach, although desirable, seems unfeasible for a sample of countries and time interval as comprehensive as ours.

This article is related to several strands of the literature in international and development economics as well as on commodity markets. Output volatility is correlated with GDP volatility and it has long been understood as detrimental for economic performance in dimensions such as development, growth, investment, inequality and institutional stability. Works in the extensive literature dealing with these issues include Ramey and Ramey (1995), Turnovsky and Chattopadhyay (2003) on a negative relationship between volatility and growth, Aizenman and Marion (1999) on a negative correlation between volatility and private investment, and Lutz (1994) on a negative relationship between terms-of-trade volatility and growth. More recently, the causes of output volatility have been explored extensively. Koren and Tenreyro (2007) found that GDP growth volatility is higher in poor countries due to, among other reasons, their degree of specialization in manufacturing. Di Giovanni and Levchenko (2009) explored the effect of trade openness on volatility using industry-level data and, among other findings, identified a positive relationship between trade, specialization and output volatility. The riskiness of exports, taking into account specialization effects, was studied by Di Giovanni and Levchenko (2010). These articles focus on the volatility of manufacturing and non-manufacturing output but with no detailed focus on the composition and behavior of commodity output. Our article, by contrast, focuses on the volatility of commodity output value, its relationship with the underlying structure of production and overall dynamics in the global commodity markets. Unlike Kalemli-Ozcan, Sørensen and Yosha (2003), which study to what extent the degree of specialization in manufacturing in countries and regions emerges as a consequence of the possibility of risk-sharing, we focus on the production of commodities for which the degree of specialization is largely a consequence of natural resource endowments and therefore mostly exogenous.

The relative contribution of world prices of capital goods and commodities to the business cycles of small open economies, including many countries in our sample, was studied by Kose (2002). The macroeconomic performance of commodity producers is also affected by commodities prices through their impact on exchange rates (Chen and Rogoff (2003); Clements and Fry (2008)). The volatility of commodity output value is a first order risk for commodity producers and therefore merits risk management. In this regard, precautionary saving for oil producers has been studied by Cherif and Hasanov (2013). The gains associated with hedging against commodity price volatility at the national level were quantified by Borensztein, Jeanne and Sandri (2013).

We focus in this paper on the effectiveness of diversification at the national level. Significant diversification efforts might occur simultaneously at the farm or firm level. Diversification, or its absence, at the single farm level involves a trade-off between the gains from economies of scale and the higher risk implied by specialization (Kurosaki (2003); Chavas and Di Falco (2012), Michler and Josephson (2017) among others). Diversification at the micro level contributes to diversification at the macro level but for the reverse to hold a smoothing effect through exchange rates (Cashin, Cspedes and Sahay (2004)) or a redistribution mechanism are needed. The impact of commodity shocks and their management on the development and welfare of commodity producers have received attention, including Van der Ploeg and Venables (2012), Arezki and Brückner (2012), and Bellemare, Barrett and Just (2013).

There is also a large literature exploring the behavior and determinants of commodity prices and their co-movement, including Pindyck and Rotemberg (1988), Borensztein and Reinhart (1994), Frankel (2006) and Ai, Chatrath and Song (2006). Most recent works on commodity co-movement, including some that cover part of the 2007-2012 period in their analysis, have found a dominant effect of fundamentals, global economic activity and macroeconomic variables in explaining correlations (Lescaroux (2009); Casassus, Liu and Tang (2013); Byrne, Fazio and Fiess (2013); Alquist and Coibion (2014); Myers et al (2014)). Increased financial speculation has also been prevalent on 2007-2012 but its relationship with correlations has found uneven support (Tang and Xiong (2012); Janzen, Smith and Carter (2013); Janzen, Carter, Smith and Adjemian (2014); Basak and Pavlova (2015)).

The article is structured as follows: In section 2 we describe our data on commodities and certain aspects of commodity price dynamics between 1987 and 2016. In this section we also present our sample of commodity producers and estimates of their diversification. In section 3 we present our empirical results on the relationship between diversification and commodity output volatility. In this section we discuss the impact of recent changes in commodity market dynamics on the risk faced by commodity producers. We conclude in section 4. The Appendix presents the derivation of an approximate relationship between national output volatility and the degree of local specialization which is used to motivate our empirical analysis in section 3.

2. Data and preliminary results

We consider in this article a comprehensive sample of 26 commodities that were international in the scope of their trading and for which there were global price benchmarks during 1987-2016. Commodity producers were selected for simultaneously being top producers of at least one commodity in our sample and for the importance of commodities in their GDP. Our sample includes industrial metals, precious metals, agricultural, soft and energy commodities, and other minerals. Table 1 displays the list of commodities, their venue of trading and the data sources employed in this article for production and exports data.

2.1. Commodity dynamics

We generally rely on near term futures prices understood to represent global prices for the commodities in the sample. On some occasions and for some countries domestic prices might have differed from the most liquid futures prices overseas due, for example, to shipping and quality considerations. Although desirable, it is unlikely that the researcher would have access to price data for actual physical transactions for a data set with a scope as wide as ours. Nevertheless, it is likely that, even if local prices differ from liquid futures, these would generally be strongly correlated on the monthly and yearly time-scale used in our analysis. Therefore, it seems reasonable to use a single price per commodity for the computation of local measures of commodity price risk. Some exceptions to using futures are the spot prices employed for iron ore, gold, silver, phosphates, thermal coal and bauxite. For instance, iron ore is special because prior to 2010 its price was set up by yearly arrangements between miners and steel producers. Futures and swaps were virtually non-existent. Therefore, in this case we use the spot price at the Chinese port of Tianjin, which was widely followed as a benchmark price. For each physical commodity

Commodity	Sector	Production data	Exports data	Price data		Volatility	
		SITC code		87-96	97-06	07-16	
Lead	Ind. Metal	USGS	685	LME	0.245	0.197	0.299
Nickel	Ind. Metal	USGS	683	LME	0.337	0.258	0.321
Copper	Ind. Metal	USGS	682	LME	0.244	0.193	0.273
Zinc	Ind. Metal	USGS	686	LME	0.211	0.212	0.253
Tin	Ind. Metal	USGS	687	LME	0.153	0.170	0.259
Oil Brent	Energy	BGS	331	NYMEX	0.298	0.309	0.325
Platinum	Prec. Metal	USGS	681	NYMEX	0.130	0.172	0.232
Palladium	Prec. Metal	USDA	684	NYMEX	0.163	0.329	0.299
Gold	Prec. Metal	USGS		LBMA	0.121	0.141	0.189
Silver	Prec. Metal	USGS	285	LBMA	0.294	0.236	0.345
Soybeans	Bulk Ags.	USDA	2214	CBOT	0.172	0.210	0.236
Wheat	Bulk Ags.	USDA	041	CBOT	0.201	0.203	0.311
Corn	Bulk Ags.	USDA	044	CBOT	0.221	0.206	0.283
Coffee	Softs	USDA/ICO	071	ICE(NY)	0.346	0.309	0.276
Cotton	Softs	USDA	263	NYBOT	0.201	0.224	0.280
Cocoa	Softs	FAO	072	NYBOT	0.221	0.243	0.208
Sugar	Softs	USDA	0611	NYBOT	0.275	0.287	0.315
Orange juice	Softs	USDA		NYBOT	0.275	0.220	0.283
Palm oil	Bulk Ags.	FAO	4222	BME	0.239	0.337	0.260
Rubber	Other	FAO	2311	TCE	0.161	0.202	0.327
Canola	Bulk Ags.	USDA		ICE	0.178	0.167	0.215
Rough rice	Bulk Ags.	FAO	0421	Bangkok	0.243	0.153	0.269
Iron ore	Ind. Metal	BGS	281	Tianjin	0.089	0.224	0.382
Phosphates	Other	BGS	2713	World Bank	0.102	0.043	0.441
Thermal coal	Energy	BGS	321	World Bank	0.112	0.179	0.289
Bauxite	Ind. Metal	BGS	2833	USGS	0.082	0.090	0.073
Avg. by World Prod.				0.229	0.255	0.310	

Table 1: Sample of commodities. Data sources and annualized volatilities for monthly returns.

we have selected the price source most likely to be seen as a global benchmark. We do not include electricity or natural gas because they are largely produced and traded domestically hence not priced in a consistent manner across the globe.

We obtained end-of-the-month prices from January 1987 to December 2016 except for some time periods in the prices of iron ore, bauxite and phosphates which were only available with yearly frequency. In this case we produced monthly prices through simple interpolation. All prices were denominated in US dollars or converted to this currency at the corresponding exchange rate. Table 1 displays annualized volatility for monthly commodity returns (monthly percentage changes) in the periods 1987-1996, 1997-2006, and 2007-2016. Inspection of Table 1 reveals certain regularities. First, volatilities in the cross-section, defined as the standard deviation of monthly returns, were of the same order of magnitude, except for iron ore, phosphates and bauxite which exhibited periods of yearly price changes. The vast majority of volatility recordings are between 15% and 30%. Hence volatilities were relatively close to their cross-sectional means. Second, cross-sectional volatility averages with commodities weighted according to the dollar value of their global yearly production, hence overweighting oil, exhibited some variation across periods ranging between 22.9% and 31.0%. Table 2 displays correlations of monthly returns between commodity sectors in our sample.[5] Average correlations between 1987 and 2006 were in the vicinity of 15% and became much higher between 2007 and 2016 at 45%. Time series evidence of the increase in correlations across commodities, particularly between 2007 and 2012, is shown in Figure 1 which displays the 1-year rolling window average correlation for all commodity pairs in our sample.[6] Hence, this is in agreement with Tang and Xiong (2012) in documenting a very strong increase in commodity correlations since 2006. In this article we make no attempt to identify the multiple causes behind the increase in commodity return correlations but rather focus on its consequences.

FIGURE 1 SHOULD BE PLACED HERE

2.2. Commodity producers

We gathered production data with yearly frequency for all commodities from the sources reported in Table 1. Based on these production statistics we selected the top 10 producers of each commodity except oil, and the top 15 producers of oil because of the large size of its physical market in dollar terms relative to other commodities. We supplemented our production data with yearly GDP data from the World Bank. The definitive sample of

[5]The return of a sector is the simple average of contemporaneous returns for all commodities in the sector.

[6]Correlations of monthly returns for individual commodity pairs are in Tables A1, A2 and A3 in the Online Appendix. Their average was close to 8% between 1987 and 2006 and 21% in 2007-2016.

