Three essays in macroeconomic volatility, productive diversification, and inter-sectoral linkages

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THÈSE PRÉSENTÉE

POUR OBTENIR LE GRADE DE

DOCTEUR DE
L'UNIVERSITÉ DE BORDEAUX

ÉCOLE DOCTORALE « ENTREPRISE, ÉCONOMIE, SOCIÉTÉ »
SPÉCIALITÉ : SCIENCES ÉCONOMIQUES

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Trois essais sur la volatilité macroéconomique, la diversification productive, et les liaisons intersectorielles

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Soutenue le 9 novembre, 2017

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Title: Three essays in macroeconomic volatility, productive diversification, and inter-sectoral linkages

Abstract: In a series of empirical essays, this thesis looks at the various intertwining aspects of growth volatility and productive diversification. In the first chapter focused on resource-rich countries, I find that while natural resources adversely affect economic growth by increasing growth volatility, these countries can offset the volatility-triggering effects of natural resources by diversifying their economies. Countries that start off with more diversified production structure or are able to diversify as they develop are likely to benefit from their resource endowment. In the second chapter, I discuss the fact that resource-rich countries willing to diversify their economies are faced with dual policy options; to either develop resource-based industries, or diversify their economies as a whole into new activities not necessarily dependent on natural resources. The empirical analysis shows that diversification through downstream and forward linkages to mining does not lead to productivity enhancements. However, broadening and diversifying the production structure as a whole offer potentials for productivity growth at higher levels of income. In the third chapter, I look at the relation between diversification and volatility from a perspective of production network composed of input-output linkages across sectors. I find that the location of a sector within the production network and its influence on other sectors have opposing effects on the risk of sectoral shocks leading to aggregate volatility. Sectors that are located in dense parts of the network have a mitigating effect on aggregate volatility via substitution effects, while those that are more influential and central in a strongly asymmetrical network generate aggregate fluctuations via contagion effects and inter-industry linkages. These suggest that the distribution and the network structure of inter-industry linkages play an important role into how diversification conditions the impact of idiosyncratic shocks on aggregate volatility.

Keywords : Productive diversification; Macroeconomic volatility; Natural resources; Input-output analysis; Inter-sectoral linkages; Production network; Network analysis

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Titre : Trois essais sur la volatilité macroéconomique, la diversification productive, et les liaisons intersectorielles

Résumé : Dans une série d'essais empiriques, cette thèse analyse les effets de la diversification productive sur la volatilité et la productivité de la croissance économique. Dans le premier chapitre concentré sur les pays riches en ressources, je montre que bien que les ressources naturelles affectent négativement la croissance économique en augmentant la volatilité, ces pays peuvent compenser les effets déclencheurs de la volatilité des ressources en diversifiant leurs économies. Les pays dont la structure de production est initialement plus diversifiée, ou qui parviennent à se diversifier au cours de leur développement économique, sont susceptibles de bénéficier de leur dotation en ressources. Dans le deuxième chapitre, j'explique que les pays riches en ressources disposés à diversifier leurs économies pour stimuler leur productivité sont confrontés à deux choix ; soit développer des industries axées sur les ressources, soit diversifier leur économie dans son ensemble vers de nouvelles activités qui ne dépendent pas nécessairement des ressources naturelles. L'analyse empirique montre que la diversification par les liens vers l'aval du secteur de l'exploitation minière ne conduit pas à des améliorations de productivité. En revanche, l'élargissement et la diversification de la structure de production dans son ensemble offrent des potentiels de croissance de la productivité à des niveaux de revenus plus élevés. Dans le troisième chapitre, j'analyse la relation entre la diversification et la volatilité du point de vue du réseau de production constitué par l'ensemble des liens d'approvisionnement entre secteurs. Je trouve que l'emplacement d'un secteur au sein du réseau et son influence sur d'autres secteurs ont des effets contradictoires sur le risque que les fluctuations subies par ce secteur génèrent une volatilité agrégée. Les secteurs situés dans des régions denses du réseau ont un effet atténuant sur la volatilité globale via les effets de substitution, tandis que ceux qui sont plus influents et au centre d'un réseau fortement asymétrique génèrent des fluctuations globales via les effets de contagion et les liaisons intersectorielles. Ceci suggère que la répartition et la structure des liens interindustriels jouent un rôle important dans la façon dont la diversification conditionne l'impact des chocs idiosyncrasiques sur la volatilité globale.

Mots clés : Diversification productive ; Volatilité macroéconomique ; Ressources naturelles ; Liaisons intersectorielles ; Réseau de production ; Analyse du réseau

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« Knowledge, in itself, is good essentially, and relatively [good] with regard to the objects of knowledge. The pleasure of knowledge is eternal and unceasing, and the pleasure… with respect to the objects of knowledge is attained in the course of learning and ceases at the time of knowing. [The servant of knowledge] must praise those earnestly engaged in the pursuit of… knowledge whenever their efforts arise from delight [in knowledge itself] rather than desire for [achieving] victory in debate. »

Biruni (d. 1048 in Ghazna, Khorasan, present-day Afghanistan)

« Knowledge exists potentially in the human soul like the seed in the soil. By learning, the potential becomes actual. »

Ghazali/aka. Algazel (d. 1111 in Tus, Khorasan)

ACKNOWLEDGEMENT

The past five years were tremendously demanding. Right after starting my Ph.D. research, I began working for the World Bank as a Country Economist for Afghanistan. The first few years at the Bank required investing a lot of my time to get through the steep learning curve that I was faced with. The current thesis is the product of my research efforts in my spare times. Though overwhelmingly busy, I am glad that these exciting five years were productive and stimulating, both intellectually and professionally.