	Ind. Metals	Prec. Metals	Energy	Softs	Bulk Ags.
Ind. Metals.					
Prec. Metals	0.149				
Energy	0.140	0.017			
Softs	0.231	0.230	0.004		
Bulk Ags.	0.166	0.030	-0.129	0.136	
Other	0.131	0.001	0.094	0.212	0.631
Average correlation among sectors between 1987 and 1996 was 0.136					
	Ind. Metals	Prec. Metals	Energy	Softs	Bulk Ags.
Ind. Metals					
Prec. Metals	0.391				
Energy	0.290	0.219			
Softs	0.233	0.220	0.015		
Bulk Ags.	0.123	0.051	-0.030	0.276	
Other	0.109	0.000	-0.006	0.204	0.485
Average correlation among sectors between 1997 and 2006 was 0.172					
	Ind. Metals	Prec. Metals	Energy	Softs	Bulk Ags.
Ind. Metals					
Prec. Metals	0.553				
Energy	0.572	0.401			
Softs	0.419	0.397	0.447		
Bulk Ags.	0.418	0.396	0.474	0.417	
Other	0.469	0.372	0.553	0.272	0.529
Average correlation among sectors between 2007 and 2016 was 0.446					

Table 2: Correlations of monthly commodity sector returns between 1987 and 2016.

commodity producers was constructed according to the following prescription. A country produces N commodities. Commodity i contributes to the value of the national basket according to the prevailing price of the commodity, $p_i(t)$, and the size of national output, $Q_i(t)$. Commodity output value is therefore

$$V(t) = \sum_{i=1}^{N} Q_i(t) p_i(t). \tag{1}$$

We kept in our sample those countries for which the ratio of commodity output value to GDP was on average larger than 5% during 1987-2016. For brevity, Table 3 displays only those countries in our sample for which the ratio of GDP to World GDP was larger that 0.2%.[7] We also collected exports data from the UN Comtrade database for the commodity producers in our sample. The availability of yearly exports discriminated by country and commodity was significantly less reliable than that of output data. Whenever available we

[7]The full sample of countries and their characteristics are in Table A4 in the Online Appendix.

Country	% Commodity GDP	% GDP World GDP	Herf. 87-96	Herf. 97-06	Herf. 07-16	Herf. 87-16	Eff. N 87-16
Argentina	9%	0.71%	0.30	0.32	0.36	0.33	3.07
Australia	9%	1.44%	0.15	0.14	0.15	0.15	6.79
Brazil	8%	2.29%	0.11	0.17	0.23	0.17	5.79
Canada	7%	2.34%	0.31	0.42	0.53	0.42	2.39
Chile	15%	0.24%	0.62	0.78	0.86	0.75	1.33
China	20%	5.27%	0.20	0.20	0.21	0.20	4.99
Colombia	16%	0.32%	0.25	0.28	0.30	0.28	3.62
Egypt	18%	0.25%	0.54	0.54	0.62	0.57	1.77
India	16%	1.75%	0.28	0.23	0.18	0.23	4.41
Indonesia	22%	0.72%	0.30	0.21	0.17	0.23	4.41
Iran	36%	0.42%	0.82	0.86	0.89	0.86	1.17
Malaysia	16%	0.30%	0.35	0.39	0.42	0.38	2.61
Mexico	10%	1.60%	0.61	0.67	0.77	0.69	1.46
Morocco	5%	0.13%	0.35	0.35	0.37	0.36	2.81
Nigeria	55%	0.26%	0.65	0.64	0.70	0.66	1.51
Norway	15%	0.58%	0.97	0.99	0.99	0.98	1.02
Pakistan	11%	0.23%	0.28	0.26	0.27	0.27	3.70
Philippines	8%	0.25%	0.34	0.32	0.27	0.31	3.24
Russia	23%	1.64%	0.66	0.70	0.77	0.71	1.41
Saudi Arabia	55%	0.64%	0.99	0.99	1.00	0.99	1.01
South Africa	13%	0.50%	0.33	0.25	0.26	0.28	3.57
Thailand	13%	0.43%	0.35	0.26	0.23	0.28	3.57
Ukraine	15%	0.22%	0.28	0.27	0.25	0.27	3.75
UAE	29%	0.33%	1.00	1.00	1.00	1.00	1.00
Venezuela	37%	0.34%	0.89	0.90	0.92	0.90	1.11

Table 3: Subsample of commodity producers and their characteristics. Output value to GDP ratio, local GDP to world GDP ratio, and measures of specialization of production for selected time periods.

recorded the dollar value of exports associated to the SITC commodity codes in Table 1 and computed for each country the time series of yearly commodity exports value. Inspection of Table 3 reveals a wide variation in the relative contribution of commodities to GDP across the sample. The cross-sectional average contribution to GDP for the full sample is close to 24% but values range from just above 5% to values above 50% for several oil producers.

In order to quantify specialization in commodity production we define the share of commodity i on the basket value of a country as

$$w_i = \frac{Q_i(t)p_i(t)}{\sum_{j=1}^{N} Q_j(t)p_j(t)},$$

so that $\sum_{i=1}^{N} w_i = 1$. The structure of production of each individual country is given by a specific set of weights $\{w_1, ..., w_N\}$. A widely used measure of specialization is the Herfindahl index

$$H \equiv \sum_{i=1}^{N} w_i^2, \tag{2}$$

which takes values between 0 and 1. In our application, a large Herfindahl index indicates a poorly diversified commodity producer. A related measure of diversification is the inverse of the Herfindahl index

$$N^{Eff} \equiv \frac{1}{H} = \frac{1}{\sum_{i=1}^{N} w_i^2}, \tag{3}$$

which is interpreted as the effective number of commodities produced by a country. In particular, in the equally weighted producer with $w^i = 1/N$ it naturally holds that $N^{Eff} = N$, and $N^{Eff} = 1$ for the fully specialized case of $w_1 = 1$.

Associated with the yearly production of each country there is a Herfindahl index and an effective number of commodities in its basket. As seen in Table 3, the degree of specialization in the production of commodities varies strongly across the sample. Brazil is a well diversified commodity producer, with low Herfindahl index and an effective number of commodities equal to 5.79. By contrast, the Herfindahl index of Saudi Arabia and Chile are very high, as these countries specialize almost exclusively in oil and copper respectively. For the most part, there is little variation in the Herfindahl indices across time. This is a consequence of the fact that most countries in our sample produce a selection of commodities according to their availability as a local natural resource. However, there exceptions to this rule, driven by technological change or by a large change in the relative pricing of different commodities. This is the case, for instance, of the increasing oil production in Canada which had an associated Herfindahl index of 0.31 in 1987-1996 and 0.53 in 2007-2016.

3. Results

We begin this section estimating the contribution of output value changes attributed to changes in prices, changes in physical output and their relationship with exports. We then focus on our main goal, namely a quantification of the interplay between diversification in production, price correlations and national output volatility. From (1), the total return of national output value is

$$r(t) = \frac{\sum_{i=1}^{N} Q_i(t+1)p_i(t+1) - \sum_{i=1}^{N} Q_i(t)p_i(t)}{\sum_{i=1}^{N} Q_i(t)p_i(t)}. \tag{4}$$

This can be decomposed, leaving aside second order terms, as

$$r(t) \approx r_{price}(t) + r_{quant}(t), \tag{5}$$

with

$$r_{price}(t) = \frac{\sum_{i=1}^{N} Q_i(t)(p_i(t+1) - p_i(t))}{\sum_{i=1}^{N} Q_i(t)p_i(t)} \tag{6}$$

being the contribution to the total return attributed to variation in commodity prices and

$$r_{quant}(t) = \frac{\sum_{i=1}^{N} p_i(t)(Q_i(t+1) - Q_i(t))}{\sum_{i=1}^{N} Q_i(t)p_i(t)} \tag{7}$$

being the component of the return in output value attributed to changes in produced quantities. This attribution is an algebraic decomposition that does not preclude endogeneity between global prices and locally produced quantities. Publicly available statistics about production are typically published yearly and report yearly physical output. In our first empirical exercise we will compute (6), (7) and their associated empirical variances using yearly changes in prices and produced quantities. Then, after verifying that (6) is the dominant contribution to (4) we will focus on the impact of commodity return dynamics, including correlations, on the variance of $r_{price}(t)$. In this last application we will choose to take advantage of information with higher frequency.

3.1. Output value return components and exports

We focus on the risk faced by commodity producers due to fluctuations in the value of their output between 1987 and 2016. Figure 2 displays the volatility of output value associated to the total basket return (4) as a function of the degree of concentration measured by the Herfindahl index for all the countries in our sample except Kuwait. A strong increasing trend is evident, so that more concentrated producers (with higher Herfindahl index) tend to experience significantly higher volatility of output value. This pattern will be explored quantitatively in the next section.

FIGURE 2 SHOULD BE PLACED HERE

Between 1987 and 2016, the volatility associated with output value returns was 31.3% on average and the volatility attributed to changes in global prices was 27.0%. Inspection of Table A5 in the Online Appendix shows that except for Angola, Kuwait, Rwanda and Zimbabwe, output value return volatility was close in magnitude to the volatility computed from price changes while keeping physical output constant within each year. Rwanda and Kuwait are exceptions probably because they suffered very severe disruptions in physical output due to armed conflict, and Angola and Zimbabwe have experienced very severe economic and political mismanagement since 1980. In these cases, fluctuations in local physical production had a significant effect in the variability of output value. In most other countries, fluctuations attributed to global price changes explain the bulk of output value volatility in an accounting sense even if price changes might not be fully exogenous. We also find that, for those countries where commodity exports data were available in at least 20 years within the 1987-2016 period, the correlation between output value and export fluctuations was on average 55%, and positive in most cases.[8] Hence, the risk associated to output value fluctuations was strongly associated with the variability in commodity exports. Figure 3 displays the correlation between output and export fluctuations as a function of GDP. Large commodity producers, including Australia, Brazil, Canada, China, Mexico and Russia exhibited large and positive correlations between output value and export fluctuations. These countries were perhaps employing a smaller fraction of their own output in local consumption than smaller countries do.

FIGURE 3 SHOULD BE PLACED HERE

3.2. Diversification, correlations and output volatility

In this section we explore the interplay between commodity co-movement and diversification in determining output value risk, and the impact of higher commodity correlations during the last decade. We are particularly interested in quantifying the value of diversification in reducing output value risk at the national level and the potential increase in risk for diversified commodity producers arising from higher correlations between 2007 and 2012. Our empirical specification is not based on any additional assumption. However, in order to motivate and interpret the empirical exercise we find it useful to provide a simplified theoretical description derived in detail in the Online Appendix. Let the variances and correlations of individual commodity returns r_i be $\{\sigma_i^2, \rho_{ij}\}$ and assume, first, that all σ_i are close to their cross-sectional average given by $\sigma_{world} = \sum_{i=1}^{N} w_i^{World} \sigma_i$ weighted according to their contribution to global output. Second, assume that correlations for all commodity pairs ρ_{ij} are close to their average given by $\rho_{world} = \frac{1}{N\,(N-1)} \sum_{i,j=1, j \neq i}^{N} \rho_{ij}$. Under these symmetry conditions it holds that the variance of the value of a national

[8] See Table A5 in the Online Appendix.

basket of commodities is

$$\sigma^2_{basket_{prices}} \approx \sigma^2_{world}\rho_{world} + H\sigma^2_{world}(1-\rho_{world}), \quad (8)$$

where H is the Herfindahl index that measures the local degree of specialization. In addition, (8) holds as an equality if the symmetry assumptions hold exactly as well. In sum, under certain symmetry assumptions about the dynamics of global commodity prices it holds that output value risk combines a structural feature, H, which is country-specific, with the average dynamics of global commodity markets for a certain time period summarized by $\{\sigma^2_{world}, \rho_{world}\}$. These cross-sectional averages might vary in time reflecting, for instance, periods of higher correlations among commodities between 2007 and 2012. The expression (8) shows that the risk faced by a commodity producer is approximately linear and increasing on the degree of specialization measured by the Herfindahl index, therefore decreasing in the degree of diversification. Hence, diversified producers face lower risk. Moreover, (8) shows that the slope and constant terms in this relationship depend on market conditions. Higher ρ_{world} in (8) tends to diminish the difference in risk faced by specialized and diversified producers. In particular, in the hypothetical case of correlations among commodities being all equal to one, (8) shows that output value risk would naturally become independent of the degree of diversification.

Motivated by (8), but without actually imposing any symmetry condition on our empirical data, we proceed to test an empirical relationship between output value risk and specialization in the cross-section of commodity producers and across time.

$$\begin{aligned} BasketVariance_k &= \beta_1 Herfindahl_k + \beta_2 \frac{CommodityProd}{GDP}_k + \beta_3 \frac{GDP}{WorldGDP}_k \\ &\quad + \beta_4 OilProd_k + Const + \epsilon_k \end{aligned} \quad (9)$$

To implement the dependent variable in (9) we aim for a higher frequency measure for (4) and its volatility. This, however, is not feasible exactly because physical output data is published yearly. We bypass this issue by relying on the large relative contribution of price changes to output value variance mentioned earlier. Hence we compute volatility estimates for returns of the form (6) using physical output data with yearly frequency and price data with monthly frequency. Based on the remarks made earlier, these volatility estimates from price changes will be used as approximate estimates for the volatility of output value. Notice that our estimates of output value variance in (9) are based on actual empirical covariances and therefore do not do not rely on the symmetry assumptions behind the derivation of (8). In other words, (8) and its underlying assumptions simply provide as a simplified description to motivate the empirical testing of a relationship between concentration and output volatility.

We perform these calculations for the 56 countries in our sample. Motivated by the striking variation in average commodity correlation shown in Figure 1 we split the sample in three periods of equal length: 1987-1996, 1997-2006 and 2007-2016, and the latter in 2007-2012 and 2013-2016.

We run a separate regression for each of the time periods under consideration in order to explore the effect of diversification under different global market conditions. The specification (9) postulates a linear relationship between Herfindahl and output value variance as in (8) but also includes several controls for other plausible determinants of output variance. These are: the relative importance of the commodity sector relative to GDP, the size of the domestic economy relative the world's, and whether the commodity producer focuses on oil. The OilProd variable is 1 if oil contributes to 75% or more of domestic commodity output value.

Ordinary least-squares estimation results with heteroscedasticity robust standard errors are presented in columns (a,c,e,g) of the bottom panel in Table 4. The empirical effect of specialization in commodity output variance is positive and very strongly significant for the four periods under consideration. Therefore, specialized producers face significantly higher risk than diversified producers, and we can provide a precise quantitative measure of this gap. The R-squared coefficients are not lower than 0.48. As stated earlier this empirical verification of the positive impact of specialization on output value risk does not require the symmetry assumption about volatilities and correlations used to derive (8). However, we are also interested in exploring to what extent the simplified description in (8) represents the risk faced by commodity producers. In columns (b,d,f,h) of the bottom panel in Table 4 we present the estimates for the slope and constant terms in (8) computed using the estimates of σ_{world} and ρ_{world} for each period reported already as averages in the upper panel of Table 4. These mean estimates represent average conditions prevailing in the commodity markets in each period. Except for the slope estimate in 1987-2016, slope and constant estimates based on average market conditions and the assumptions leading to (8) are close to the coefficients estimated through OLS for all periods. In particular, the large increase in commodity return correlations during 2007-2012 is evident in the sizeable constant term for the 2007-2016 period. In this sense, cross-sectional average volatility and correlations are relevant to explain the output value volatility of individual commodity producers. Among the control variables in the regressions in Table 4, only being an oil producer is generally significant and it has a positive effect on output value volatility. This is likely due to the fact that Brent oil was more volatile than most other commodities in the sample as seen in Table 1.

Further understanding of the risks faced by different producers is gained by inspection of Figures 4, 5 and 6. Here we choose to display the percentage volatility of output value due to price changes as a function of the effective number of commodities produced by each country. This a simple but convenient transformation of the main variables used for the analysis in Table 4. Representing annual volatility rather than variance, and

Heteroscedasticity robust OLS estimation results of the relationship between the variance of commodity output value, specialization represented by the Herfindahl index, and controls,

$$BasketVariance_k = \beta_1 Herfindahl_k + \beta_2 \frac{CommodityProd}{GDP}_k + \beta_3 \frac{GDP}{WorldGDP}_k + \beta_4 OilProd_k + Const + \epsilon_k.$$

OLS results are compared with empirical estimates of the slope and constant coefficients in the approximate relationship between output variance and the Herfindahl index derived in the Appendix:

$$\sigma^2_{basket_{prices}} \approx \sigma^2_{world}\rho_{world} + Herfindahl\ \sigma^2_{world}(1-\rho_{world}).$$

Basket variance computed on monthly returns due to price changes as in (6), on periods 1987-1996, 1997-2006, 2007-2012 and 2013-2016. σ_{world} and ρ_{world} computed on monthly commodity returns. Sample: 56 commodity producers in Table A4 and 26 commodities in Table 1. By *, ** and *** we indicate statistical significance at the 10%, 5% and 1% levels.

	87-96	97-06	07-12	13-16
σ_{world}	0.229	0.255	0.315	0.296
ρ_{world}	0.072	0.090	0.260	0.100
Slope	0.049	0.059	0.073	0.079
Constant	0.004	0.006	0.026	0.009

	87-96 OLS (a)	87-96 Approx. (b)	97-06 OLS (c)	97-06 Approx. (d)	07-12 OLS (e)	07-12 Approx. (f)	13-16 OLS (g)	13-16 Approx. (h)
Herfindahl	**0.083*****	**0.049**	**0.054*****	**0.059**	**0.076*****	**0.073**	**0.056*****	**0.079**
	(0.006)		(0.018)		(0.009)		(0.021)	
$\frac{CommodityProd}{GDP}$	-0.015**		0.012		-0.025		0.014	
	(0.006)		(0.009)		(0.015)		(0.014)	
$\frac{GDP}{WorldGDP}$	-0.19		-0.19		0.44		0.04	
	(0.17)		(0.12)		(0.41)		(0.17)	
Oil producer	0.010**		0.023**		0.008		0.043***	
	(0.004)		(0.010)		(0.010)		(0.013)	
Constant	**-0.002**	**0.004**	**0.007**	**0.006**	**0.026*****	**0.026**	**0.002**	**0.009**
	(0.003)		(0.006)		(0.006)		(0.007)	
Sample size	56		56		56		56	
R-squared	0.88		0.77		0.48		0.83	

Table 4: Empirical estimates of the effect of specialization in commodity production and controls on the variance of commodity output value.

	1987-1996	1997-2006	2007-2012	2013-2016
Specialized producers				
Effective number of commodities $\leq$ 1.5				
Mean basket volatility	0.273	0.267	0.304	0.293
Standard error	(0.009)	(0.016)	(0.011)	(0.017)
Number of countries	13	14	17	17
Diversified producers				
Effective number of commodities $\geq$ 3				
Mean basket volatility	0.120	0.134	0.195	0.135
Standard error	(0.007)	(0.007)	(0.005)	(0.007)
Number of countries	21	22	22	22

Effective number of commodities defined as the inverse of the Herfindahl index.

Table 5: Empirical estimates of output value volatility for specialized and diversified producers.

effective number of commodities rather than the Herfindahl index, facilitates an economic interpretation. Naturally, the relationship between these variables is no longer close to linear. Comparison of Figures 4, 5 and 6 shows very similar volatility levels for diversified producers between 1987 and 2006 and significantly higher volatility between 2007 and 2016, driven by the increase in correlations during 2007-2012.

FIGURE 4 SHOULD BE PLACED HERE

FIGURE 5 SHOULD BE PLACED HERE

FIGURE 6 SHOULD BE PLACED HERE

Numerical estimates of this effect are provided in Table 5. The average output volatility for specialized producers, defined as those effectively producing a single commodity, had a mild increase from 27.0% to 30.4% from 1987-2006 to 2007-2012. However, diversified producers suffered a volatility increase from 12.7% to 19.5% in the comparison between 1987-2006 to 2007-2012. Hence the increase in risk for diversified producers was roughly two times larger in absolute terms than that suffered by specialized producers. In relative terms the difference is even starker as the risk for specialized producers increased roughly by a tenth of its value while that of diversified producers increased by more than half. This is the direct consequence of commodity correlations increasing from 8% during 1987-2006 to 26.0% in 2007-2012. Some cases merit special attention.