There are many individuals in my academic and professional circles to whom I am indebted for the support they extended during the course of my Ph.D completion. First of all, I'd like to thank my supervisors of research, Eric Rougier and François Combarnous, whose guidance and motivation throughout the course of my research have been pivotal. Eric Rougier entrusted me with enough freedom in shaping my research agenda, for which I am much grateful. I am also glad for the exciting experience I had in co-authoring my third paper with him. Through François Combarnous I was encouraged to use input-output data in my analysis, which opened exciting new applications and methods which I employed in my first two articles.

I am enormously thankful to Jean Imbs, Jean Louis Combes, Isabelle Méjean, and Antoine Bouet for accepting our invitation to be part of the jury for this thesis. I am extremely honoured to have them in the jury.

I am also grateful to my colleagues in the World Bank, in particular Claudia Nassif whose support helped me stay on-track with my PhD research. My former manager, Shubham Chaudhuri, offered me a six-month assignment to the Bank's Development Effectiveness Research Group (DECRG) during which I worked on my third essay. For this, I am much thankful. In DECRG, Aaditya Mattoo and Luis Servén hosted me with great high-mindedness. I am enormously grateful to both. Finally, Robert Saum, the former country director for Afghanistan, always inquired about my research progress, and his reminders from time to time helped me not to lose my focus on studies despite tremendous work pressures and stress.

I am also thankful to Patrick Asea, who always shared valuable research tips with me ever since I worked with him in the monetary policy department of the Central Bank of Afghanistan in 2008/09. I'm also thankful to him for his very helpful comments and suggestions on my third paper.

I have also benefited from discussions with peers and researchers in GREThA, particularly with Pauline Lectard whose Ph.D. research topic was also related to diversification. My friend, Obaidullah Burhani, has also been resourceful as we exchanged ideas and thoughts when he was working on his Master's thesis – also focused on natural resources – at the Université Panthéon-Sorbonne.

I would like to acknowledge the French Government's support to my studies in France. I was granted a scholarship for my undergraduate and graduate studies, and a partial scholarship in the first four years of my Ph.D. program. I'd like to thank Olivier Huynh-Van, a former official of the French Embassy in Kabul, for passionately supporting the Afghan students.

My earliest memories of my life start with war, conflict and displacement. My parents' support during my years of schooling, which marked the most difficult period of our lives when we were refugees in a neighbouring country, and their encouragement throughout my higher studies were crucial. Last but not least, my thesis would have not reached this stage without the support, care and love of my wife, Atifa. I am indebted to her, the most.

I dedicate this thesis to all my teachers in secondary and high schools for their efforts and hard work in educating the young generation in Afghanistan. They had chosen a profession with the least pecuniary benefits, while they could have moved to any other job with higher remuneration at any point in time. Teaching is one of the lowest paid jobs in my country. Yet, teachers choose to teach just for the pure sake of teaching and educating – a purpose most virtuous and noble of all.

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Introduction

Economic development entails a structural change in the economy, which consists of diversifying away from traditional, low-productivity activities towards modern, high-productivity ones (Lin, 2011; McMillan and Rodrik, 2014). Diversification of production (and trade) is central to a growth-enhancing structural change. Empirical evidence shows that productive diversification is associated with sustained increases in economic growth and per capita income (Imbs and Wacziarg, 2003; Hesse, 2008; Papageorgiou and Spatafora, 2012), leads to lower volatility in economic growth rates (Acemoglu and Zilibotti, 1997; Malik and Temple, 2009; Haddad et al., 2010; Koren and Tenreyro, 2007, 2013), and reduces the productivity gap between traditional and modern sectors in the economy (McMillan and Rodrik, 2014).

Most studies in the economic literature that have empirically studied the relation between diversification and other economic aggregates have relied on export concentration measures. By doing so, they fail to capture the *inter-sectoral linkages* in the economy which play a crucial part in such economic outcomes as volatility transmission or productivity growth. In open economies, the process of structural transformation requires diversification of the production structure as a whole, and not merely of the exports, with this diversification of production being intensively connected to external economic conditions. With the global economy becoming more interconnected through the growth of global value chains, production sharing, and vertical integration over the past couple of decades, inter-industry linkages are now an important channel for the transmission of sectoral shocks across countries (di Giovanni and Levchenko, 2010).

In this thesis, I investigate the impact of *productive diversification*, i.e. diversification of the production structure of the economy, through the lens of inter-sectoral linkages. To assess how productive diversification relates to output volatility and productivity growth, I use input-output data to capture the inter-industry linkages of the productive system. In the first and second essays, I measure inter-sectoral linkages by methods employed in input-output analysis. In the third essay, I consider the input-output structure as a *production network* consisting of nodes (sectors) and links (inter-industry flow of goods). The analysis undertaken in the three essays presented in this thesis suggests that assessing the inter-industry linkages by different approaches and techniques offers novel solutions in better understanding the diversification-volatility link.

Macroeconomic volatility is at the core of two essays. Empirical studies have found that macroeconomic volatility has significant costs in terms of decline in economic growth, loss in welfare, and increase in inequality and poverty (Aizenman and Pinto, 2005). In a seminal paper, Ramey and Ramey (1995) showed that volatility does not come without costs; it adversely affects economic growth. They showed that countries with higher volatility tend to have lower average growth, even after controlling for other country-specific growth correlates. Hnatkovska and Loayza (2005) assessed the cost of volatility and estimated that a one-standard-deviation increase in growth volatility leads to a 1.3 percentage-point drop in the growth rate. They also found that the adverse effects of volatility on growth are larger in countries that are poor, institutionally underdeveloped, undergoing intermediate stages of financial development, or are unable to conduct countercyclical fiscal policies.

Natural resources are also a central theme in the first two essays, in which I show that resource abundance can be both an obstacle to diversification and an opportunity for productive transformation. Natural resources represent important factor endowments in many countries. They can be thought of as 'natural capital' – the quantities and qualities of which are provided by nature. Unlike other types of capital such as financial and human capitals, the natural capital needs to be first transformed into 'productive assets' to be able to contribute more sustainably to economic growth and development.

However, the process through which the natural capital is turned into productive assets generates a number of externalities which adversely affect the growth process. The negative externalities stemming from natural resource exploitation affect economic growth either directly by appreciating the real exchange rate and increasing growth volatility, or indirectly by weakening the institutions. How to deal with the negative externalities of natural resources is the subject-matter of the first two essays in this thesis. I particularly focus on 'growth volatility', as an externality to resource exploitation, and on 'productive diversification', as a policy response to volatility in resource-abundant countries.

The negative externalities of natural resource exploitation have been extensively discussed in the economic literature. The 'Dutch disease' theory, put forward by Corden and Neary (1982) and Bruno and Sachs (1982), explains that the exploitation of natural resources leads to a decline in manufacturing output, through the appreciation of the real exchange rate, which eventually leads to poor economic performance. The 'resource curse' theory, popularised since 1990s, include a broader set of developmental, institutional, and political economy issues. Economists have argued that natural resource abundance encourages rent-seeking in the economy, weakens the institutions, damages democracy, increases the probability of civil war, and leads to poor development outcomes (Rosser, 2006).

Resource-rich countries also experience higher macroeconomic volatility. The structural characteristics of resource-intensive economies are such that they lead to increased volatility in growth, prices, and public spending. First, resource-rich countries tend to have greater export concentration which itself is strongly correlated with higher output volatility (Malik and Temple, 2009). Second, resource-rich countries are usually commodity exporters which are more prone to commodity prices shocks and terms-of-trade shocks (Blattman et al., 2004), while studies have found that terms-of-trade shocks account for a significant portion of output fluctuations (Mendoza, 1995; Kose and Riezman, 2001). Third, resource-rich countries risk running pro-cyclical fiscal policies if rigorous fiscal discipline is not put in place. In absence of good fiscal management, resource rents tend to distort fiscal policy and lead to large fluctuations in fiscal indicators. Bleaney and Halland (2009) showed that resource-rich countries tend to have higher volatility of government spending and of aggregate growth. Finally, resource abundance leads to increased macroeconomic volatility by weakening the institutions – an outcome which is a typical consequence of the resource curse (Rodrik, 1999; Acemoglu et al., 2003).

Volatility is, therefore, one of the main transmission mechanisms through which natural resources adversely affect economic growth. Van der Ploeg and Poelhekke (2009) explain that resource abundance indirectly affects economic growth by increasing volatility. They argued that any direct impact of natural resources on economic growth is, in fact, trumped by their indirect effect through volatility.

Hence, in the **first essay**, I study to what extent diversification reduces the volatility triggering effects of natural resources. Similar to van der Ploeg and Poelhekke (2009), I find that resource abundance per se is not a drag on economic growth; it adversely affects growth through the volatility channel. As a matter of fact, resource-rich countries tend to have higher economic growth compared to resource-scarce countries with comparable levels of growth volatility. However, the indirect adverse effects of natural resources on growth through the volatility channel may hamper the positive direct effects of resource endowment on growth.

The results suggest that greater diversification offsets the adverse impact of resource abundance on growth which takes place through the volatility channel.

Countries that start off with more diversified production structure or succeed in diversifying their economy as they develop are likely to enjoy fuller positive effects of resource abundance on economic growth. Nonetheless, it is *productive* diversification that is important. Export diversification, by its own, cannot be helpful unless the country diversifies its production structure as a whole. Productive diversification provides an optimal strategy for resource-rich countries to offset the negative impact of natural resources on growth and allows them to reap the benefits of their resource endowment.