Members of the Organization of Petroleum Exporting Countries (OPEC) in our sample (Angola, Ecuador, Iran, Kuwait, Libya, Nigeria, Saudi Arabia, UAE and Venezuela) had an average output volatility of 26.4% in 1987-2006 and 30.1% in 2007-2012. Finally, in the period 2013-2016, commodity correlations decreased to 10.0% on average and levels of output volatility reverted to 29.3% and 13.5% for specialized and diversified producers respectively, in line with the results for 1987-2006.

Our findings are economically significant in their cross-sectional and time dimensions. The average ratio of commodity output value to GDP for the countries in our sample is close to 24%. Therefore, the reported variations in risk associated to commodities suggest significant variations in GDP volatility. In addition, as pointed out earlier, exports correlate strongly with output value fluctuations. Our findings are consistent with some works (Lescaroux (2009), Erten and Ocampo (2013)) indicating that commodity dynamics, including correlations might have cyclical components.

In summary, the benefit in risk reduction due to diversification in the production of commodities was large but variable between 1987 and 2016, with a significant reduction in the 2007-2012 period due to an increase in correlations among commodities. This reduction on the effectiveness of diversification occurred precisely at the time of macroeconomic distress. The variations in risk faced by producers, which are in principle dependent on the statistical properties of the specific commodities in each national basket, were well approximated by (8).

4. Conclusions

We have studied the determinants and behavior of output value risk faced by 56 producers of 26 agricultural, mineral and energy commodities between 1987 and 2016. We report four findings. First, the volatility of national output value for commodity producers, taking into account both price and physical output changes between 1987 and 2016, was strongly increasing as a function of the degree of specialization in production. Furthermore, fluctuations in output value exhibited strongly positive correlation with fluctuations in exports. Therefore, concentrated producers suffered significantly higher levels of risk. Second, between 1987 and 2006, specialized commodity producers, essentially engaged in the production of a single commodity, experienced an average volatility of output value of 27.0%. During the same period, producers diversified in three or more commodities experienced an average volatility of 12.7%. Average pairwise commodity correlation during this period was close to 8%. Third, the period 2007-2012 experienced higher pairwise commodity correlations averaging 26%, leading to output volatilities for specialized and diversified commodities of 30.4% and 19.5% respectively. Hence, strongly reducing the relative benefit of diversification at the height of the financial crisis and the commodities boom. In 2013-2016, volatilities for specialized and diversified producers reverted to 29.3% and 13.4% as commodities decorrelated again to 10% on average. The variation in commodity output volatility for diversified producers is economically important because commodities contribute a significant portion of GDP and exports for the countries in our sample. All of the previous findings are empirical in nature and do not require any additional assumption about the covariance structure of commodity returns. In addition, we find that national output variance due to price changes is described approximately, both in the cross-section of producers and across time, by an analytical expression in terms of the degree of diversification of local commodity production, world average commodity volatility and average commodity return correlation. The findings in this article should be relevant to local policy makers in charge of managing natural resources and diversification efforts. We find clear but variable benefits to diversification. These findings should be of interest as well to global investors and multilateral organizations with exposure to local macroeconomic risk.

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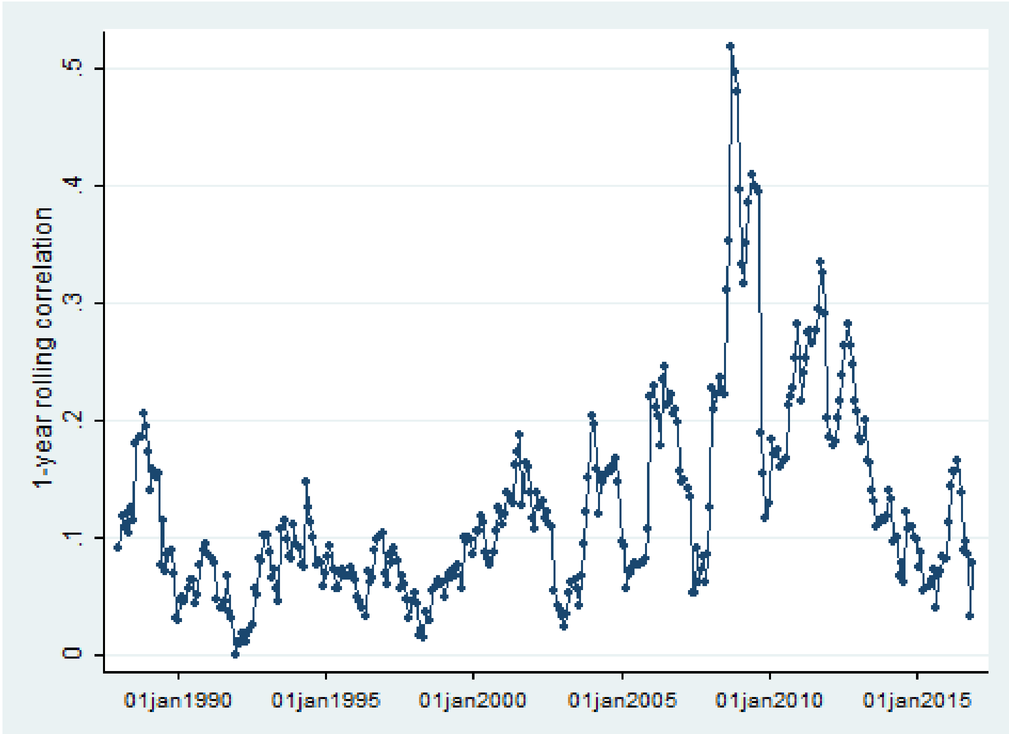

Figure 1: 1-year rolling correlation of commodity returns, averaged over all commodity pairs

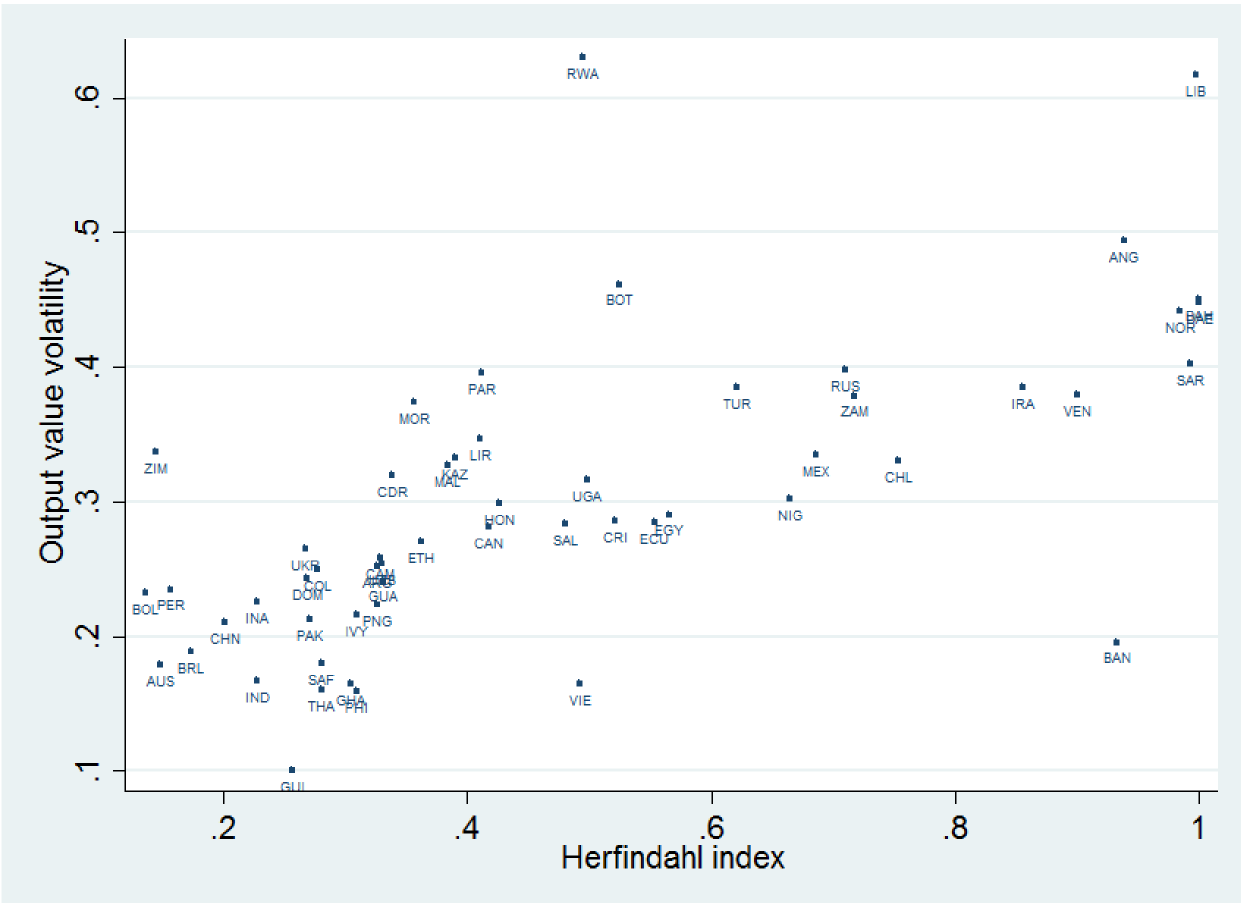

Figure 2: Output value volatility and Herfindahl index. Based on yearly changes in prices and produced quantities, 1987-2016