The approach adopted in the first essay is innovative in two ways. First, it focuses on productive diversification, instead of the commonly focused export diversification. Most studies that have attempted to look into the relation between diversification and other economic aggregates have often relied on exports concentration measures (Hesse, 2008; Malik and Temple, 2009; Haddad et al., 2010; Cadot et al., 2011). To the author's best knowledge, the few studies that have focused on productive diversification are Imbs and Wacziarg (2003) and Papageorgiou and Spatafora (2012).

Second, I construct an indicator of diversification that is computed based on input-output data. In addition to using a modified Entropy index to measure the diversity of sectoral outputs and transactions in the economy, the indicator also incorporates the *density* of inter-industry linkages in the economy. Inter-sectoral linkages determine the extent to which shocks affect the economy; whether they are averaged out or are magnified at the aggregate level as they propagate across sectors. The larger the density of linkages, the stronger the transmission of shocks across sectors.

The conclusion of the first essay – that, diversification provides an optimal strategy for resource-rich countries to escape the 'resource curse' – is in conformity with the suggestions of others in the economic literature (Gelb and Grasmann, 2010; Murshed and Serino, 2011; Ahmadov, 2014; Massol and Banal- Estañol, 2014). Diversification limits propagation of shocks in the economy, reduces output volatility by diversifying idiosyncratic risks, allows for a gradual allocation of resources in the economy to their most productive uses, and prevents the Dutch Disease from affecting the manufacturing and other non-tradable sectors. Murshed and Serino (2011) wrote that "it is only specialization in unprocessed natural resource products that slows down economic growth, as it impedes the emergence of more dynamic patterns of trade specialisation." Chile, Brazil, Malaysia, Mexico and Sweden represent some of the best examples of resource-rich countries that were able to diversify their economies, yet maintaining successful growth and development outcomes.

But how should resource-rich countries diversify? This is the subject matter of the **second essay**. For resource-rich countries, diversification means moving away from commodity exports, because commodity exporters are directly exposed to global prices shocks, they often run procyclical fiscal policy with respect to their terms of trade and are likely to experience larger growth fluctuations. Diversification away from commodity exports can be achieved either by: (i) processing the minerals and extractives domestically and then exporting the intermediate and final goods, or (ii) developing new industries that are not necessarily connected to the resources sector. The former basically means pursuing a *resource-based industrialisation* strategy which consists of developing resource-based sectors particularly for downstream activities, while the latter means pursing a *broad-based diversification* strategy and discovering new industries that would have enough low costs for the country to be profitable.

Economic theory diverges on the question that which of the two patterns of diversification is productivity-enhancing for resource-rich countries. The debate hovers around whether the comparative advantage of resource-intensive economies is defined by their factor endowments (Leamer, 1984; Harrigan and Zakrajsek, 2000 Costinot, 2009), *or* by their idiosyncratic elements and characteristics (Hausmann, Hwang and Rodrik, 2007; Lederman and Xu, 2007). Should resource-rich countries automatically diversify into processed natural resources because they are easily accessible to them, which would allow them to benefit from gains in economies of scale? Or, can these countries reshape their production structure and develop new industries that could have higher productivity potentials?

In the second essay, I look for empirical evidence to answer these questions. I study which of the two patterns of diversification is productivity-enhancing for resource-rich countries. The reason for focusing on *productivity* is that different patterns of diversification mean different structural transformations of the economy and thus different productivity levels in the long run. The empirical literature that has studied structural changes in countries often focuses on productivity differentials, for instance McMillan and Rodrik (2014), because productivity growth best captures the performance of countries throughout their development path.

While diversification patterns are difficult to be measured quantitatively, one option is to look at industrial linkages that are formed in the economy. Inter-industry linkages show how sectors within an economy trade with each other. A resource-based industrialised economy, for instance, would show stronger linkages between mining and processing industries. I therefore employ the indicator of forward-linkages to mining and extractives to measure the extent to which downstream processing industries have developed in the economy. Countries that embark on resource-based industrialisation have stronger forward-linkages to mining and extractives. On the contrary, in countries that pursue a broad-based diversification strategy, one should expect a diversified production structure as a whole and not necessarily denser forward linkages to mining and extractives sector alone.

The results in the second essay suggest that a resource-based industrialisation is associated with lower rates of productivity growth. Developing downstream processing industries for minerals and extractives does not help the resource-rich countries to achieve higher levels of labour productivity. A broad-based diversification, however, offers potentials for productivity enhancement at later stages of development. Diversification leads to higher productivity growth when countries reach the high-income group level.