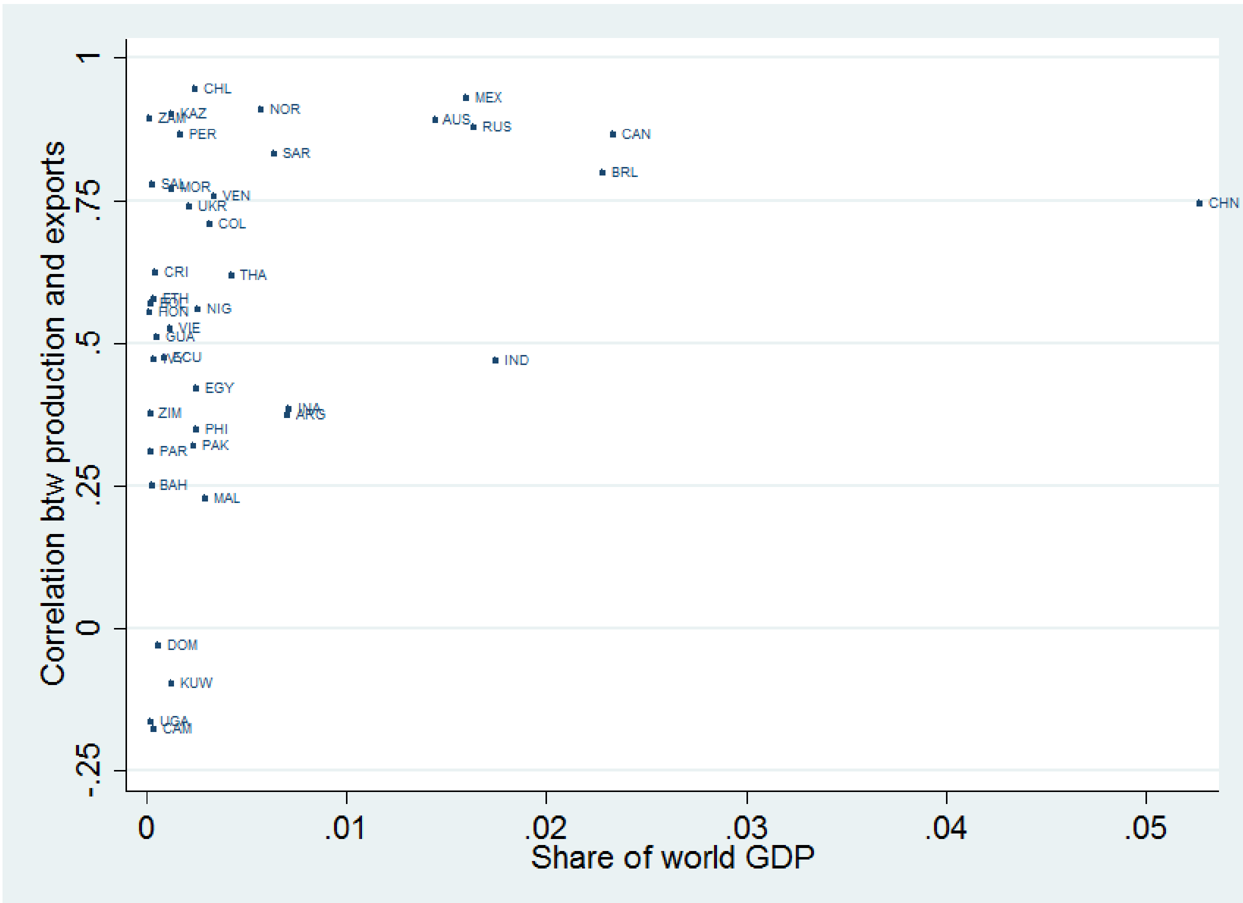

Figure 3: Correlation between output value and export returns, and GDP. Based on yearly returns, 1987-2016

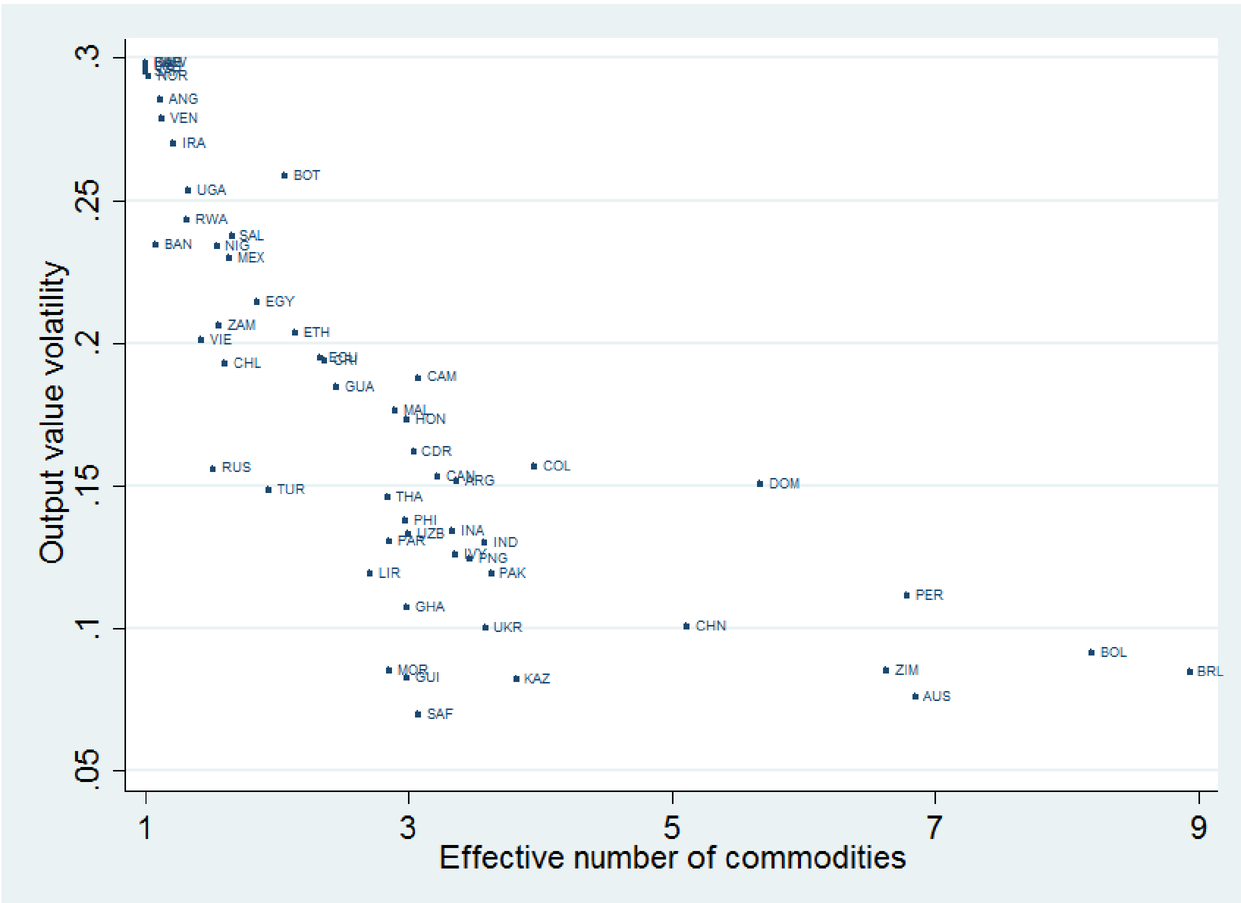

Figure 4: Volatility of output value attributed to price changes and effective number of commodities produced locally. Based on monthly returns for 1987-1996

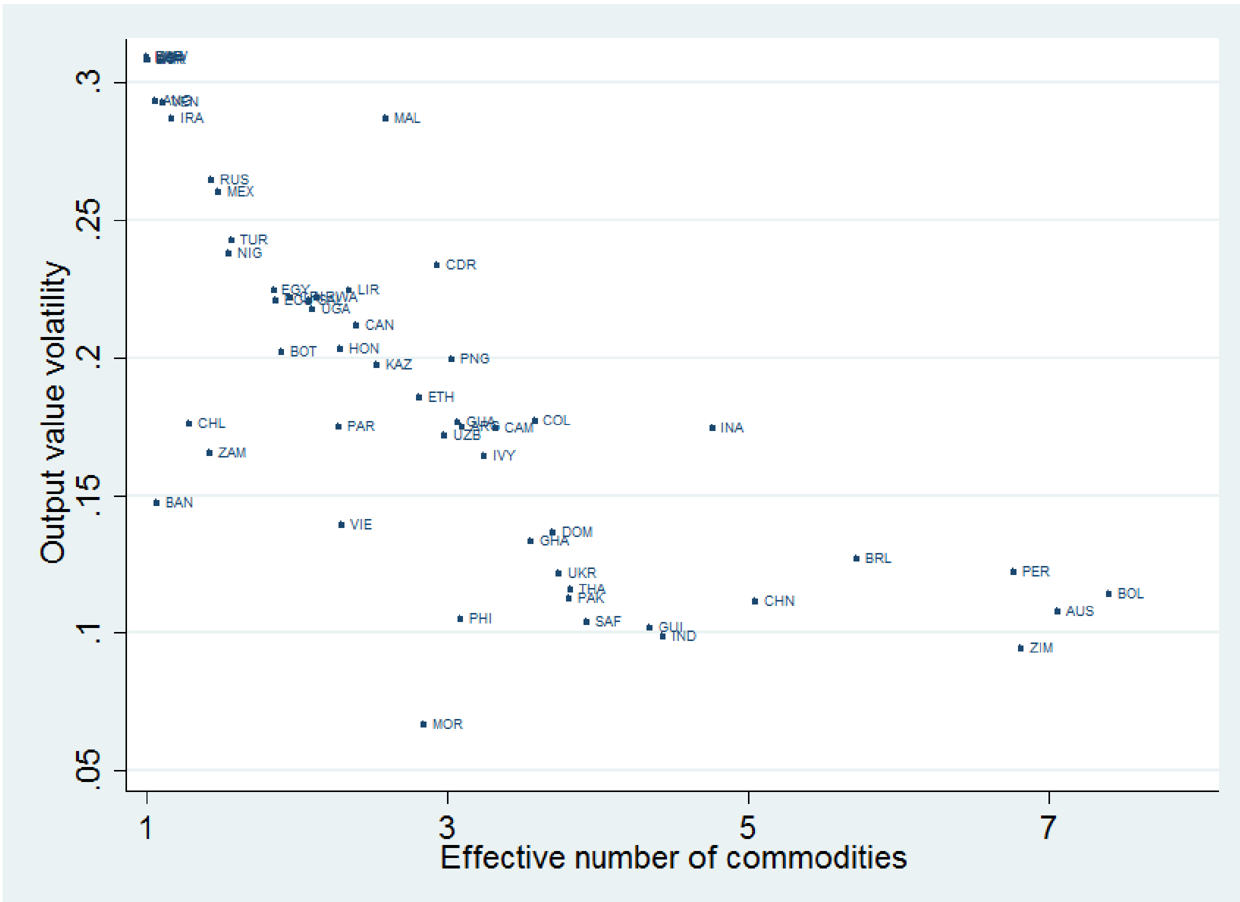

Figure 5: Volatility of output value attributed to price changes and effective number of commodities produced locally. Based on monthly returns for 1997-2006