Nonetheless, even at lower levels of income, diversification initially reduces the large productivity gaps which exist between the traditional and modern sectors of the economy. McMillan and Rodrik (2014) show that large productivity gaps exist in developing countries between the traditional and modern sectors due to allocative inefficiencies. The diversification process initially reduces the productivity gap in developing countries, which may show lower growth in the economy-wide productivity. Further, the effect of resource misallocation on productivity in developing countries can be amplified through the input-output structure of the economy (Jones, 2011). Misallocation associated with microeconomic distortions not only affects directly sectoral productivities, but also indirectly through the inter-industry linkages. In more diversified economies, as the input-output structure is larger, resource misallocation would reduce economy-wide productivity more so than in less diversified economies. Finally, variations in sectoral composition across countries also explain the differences in aggregate productivity performances. Sectoral reallocation associated with structural transformation could generate episodes of acceleration or slowdown in economy-wide productivity growth, even if sectoral productivities are growing (Herrendorf et al., 2014).

Therefore, it should not be inferred that developing countries should not develop resource-based industries at all and/or not diversify until they reach the status of high-income countries. In fact, it is only specialisation in mining alone and the fact of remaining a commodity exporter which substantially lowers productivity growth. I find that resource-rich countries with smallest forward linkages to mining (i.e., those with smallest resource-based industries) and higher exports concentration (i.e., least diversified) have experienced lowest average productivity growth at 1.5 percent over 1970-2010. Countries that have developed resource-based industries but have not diversified their economies as a whole have had an average productivity growth of 3.8 percent. Conversely, countries that have diversified their economies as a whole have experienced highest average productivity growth rates between 7 and 9 percent on average. Thus, a broad-based diversification can potentially help countries achieve higher productivity growth outcomes over time.

Countries endowed with natural resources are not destined to remain commodity exporters and/or specialise uniquely into resource-based industries. These countries have the option to reshape their production structure and discover new industries that would have enough low costs for them to be profitable. The examples of such countries are not rare. Advanced economies such as the United Kingdom, the United States, and Sweden, which started off as resource-rich countries in 18th and 19th centuries, diversified extensively their economies towards modern activities, sophisticated products and high-tech industries. More recent examples of developing resource-rich countries include Malaysia, Mexico and South Africa, whose production structures are not limited anymore to mining and resource-based industries. Chile and Brazil have also diversified in recent years into fishery, horticulture and other agriculture products.

A broad-based diversification is not necessarily exclusive of resource-based industrialisation. Broadening the production structure in a resource-rich country does not mean that it should avoid mineral processing while looking for other productive industries to develop. The core concept of a broad-based diversification is that a resource-abundant country should not uniquely rely on activities that are based on natural resources. With a more diversified economic structure, potentials for minimizing growth volatility that result from natural resources production are higher and opportunities for productivity enhancements are larger.

In the **third essay**, I take the volatility-diversification discussion to a different and more general setting: I study the volatility-diversification link in a *production network* composed of input-output linkages across sectors. Over the past decade, network analysis has attracted much interest in economics, particularly due to new sets of methods and applications it has brought forward for more thorough analyses of economic flows and relations. An economy can be viewed as a production network where each node represents a sector, and the links joining the nodes/sectors represent the inter-industry flows of goods from one sector to another. The input-output structure of the economy can thus be reproduced in an input-output network – also called a production network – which would allow us to calculate various measures of density, influence, connectivity and resilience, which are much more sophisticated and comprehensive than the traditional input-output analysis *à la Hirschman*.

In the economic literature, the traditional diversification argument has held that, in diversified economies, shocks to individual sectors are unimportant because as the number of independent and identically distributed shocks increases in an economy, each independent sectoral shock would become inconsequential according to the law of large numbers (Lucas, 1977). However, a more nuanced answer to the question was provided by recent work having demonstrated the importance of independent sectoral shocks for aggregate output. One recent path-breaking paper by Acemoglu et al. (2012) has derived theoretical conditions under which firm-level or sector-level shocks can have aggregate implications in a network macroeconomic model. The authors show that in such a network model, highly diversified economies can be buffeted by aggregate volatility emanating from independent sector shocks. Therefore, greater productive diversification does not always immunize economies from higher volatility for sectoral shocks satisfying the theoretical conditions described in Acemoglu et al. (2012).

The traditional literature has supported the assumption that *sectoral* diversification (i.e., expansion in the number of sectors) reduces economic volatility. This assumption relies on two different theoretical mechanisms. First, a series of papers inspired by the financial portfolio theory have established that the pooling of risk across firms, notably through financial tools, ensures that aggregate and firm-level volatility follow inverse relation (Saint-Paul, 1992; Obstfeld, 1994; Acemoglu and Zilibotti, 1997). Second, models based on trade diversification (Koren and Tenreyro, 2007; di Giovanni and Levchenko, 2009; Cuberes and Jerzmanowski, 2009) have also found that increased trade specialisation, in more volatile export sectors, raises aggregate volatility. Indeed, empirical papers have essentially provided evidence supporting the prediction that sectoral diversification of export or output reduces aggregate volatility (di Giovanni and Levchenko, 2006; Malik and Temple, 2009; Haddad et al., 2010).