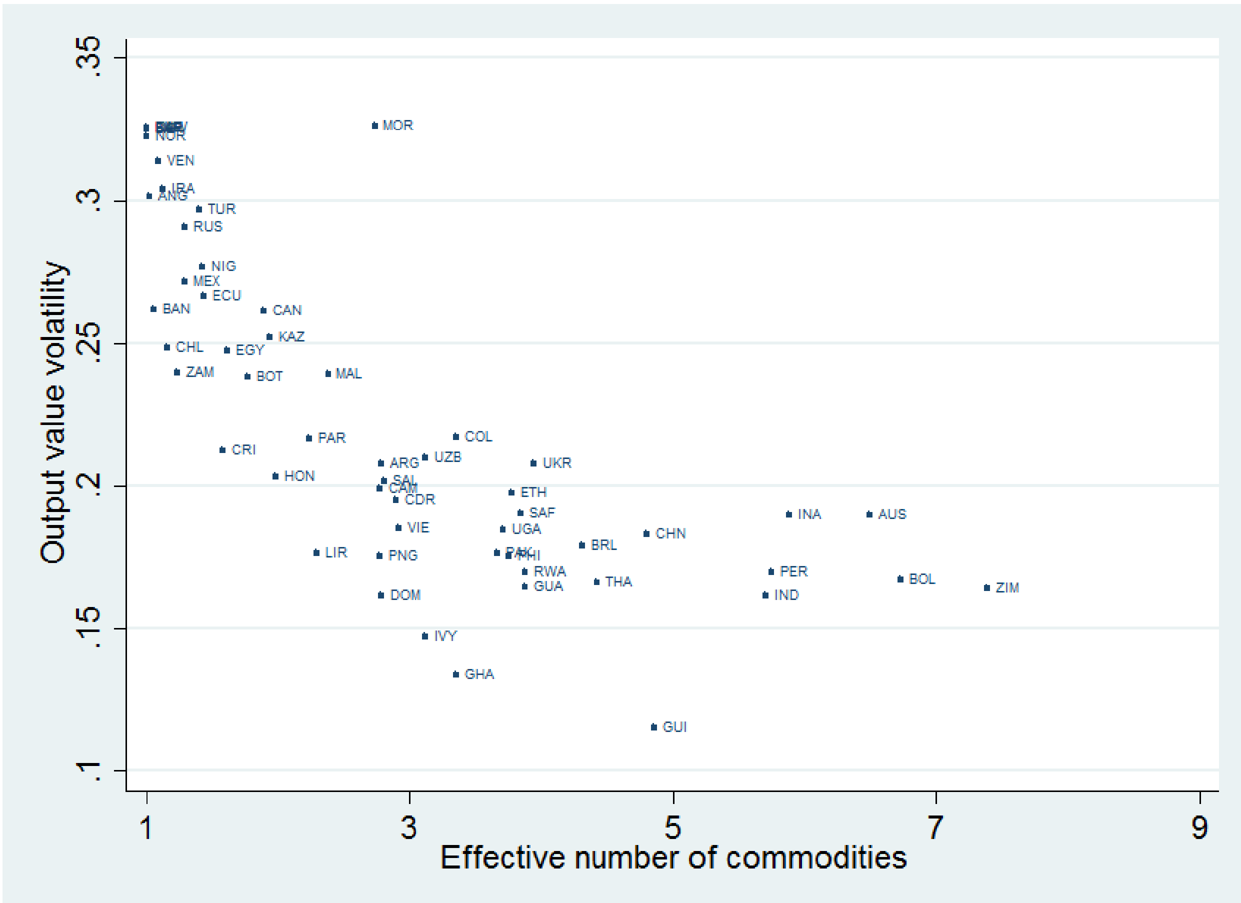

Figure 6: Volatility of output value attributed to price changes and effective number of commodities produced locally. Based on monthly returns for 2007-2016

Online Appendix: A decomposition for output volatility

In this section we present a simple decomposition for the variance of the market value of a commodities basket, which is to be interpreted as the national output of a commodity producer. Our immediate goal is to formulate a framework that will guide us later in our empirical work. The economic issue that we want to explore is the interplay between specialization in commodity production, global commodity market conditions and national output volatility.

We can write the price component of the basket return (6) as

$$r_{price}(t) = \sum_{i=1}^{N} w_i r_i(t),$$

where $r_i(t)$ is the return of commodity i. Let $\sigma^2_{basket_{prices}}$ be the variance of $r_{price}(t)$, which can be written in terms of the variances and correlations of individual commodity returns $\{\sigma_i^2, \rho_{ij}\}$ as

$$\sigma^2_{basket_{prices}} = \sum_{i=1}^{N} w_i^2 \sigma_i^2 + \sum_{i=1, j \neq i}^{N} w_i w_j \sigma_i \sigma_j \rho_{ij}. \tag{A1}$$

Our goal is to characterize (A1) in terms of the statistical properties of underlying commodity returns and the degree of specialization given by the Herfindahl index H implicit in $\{w_1, ..., w_N\}$. In order to reduce the dimensionality of the problem it is convenient to disregard the cross-sectional variation in volatilities and correlations across commodities and replace them by parameters assumed valid for all commodities. An analogous symmetry assumption is made by Giovanni and Levchenko (2009) for the volatilities and correlations of industrial sectors. The validity of this assumption in the context of commodities will be justified empirically in later sections. For the construction of average parameters let

$$\sigma_{world} = \sum_{i=1}^{N} w_i^{World} \sigma_i \tag{A2}$$

be the cross-sectional average of commodity volatilities where each commodity is weighted according to its contribution to the value of global output. Let

$$\rho_{world} = \frac{1}{N\left(N-1\right)} \sum_{i,j=1, j\neq i}^{N} \rho_{ij} \tag{A3}$$

be the average pairwise correlation. The average dynamics of global commodity markets for a certain time period is then summarized by $\{\sigma^2_{world}, \rho_{world}\}$. These cross-sectional averages might vary in time reflecting, for instance, periods of heightened volatility such as the financial crisis of 2008/2009 and higher correlations among commodities between 2004 and 2012.

We are interested in an approximate yet simple decomposition of $\sigma^2_{basket_{prices}}$ in terms of the local structure of production summarized by H and the global dynamics given by $\{\sigma^2_{world}, \rho_{world}\}$. From (A1) it holds that

$$\begin{aligned}
\sigma^2_{basket_{prices}} &= \sum_{i=1}^{N} w_i^2 \sigma_i^2 + \sum_{i,j=1, j\neq i}^{N} w_i w_j \sigma_i \sigma_j \rho_{ij} \\
&\approx \sigma^2_{world} \sum_{i=1}^{N} w_i^2 + \sigma^2_{world} \rho_{world} \sum_{i,j=1, j\neq i}^{N} w_i w_j \\
&= \sigma^2_{world} \sum_{i=1}^{N} w_i^2 + \sigma^2_{world} \rho_{world} ((\sum_{i=1}^{N} w_i)^2 - \sum_{i=1}^{N} w_i^2) \\
&= \sigma^2_{world} H + \sigma^2_{world} \rho_{world} (1-H),
\end{aligned}$$

and therefore,

$$\sigma^2_{basket_{prices}} \approx \sigma^2_{world}\rho_{world} + H\sigma^2_{world}(1-\rho_{world}). \quad \text{(A4)}$$

The identity given by (A4) has the form derived by Giovanni and Levchenko (2009) for the relationship between aggregate output variance, specialization and the volatility of manufacturing sectors. By contrast, our article focuses on the variance of commodity output value. Several conclusions can be derived from (A4).

- The relationship between the variance of commodity output value, the degree of specialization H of a commodity producer, and average commodity market dynamics given by $\{\sigma^2_{world}, \rho_{world}\}$, is non-linear.

- For fixed $\{\sigma^2_{world}, \rho_{world}\}$, $\sigma^2_{basket_{prices}}$ is linear and increasing in H. The lowest possible value of $\sigma^2_{basket_{prices}}$ is $\sigma^2_{world}\rho_{world}$ at $H = 0$ which corresponds to the systematic risk faced by a fully diversified commodity producer engaged in the production of correlated commodities. The highest possible value of $\sigma^2_{basket_{prices}}$ is σ^2_{world} at $H = 1$ which corresponds to the completely specialized commodity producer. The slope in the linear relationship between specialization and output value variance is $\sigma^2_{world}(1-\rho_{world})$ and the constant term is $\sigma^2_{world}\rho_{world}$.

- Changes in global commodity market conditions represented by $\{\sigma^2_{world}, \rho_{world}\}$ imply variations in output value risk. In particular,

$$\frac{\partial\sigma^2_{basket_{prices}}}{\partial\sigma^2_{world}} = \rho_{world} + H(1-\rho_{world}),$$

  therefore specialized producers, with higher values of H, are more sensitive than diversified producers to an increase in commodity volatility and

$$\frac{\partial \sigma^2_{basket_{prices}}}{\partial \rho_{world}} = \sigma^2_{world}(1 - H),$$

therefore specialized producers are less sensitive than diversified producers to an increase in correlations. Both partial derivatives are non-negative. Graphically, an increase in the overall degree of commodity co-movement represented by ρ_{world} leads to an increase in the constant term and decrease in the slope in (A4) so that the output volatility for diversified producers increases by a larger amount than that of specialized producers.