In addition to the concept of sectoral diversification, Koren and Tenreyro (2013) proposed to think of diversification as an expansion in the varieties of inputs, which they labelled as *technological* diversification. In an endogenous growth model with expanding varieties of inputs, with each input variety being associated with specific risks of productivity shocks, they show that any expansion in the number of varieties might reduce the risk of aggregate volatility. Similar to the Lucas effect based on the law of large numbers, as the number of input varieties increases, productivity and output will become less volatile because each individual input will matter less in the production process. However, technological diversification also waives volatility through the behaviour of firms adjusting the use of other varieties of inputs in order to partially offset any idiosyncratic shock on a particular variety. For Koren and Tenreyro (2013), the *substitution* effect between different technologies incorporated into the variety of inputs primarily explains why idiosyncratic shocks have no impact on aggregate volatility.

The substitution effect, however, can only be envisaged if the productive system is analysed as a collection of uncorrelated, or imperfectly correlated, sectors among which compensation is possible. In more complex models of productive economies, with sectors being linked through backward and forward linkages, the substitution effect may not apply anymore since output or productivity change may be correlated across sectors via inter-sectoral demand or supply effects. As opposed to the sectoral diversification approach, the technological diversification approach considers that sectoral output deviations are potentially cross-correlated via the network structure of input-output linkages. In this set-up, a more diversified distribution of input linkages will not automatically preclude an idiosyncratic sectoral shock from translating into aggregate volatility.

Two recent papers by Gabaix (2011) and by Acemoglu et al. (2012) have established the conditions under which inter-firm or inter-sectoral linkages condition the transmission of idiosyncratic shocks to aggregate volatility. They show that in highly asymmetric production networks, that is networks where some sectors or firms are larger input suppliers to the rest of the economy or the distribution of firm sizes is strongly leptokurtic, idiosyncratic shocks to these sectors or firms can prompt aggregate output fluctuations through *contagion* effects across the network of inter-sectoral linkages. Importantly, these results hold for economies comprising a large number of sectors.

While the theoretical result in Acemoglu et al. (2012) is important and insightful, a deeper understanding of the relationship between diversification and output volatility requires the theory to be taken to the data. The third essay does so and contributes to our understanding of sectoral shocks in network economies in two ways. First, it is the first to derive empirical results from a *real-world* network of a multi-country global economy to assess the impact of idiosyncratic shocks on aggregate volatility. Unlike other studies which have relied on simulations of theoretical models calibrated usually on the US economy, I use an econometric model to study how inter-sectoral linkages determine the impact of idiosyncratic shocks on aggregate volatility. Second, it is the first to identify the causal impact of network features on various measures of output volatility. Establishing causality from observational data is extremely challenging. I overcome this challenge by utilizing the natural experiment of the Global Financial Crisis of 2007-8. This natural experiment provides plausible exogenous variation in sectoral shocks to the countries in our sample. Establishing causality is a considerable achievement because the previous empirical analysis based on conditional correlations or matching moments to the data may be spurious.

Using sector-level panel data comprising 40 developing and developed countries, I find that both the location of a sector within the network economy, and its influence on other sectors determine its importance in transmitting idiosyncratic shocks to aggregate output. In other words, not every sectoral shock can generate aggregate fluctuations, but this capacity rather depends on the two distinct topological characteristics of the sector, namely its 'local density' and 'centrality'. First, the results suggest that sectors that are located in dense parts of the network where shocks fade out over a large number of alternative paths of propagation due to *substitution* effects, have a mitigating effect on aggregate volatility. This substitution between diversified alternative links literally breaks down the propagation of idiosyncratic shocks across the different nodes (sectors) of the production network, through input provision.

Second, and on the contrary, the sectors that are more influential and central in a strongly asymmetrical network economy generate aggregate fluctuations through *contagion* effects and inter-sectoral linkages. This finding must therefore be related to Acemoglu et al.'s (2012) analytical argument that higher-order interconnections, subsumed by their 'influence vector', prompt aggregate volatility through 'cascade' effects, whereby sectoral shocks propagate to the rest of the economy through the sequence of links between downstream (for supply shocks) or upstream (for demand shocks) sectors. Sectoral shocks contribute more strongly to aggregate fluctuations if the distribution of inter-sectoral linkages is strongly asymmetrical across the input-output matrix, i.e. if the productive structure comprises a handful of very large and influential sectors.

The results of the third essay give a more nuanced perspective on the relation between diversification and volatility. The structure of the production network and inter-industry linkages plays an important role in how diversification conditions the impact of idiosyncratic shocks on aggregate volatility. The structure of any single production network may convey simultaneously both substitution and contagion effects: shocks to sectors situated in dense sub-networks dissipate across the network of inter-sectoral linkages due to possibility of substitution between alternative input-output routes, whereas shocks to more influential sectors translate into aggregate volatility through contagion effects. Marginal effect computation shows that, everything else equal, we would expect a 4 to 7 percent point increase in aggregate volatility after a one unit increase (on a scale of 14) in the intensity of shock for sectors with very high centrality (top 1% of PageRank centrality distribution), and a 5 to 10 percent point decrease in aggregate volatility after a one unit increase in the intensity of shock for sectors with high local density (top 40% of the "average degree of neighbours" distribution). The former result is in-line with the works by Gabaix (2011) and Acemoglu et al. (2012) which insist on the fat-tailed distribution of firm or sectoral influence within the productive network. These results suggest that while there are only few sectors that may transform idiosyncratic shocks into aggregate volatility due to their influence over the whole productive network, there might be more numerous sectors for which the local density of linkages might absorb idiosyncratic shocks.