Online Appendix: Empirical data

	Lead	Nickel	Copper	Zinc	Tin	Oil	Plat.	Pallad.	Gold	Silver	Soybean	Wheat	Corn
Nickel	0.35												
Copper	0.37	0.39											
Zinc	0.38	0.41	0.25										
Tin	0.25	0.16	0.14	0.20									
Oil Brent	0.02	0.07	0.06	-0.05	0.05								
Platinum	0.23	0.21	0.12	0.09	0.00	0.09							
Palladium	0.15	0.16	0.02	0.07	0.13	0.02	0.62						
Gold	0.11	0.13	0.13	-0.15	-0.13	0.27	0.59	0.33					
Silver	0.15	0.10	0.01	0.02	-0.04	0.07	0.55	0.38	0.70				
Soybeans	0.09	0.11	0.12	0.15	0.07	-0.01	0.14	0.07	0.10	0.19			
Wheat	-0.02	-0.01	0.09	0.05	0.02	-0.19	0.05	0.06	-0.07	0.03	0.34		
Corn	0.09	0.10	0.01	0.18	0.09	-0.26	0.06	0.04	-0.03	0.15	0.71	0.51	
Arabica coffee	0.18	0.07	0.18	-0.01	-0.09	0.06	0.10	0.17	0.09	0.17	0.06	0.02	0.00
Cotton	0.17	0.12	0.14	0.09	0.14	-0.08	0.20	0.11	-0.04	0.04	0.15	-0.05	0.18
Cocoa	0.16	0.07	0.17	0.17	-0.13	-0.03	0.10	-0.02	0.09	0.13	0.04	0.02	0.02
Sugar	-0.01	0.10	-0.04	0.23	0.13	-0.05	-0.01	0.04	0.11	0.13	0.16	0.01	0.23
Orange juice	0.04	-0.12	-0.01	-0.08	0.10	-0.03	0.07	0.03	0.13	0.02	0.06	-0.02	0.17
Palm oil	0.02	0.06	0.30	0.11	0.09	-0.08	-0.05	-0.01	-0.05	-0.12	0.28	0.23	0.24
Rubber	-0.07	0.00	-0.09	0.14	0.00	0.10	-0.03	0.07	-0.12	-0.06	0.10	-0.04	0.13
Canola	0.08	0.16	0.15	0.19	0.13	-0.04	0.05	0.04	-0.01	0.04	0.75	0.34	0.66
Rough rice	0.02	-0.03	-0.15	-0.06	0.18	-0.17	-0.08	0.06	-0.12	-0.08	0.01	0.19	0.11
Iron ore	0.05	-0.03	-0.07	0.14	-0.21	-0.09	0.02	-0.01	-0.07	-0.03	-0.03	-0.03	0.04
Phosphates	-0.04	0.04	-0.13	0.08	-0.06	0.06	-0.07	0.02	0.00	0.03	0.05	-0.03	0.06
Thermal coal	0.09	0.29	0.24	0.16	0.09	-0.06	-0.13	-0.09	-0.15	-0.34	0.15	0.13	0.15
Bauxite	-0.12	-0.04	-0.13	0.01	-0.07	-0.04	-0.08	0.01	0.02	0.00	0.01	-0.05	0.01

	Coffee	Cotton	Cocoa	Sugar	OJ	Palm	Rubber	Canola	Rice	Iron	Phosph.	Coal
Cotton	-0.10											
Cocoa	0.23	0.05										
Sugar	-0.03	0.05	0.09									
Orange juice	0.01	-0.07	-0.01	0.13								
Palm oil	0.06	0.07	-0.01	0.20	0.03							
Rubber	0.08	0.09	0.02	0.21	0.00	0.24						
Canola	-0.05	0.28	-0.05	0.23	0.03	0.42	0.16					
Rice	-0.12	-0.02	-0.15	0.00	-0.07	0.09	0.03	0.02				
Iron	0.06	0.04	0.20	0.01	0.10	-0.02	-0.01	-0.03	0.08			
Phosphates	0.10	-0.04	0.01	0.16	0.05	0.00	0.09	0.03	0.14	0.02		
Thermal coal	0.02	0.03	0.05	0.12	0.07	0.05	0.05	0.20	0.03	0.13	0.01	
Bauxite	0.04	-0.06	-0.01	0.08	0.04	-0.07	-0.01	-0.09	0.08	0.02	0.52	-0.03

Average pairwise correlation in this period is 0.072.

Table A1: Correlations of monthly commodity returns. 1987-1996.

	Lead	Nickel	Copper	Zinc	Tin	Oil	Plat.	Pallad.	Gold	Silver	Soybean	Wheat	Corn
Nickel	0.32												
Copper	0.31	0.48											
Zinc	0.46	0.44	0.56										
Tin	0.28	0.35	0.32	0.29									
Oil Brent	-0.01	0.27	0.26	0.15	0.13								
Platinum	0.11	0.28	0.40	0.27	0.15	0.20							
Palladium	0.01	0.17	0.22	0.18	0.14	0.16	0.53						
Gold	0.22	0.28	0.34	0.31	0.15	0.17	0.48	0.20					
Silver	0.25	0.27	0.31	0.29	0.18	0.05	0.29	0.19	0.54				
Soybeans	0.04	0.18	0.17	0.08	0.20	-0.04	0.01	0.07	0.07	0.06			
Wheat	0.13	0.14	0.11	0.13	0.17	0.04	-0.04	0.06	-0.04	-0.09	0.38		
Corn	0.05	0.11	0.01	0.13	0.20	-0.06	-0.10	0.12	0.01	0.06	0.65	0.65	
Arabica coffee	0.14	0.25	0.07	0.26	0.20	-0.04	0.13	0.07	0.19	0.17	0.18	0.11	0.14
Cotton	0.12	0.08	0.06	0.10	0.14	0.09	0.06	0.11	-0.07	-0.03	0.31	0.11	0.16
Cocoa	0.10	-0.04	-0.02	0.03	0.02	0.03	0.04	-0.02	0.06	0.03	-0.07	0.17	0.09
Sugar	0.07	-0.05	0.15	0.14	0.06	0.12	0.22	0.17	0.05	0.15	0.03	0.11	-0.02
Orange juice	-0.04	-0.02	-0.01	-0.01	-0.07	-0.10	-0.04	0.05	0.01	0.07	0.13	0.20	0.12
Palm oil	0.08	-0.11	-0.12	-0.05	-0.02	-0.15	-0.09	-0.01	0.00	0.03	0.26	0.04	0.18
Rubber	-0.08	0.04	0.15	0.04	0.09	0.06	0.04	-0.14	0.02	-0.03	0.23	0.04	0.00
Canola	0.06	0.09	0.12	0.04	0.12	-0.13	0.00	0.02	0.15	0.11	0.70	0.41	0.56
Rough rice	0.02	-0.05	0.17	-0.02	0.11	-0.02	0.01	0.11	-0.01	0.05	0.01	-0.13	-0.04
Iron ore	0.10	0.04	0.09	0.12	0.15	0.01	-0.02	-0.04	-0.02	0.13	0.04	0.01	0.03
Phosphates	0.02	-0.08	-0.04	0.06	0.03	0.09	-0.11	0.03	-0.07	0.00	-0.02	-0.05	0.03
Thermal coal	0.12	0.15	0.19	0.13	0.31	0.19	0.15	0.12	0.03	0.09	0.15	0.12	0.18
Bauxite	0.07	-0.01	0.07	0.08	0.06	0.07	0.07	-0.02	0.03	0.11	0.06	0.05	0.08

	Coffee	Cotton	Cocoa	Sugar	OJ	Palm	Rubber	Canola	Rice	Iron	Phosph.	Coal
Cotton	0.05											
Cocoa	0.03	-0.02										
Sugar	0.10	-0.04	0.18									
Orange juice	0.08	0.00	0.02	0.11								
Palm oil	0.01	0.15	-0.01	-0.01	0.18							
Rubber	-0.03	0.20	0.14	-0.06	0.05	-0.13						
Canola	0.10	0.19	0.06	-0.02	0.26	0.36	0.14					
Rough rice	0.10	0.07	-0.01	-0.03	-0.01	0.11	-0.10	-0.02				
Iron ore	0.11	-0.03	0.06	0.06	0.01	-0.01	0.05	-0.08	0.07			
Phosphates	0.04	-0.05	-0.02	-0.07	-0.01	0.14	-0.04	-0.07	0.25	-0.01		
Thermal coal	-0.01	-0.03	0.01	0.13	-0.24	-0.08	-0.02	0.09	0.13	0.00	0.07	
Bauxite	0.03	0.15	-0.02	0.18	-0.04	-0.19	0.04	0.02	-0.13	0.03	-0.26	0.13

Average pairwise correlation in this period is 0.090.

Table A2: Correlations of monthly commodity returns. 1997-2006.

	Lead	Nickel	Copper	Zinc	Tin	Oil	Plat.	Pallad.	Gold	Silver	Soybean	Wheat	Corn
Lead													
Nickel	0.49												
Copper	0.69	0.64											
Zinc	0.66	0.62	0.73										
Tin	0.50	0.58	0.57	0.51									
Oil Brent	0.39	0.38	0.55	0.38	0.48								
Platinum	0.45	0.49	0.58	0.46	0.54	0.37							
Palladium	0.50	0.59	0.65	0.51	0.51	0.37	0.73						
Gold	0.14	0.17	0.12	0.12	0.29	0.06	0.54	0.31					
Silver	0.26	0.29	0.28	0.25	0.45	0.21	0.59	0.46	0.81				
Soybeans	0.24	0.30	0.30	0.21	0.32	0.44	0.37	0.29	0.21	0.22			
Wheat	0.22	0.12	0.21	0.11	0.12	0.14	0.19	0.13	0.15	0.12	0.61		
Corn	0.05	0.22	0.23	0.12	0.29	0.23	0.29	0.23	0.20	0.26	0.62	0.56	
Arabica coffee	0.21	0.20	0.21	0.26	0.25	0.20	0.15	0.19	0.19	0.22	0.29	0.30	0.30
Cotton	0.28	0.28	0.32	0.25	0.27	0.29	0.28	0.33	0.09	0.26	0.37	0.27	0.31
Cocoa	0.07	0.19	0.21	0.14	0.19	0.35	0.33	0.24	0.16	0.23	0.23	0.08	0.17
Sugar	0.27	0.10	0.19	0.23	0.22	0.15	0.13	0.21	0.15	0.23	0.20	0.15	0.11
Orange juice	0.09	0.24	0.20	0.27	0.25	0.08	0.16	0.24	0.08	0.11	0.16	0.09	0.15
Palm oil	0.20	0.22	0.35	0.27	0.26	0.28	0.37	0.32	0.12	0.14	0.42	0.26	0.25
Rubber	0.15	0.22	0.37	0.15	0.28	0.30	0.19	0.36	-0.05	0.12	0.11	0.03	0.19
Canola	0.30	0.29	0.35	0.21	0.36	0.37	0.44	0.37	0.19	0.26	0.73	0.47	0.47
Rough rice	0.10	0.06	0.17	0.07	0.19	0.13	0.27	0.09	0.06	0.10	0.04	-0.02	0.11
Iron ore	-0.01	0.02	0.01	-0.06	0.14	0.14	0.09	0.08	0.00	-0.04	0.15	0.14	0.08
Phosphates	-0.10	-0.05	-0.01	-0.07	0.08	0.06	0.01	-0.05	-0.06	-0.05	0.06	0.21	0.21
Thermal coal	0.29	0.19	0.34	0.18	0.35	0.34	0.37	0.41	0.15	0.18	0.38	0.19	0.23
Bauxite	-0.08	-0.02	-0.07	-0.08	-0.08	-0.09	-0.10	-0.05	-0.03	-0.07	0.04	0.00	0.12

	Coffee	Cotton	Cocoa	Sugar	OJ	Palm	Rubber	Canola	Rice	Iron	Phosph.	Coal
Cotton	0.26											
Cocoa	0.21	0.16										
Sugar	0.36	0.19	0.13									
Orange juice	0.25	0.20	0.00	0.34								
Palm oil	0.18	0.25	0.11	0.11	0.10							
Rubber	-0.07	0.31	0.09	0.00	0.00	0.09						
Canola	0.19	0.33	0.18	0.23	0.16	0.55	0.09					
Rough rice	-0.05	0.07	0.11	0.07	-0.07	0.00	0.06	0.06				
Iron ore	0.03	0.04	0.13	-0.01	0.02	0.13	0.14	0.17	0.09			
Phosphates	0.04	0.12	0.07	-0.02	-0.08	-0.06	0.07	0.08	0.32	0.06		
Thermal coal	0.22	0.27	0.29	0.21	0.26	0.22	0.27	0.49	0.15	0.27	0.04	
Bauxite	0.00	-0.02	-0.06	-0.04	-0.12	-0.06	0.15	0.02	-0.01	-0.06	0.16	0.02

Average pairwise correlation in this period is 0.208.