Diversification should therefore be analysed at a more disaggregated level by looking at the local distribution of linkages around sectors playing strategic roles as input providers to other sectors. Our results suggest that service industries should be more carefully considered by scholars and policy makers since they may be a crucial vector of aggregate volatility. These results can have strong implications for how countries would go about diversifying their economies. The choice of sectors and investment promotion strategies need to be based on a careful understanding of the structure of the economy. Sector strategies must not be developed in isolation to other sectors, and must take into account its linkages with other sectors, its position in the production network, and its importance or influence in terms of how large of a supplier or purchaser it is in the economy.

In a case study, annexed to this thesis in the appendix, I discuss the challenges associated with productive diversification in a more 'comprehensive' manner including the political economy issues. I focus on a prospective resource-rich country with weak institutions and conflict-prone political environment, namely Afghanistan, and demonstrate how in practice various policies and arrangements intended to escape the 'resource curse' and achieve a productivity-enhancing structural change in the country might be faced with political economy challenges. Specifically, I discuss how resource rents can be used to strengthen political stability and to support the diversification process in Afghanistan. I propose a semi-rentier state thesis, according which financial benefits of natural resources in Afghanistan are allocated through cash payments or social transfer systems to those communities that maintain peace and stability, and defend the government vis-à-vis the insurgents; and to those political leaders and former warlords whose interests are aligned with supporting the government and are such to oppose the current insurgent groups. I also suggest a number of specific arrangements for how Afghanistan can use the resource rents as a source of financing to support its diversification process.

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Growth and volatility in resource-rich countries: Does diversification help?

Abstract

This paper[1] studies the « natural resources – volatility – growth » link by evaluating the role of economic diversification. I study whether resource-rich countries are able to offset the volatility triggering effects of natural resources by diversifying their economies. Using input-output data, I construct an indicator that captures diversification of the production structure of the economy and density of inter-industry linkages. The results show that resource abundance exerts negative impact on growth through the volatility channel. While the direct effects of natural resources on growth are positive, their adverse indirect effects through volatility could be larger. I find that productive diversification offsets the volatility impact of natural resources. When diversification is controlled for, the negative growth impact of volatility induced by resource abundance disappears. However, the results do not hold true if export concentration measure is used instead of productive diversification.

1. Introduction

Natural resources remain an area on which economists have failed to reach a consensus. Up until 1980s, most neo-liberal economists believed that natural resources were a major advantage for countries to enjoy rapid growth and development. Walt Rostow (1961), for instance, considered natural resource abundance an element of preconditions for the "take-off" from a state of underdevelopment to that of an industrial development, as it was in the cases of Britain, Australia, Canada, United States, and Sweden. Béla Balassa (1980) emphasized that "a country's endowment of natural resources will benefit its industrial development" by providing funds for investment and generating demand through market linkages.

[1] The paper is published in *Structural Change and Economic Dynamics*, Vol. 35 (2015): pp. 38-55, under the same title.

However, since the 1980s most economists have been sceptical about the idea that natural resource abundance induces good economic outcome. The literature that has emerged since then has argued that natural resource endowment can have adverse impact on growth and development and could become a “curse”. Corden and Neary (1982) and Bruno and Sachs (1982) put forward the “Dutch disease” theory that attracted most attention. They argued that exploitation of natural resources leads to a decline in manufacturing output, through the appreciation of the real exchange rate.

Subsequent studies in 1980s and later years evaluated the empirical validity of the Dutch disease effect. Gelb (1988) studied the economic performance of oil-exporting developing countries and found that these countries exhibited poor economic performance during the boom periods of 1970s and 1980s. Sachs and Warner (1995, 2001) were the first to initiate the econometric literature on the impact of resource abundance on economic growth. The authors found that “economies with abundant natural resources have tended to grow less rapidly than natural-resource-scarce economies.” Other studies such as Leite and Weidmann (1999), Gylfason et al. (1999), Auty (2001) and Sala-i-Martin and Subramanian (2003) also found similar results.

The “resource curse” theory, however, has not been limited to only poor economic performance; it has developed into a multi-dimensional phenomenon that takes into account developmental issues, institutional quality, and political economy considerations. Economists have explained that natural resource abundance encourages rent-seeking in the economy, weakens the institutions, damages democracy, increases the probability of civil war, and leads to poor development outcomes.

However, despite extensive empirical evidence for the resource curse theory, the literature has not reached a consensus (Rosser, 2006). Conceptual disagreements on the measures of resource abundance, the types of natural resources, as well as econometric techniques to assess the impact of natural resources on growth and development are the ongoing sources of debate. Some studies have found no evidence for the resource curse, and instead found a positive correlation between resource endowment and growth (Davis, 1995; Lederman and Maloney, 2007; Alexeev and Conrad, 2009). Some others used alternative measures for resource abundance (Stigns, 2000; Herb, 2005; Fearon, 2005) and some distinguished between different types of natural resources (Isham et al., 2002; Sala-i-Martin and Subramanian, 2003; Ross, 2003), which led them to conclude that resource abundance does not necessarily lead to poor economic and development outcomes.