Table A3: Correlations of monthly commodity returns. 2007-2016.

Country	% Commodity GDP	% GDP World GDP	Herf. 87-96	Herf. 97-06	Herf. 07-16	Herf. 87-16	Eff. N 87-16
Angola	65%	0.07%	0.90	0.94	0.97	0.94	1.06
Argentina	9%	0.71%	0.30	0.32	0.36	0.33	3.07
Australia	9%	1.44%	0.15	0.14	0.15	0.15	6.79
Bahrain	6%	0.03%	1.00	1.00	1.00	1.00	1.00
Bangladesh	20%	0.16%	0.93	0.93	0.94	0.93	1.07
Bolivia	14%	0.03%	0.12	0.14	0.15	0.14	7.39
Botswana	6%	0.02%	0.48	0.53	0.56	0.52	1.91
Brazil	8%	2.29%	0.11	0.17	0.23	0.17	5.79
Cameroon	22%	0.04%	0.32	0.30	0.36	0.33	3.04
Canada	7%	2.34%	0.31	0.42	0.53	0.42	2.39
Chile	15%	0.24%	0.62	0.78	0.86	0.75	1.33
China	20%	5.27%	0.20	0.20	0.21	0.20	4.99
Colombia	16%	0.32%	0.25	0.28	0.30	0.28	3.62
Costa Rica	7%	0.05%	0.42	0.51	0.63	0.52	1.92
Ivory Coast	29%	0.04%	0.30	0.31	0.32	0.31	3.24
DR Congo	21%	0.03%	0.33	0.34	0.34	0.34	2.96
Dominican R.	6%	0.06%	0.18	0.27	0.36	0.27	3.73
Ecuador	26%	0.09%	0.43	0.54	0.69	0.55	1.81
Egypt	18%	0.25%	0.54	0.54	0.62	0.57	1.77
El Salvador	5%	0.03%	0.60	0.48	0.36	0.48	2.09
Ethiopia	10%	0.04%	0.47	0.35	0.26	0.36	2.76
Ghana	22%	0.03%	0.33	0.28	0.30	0.30	3.28
Guatemala	9%	0.06%	0.41	0.33	0.26	0.33	3.03
Guinea	40%	0.01%	0.33	0.23	0.21	0.26	3.89
Honduras	20%	0.02%	0.33	0.44	0.50	0.43	2.35
India	16%	1.75%	0.28	0.23	0.18	0.23	4.41
Indonesia	22%	0.72%	0.30	0.21	0.17	0.23	4.41
Iran	36%	0.42%	0.82	0.86	0.89	0.86	1.17
Kazakhstan	51%	0.13%	0.26	0.39	0.51	0.39	2.56
Kuwait	59%	0.13%	1.00	1.00	1.00	1.00	1.00
Liberia	80%	0.00%	0.37	0.43	0.44	0.41	2.44
Libya	61%	0.09%	1.00	1.00	1.00	1.00	1.00
Malaysia	16%	0.30%	0.35	0.39	0.42	0.38	2.61
Mexico	10%	1.60%	0.61	0.67	0.77	0.69	1.46
Morocco	5%	0.13%	0.35	0.35	0.37	0.36	2.81
Nigeria	55%	0.26%	0.65	0.64	0.70	0.66	1.51
Norway	15%	0.58%	0.97	0.99	0.99	0.98	1.02
Pakistan	11%	0.23%	0.28	0.26	0.27	0.27	3.70
Papua NG	65%	0.01%	0.29	0.33	0.36	0.33	3.07
Paraguay	14%	0.03%	0.35	0.44	0.45	0.41	2.43
Peru	16%	0.17%	0.15	0.15	0.17	0.16	6.40
Philippines	8%	0.25%	0.34	0.32	0.27	0.31	3.24
Russia	23%	1.64%	0.66	0.70	0.77	0.71	1.41
Rwanda	5%	0.01%	0.76	0.47	0.26	0.49	2.02
Saudi Arabia	55%	0.64%	0.99	0.99	1.00	0.99	1.01
South Africa	13%	0.50%	0.33	0.25	0.26	0.28	3.57
Thailand	13%	0.43%	0.35	0.26	0.23	0.28	3.57
Turkmenistan	46%	0.02%	0.51	0.64	0.71	0.62	1.61
Uganda	10%	0.02%	0.75	0.48	0.27	0.50	2.01
Ukraine	15%	0.22%	0.28	0.27	0.25	0.27	3.75
UAE	29%	0.33%	1.00	1.00	1.00	1.00	1.00
Uzbekistan	26%	0.04%	0.33	0.33	0.32	0.33	3.04
Venezuela	37%	0.34%	0.89	0.90	0.92	0.90	1.11
Vietnam	40%	0.12%	0.70	0.44	0.34	0.49	2.03
Zambia	29%	0.02%	0.64	0.70	0.81	0.72	1.39
Zimbabwe	16%	0.02%	0.15	0.15	0.14	0.14	6.93
Average	23.65%	0.44%	0.48	0.48	0.49	0.49	2.78
Std Error	2.46%	0.12%	0.04	0.04	0.04	0.04	0.21

Table A4: Sample of commodity producers and their characteristics. Output value to GDP ratio, local GDP to world GDP ratio, and measures of specialization of production for selected time periods.

	Volatility output value ret.	Volatility price ret.	Volatility physical output ret.	Correlation price/output	Correlation output value/exports
Angola	0.494	0.397	0.210	0.00	
Argentina	0.252	0.228	0.098	-0.20	0.37
Australia	0.179	0.192	0.043	-0.47	0.89
Bahrain	0.450	0.438	0.099	-0.11	0.25
Bangladesh	0.196	0.166	0.054	-0.08	
Bolivia	0.232	0.186	0.094	0.03	0.57
Botswana	0.462	0.395	0.144	0.32	
Brazil	0.188	0.175	0.047	0.29	0.80
Cameroon	0.258	0.236	0.077	0.04	-0.18
Canada	0.281	0.286	0.030	-0.11	0.87
Chile	0.330	0.316	0.058	-0.34	0.94
China	0.211	0.181	0.048	0.20	0.74
Colombia	0.249	0.241	0.054	-0.07	0.71
Costa Rica	0.286	0.301	0.053	-0.04	0.62
Ivory Coast	0.215	0.222	0.070	-0.07	0.47
Congo RD	0.319	0.290	0.122	0.02	
Dominican R.	0.244	0.217	0.126	-0.22	-0.03
Ecuador	0.285	0.276	0.108	0.04	0.47
Egypt	0.291	0.288	0.035	-0.20	0.42
El Salvador	0.284	0.255	0.121	-0.09	0.78
Ethiopia	0.271	0.219	0.081	0.18	0.58
Ghana	0.165	0.166	0.083	-0.46	
Guatemala	0.242	0.236	0.082	-0.09	0.51
Guinea	0.100	0.100	0.061	-0.10	
Honduras	0.298	0.281	0.073	0.06	0.55
India	0.166	0.145	0.046	0.24	0.47
Indonesia	0.225	0.203	0.049	0.40	0.38
Iran	0.385	0.392	0.066	0.07	
Kazakhstan	0.332	0.289	0.091	-0.01	0.90
Kuwait	0.997	0.438	0.946	-0.11	-0.10
Liberia	0.346	0.272	0.183	-0.16	
Libya	0.617	0.437	0.443	0.01	
Malaysia	0.327	0.333	0.058	0.18	0.23
Mexico	0.335	0.347	0.033	-0.18	0.93
Morocco	0.374	0.346	0.213	0.04	0.77
Nigeria	0.301	0.301	0.055	0.14	0.56
Norway	0.442	0.435	0.096	-0.12	0.91
Pakistan	0.212	0.170	0.185	-0.19	0.32
Papua NG	0.223	0.233	0.091	-0.06	
Paraguay	0.396	0.201	0.250	-0.30	0.31
Peru	0.235	0.217	0.061	0.43	0.86
Philippines	0.159	0.127	0.071	0.00	0.35
Russia	0.397	0.378	0.097	0.13	0.88
Rwanda	0.630	0.241	0.505	-0.10	
Saudi Arabia	0.402	0.436	0.139	-0.20	0.83
South Africa	0.180	0.184	0.046	-0.07	
Thailand	0.160	0.160	0.068	0.21	0.62
Turkmenistan	0.385	0.354	0.103	0.08	
Uganda	0.317	0.239	0.159	0.25	-0.16
Ukraine	0.265	0.200	0.153	-0.30	0.74
UAE	0.448	0.438	0.099	-0.17	
Uzbekistan	0.254	0.257	0.053	0.29	
Venezuela	0.380	0.406	0.059	0.02	0.76
Vietnam	0.165	0.153	0.051	-0.25	0.53
Zambia	0.379	0.311	0.109	0.36	0.89
Zimbabwe	0.337	0.183	0.217	-0.20	0.38
Average	0.313	0.270	0.123	-0.019	0.553
Std Error	0.019	0.012	0.019	0.027	0.048

Table A5: Measures of output value risk at the national level and correlations with exports. Yearly data, 1987-2016.