Recent propositions have been made around the volatility channel. Van der Ploeg and Poelhekke (2009) argued that the positive effects of natural resources on growth are trumped by their adverse *indirect* effects through the volatility. In fact, natural resources are known to exacerbate macroeconomic volatility (Blattman et al., 2004; Bleaney and Halland, 2009; Malik and Temple, 2009; Frankel, 2010), while empirical studies confirm a negative relation between volatility and growth (Aizenman and Pinto, 2005; Hnatkovska and Loayza, 2005). Macroeconomic volatility is found to have significant costs in terms of decline in economic growth, loss in welfare, and increase in inequality and poverty (Aizenman and Pinto, 2005). In a seminal paper, Ramey and Ramey (1995) found that volatility adversely affects economic growth. They showed that countries with higher volatility tend to have lower mean growth, even after controlling for other country-specific growth correlates.

Studies have found that less diversified economies face higher risk of external shocks. Low levels of diversification are associated with higher volatility (Acemoglu and Zilibotti, 1997; di Giovanni and Levchenko, 2006; Haddad et al., 2010; Papageorgiou and Spatafora, 2012). Malik and Temple (2009) found that resource-rich countries tend to have greater export concentration which itself is strongly correlated with higher output volatility.

Thus if natural resources adversely affect economic growth through the volatility channel, *diversification* could offer an optimal strategy for resource-rich countries to offset the negative impact of natural resources and allow them to reap the benefits of their resource endowment. Murshed and Serino (2011) argued that "it is only specialization in unprocessed natural resource products that slows down economic growth, as it impedes the emergence of more dynamic patterns of trade specialization." Many economists have suggested that diversification into processed natural resources ("resource-based industrialisation") can be seen as a way out of the resource curse (Gelb and Grasmann, 2010; Murshed and Serino, 2011; Massol and Banal-Estañol, 2012). Diversification reduces aggregate volatility by diversifying idiosyncratic risks in the economy, allows for a gradual allocation of resources to their most productive uses in the economy, and prevents the Dutch disease from affecting the manufacturing and other non-tradable sectors. Chile, Brazil, Malaysia, Mexico and Sweden represent some of the best examples of resource-rich countries that were able to diversify their economies, yet maintaining successful growth and development outcomes.

In this paper, I study whether diversification reduces growth volatility in resource-rich countries. Similar to van der Ploeg and Poelhekke (2009), I find that resource abundance *per se* is not a drag on economic growth; it adversely impacts growth through the volatility channel. As a matter of fact, resource-rich countries tend to have higher economic growth compared to resource-scarce countries with comparable levels of growth volatility. However, the indirect adverse effects of natural resources on growth through the volatility channel may hamper the positive direct effects of resource endowment on growth. The results suggest that greater diversification offsets the adverse impact of resource abundance on growth which takes place through the volatility channel. Countries that start off with more diversified economies or diversify as they develop are likely to enjoy the positive effects of resource abundance on economic growth.

This paper relates to the three domains in economic literature which were discussed heretofore. First, it relates to the literature on the resource curse theory and attempts to explore the impact of resource endowment on growth by looking at the volatility channel. It builds on van der Ploeg and Poelhekke (2009) who studied the *indirect* volatility impact of natural resources on growth. Second, it is linked to the volatility-growth literature initiated by Ramey and Ramey (1995). This paper employs Ramey and Ramey's model to evaluate the impact of volatility on growth in resource-rich countries. Finally, it relates to the literature that has studied the impact of diversification on growth volatility. This paper links these three areas of research and addresses a question that has remained unexplored in the literature: does diversification help offset the adverse impact of natural resources on economic growth by reducing volatility?

This study is innovative in two ways. First, it focuses on *productive diversification* – diversification of the production structure of the economy – instead of the commonly focused notion, export diversification. Most studies that have attempted to look into the relation between diversification and other economic aggregates have often relied on exports concentration measures (Hesse, 2008; Malik and Temple, 2009; Haddad et al., 2010; Cadot et al., 2011). To the author's best knowledge, the few studies that have focused on productive diversification are Imbs and Wacziarg (2003) and Papageorgiou and Spatafora (2012).

Second, I construct an indicator of diversification that is computed on input-output data. In addition to using a modified Entropy index to measure the diversity of sectoral outputs and transactions in the economy, the indicator also incorporates the *density* of inter-industry linkages in the economy. Inter-sectoral linkages determine the extent to which shocks affect the economy; whether they are averaged out or are magnified at the aggregate level as they propagate across sectors. The larger the density of linkages, the stronger the transmission of shocks across sectors.

The use of input-output data, instead of trade data, has two important advantages. First, it allows us to measure diversification of the *production structure* of the economy, and not only that of the exports structure. Second, it enables us to capture the inter-sectoral linkages and transactions in the economy. Other studies that use concentration and dispersion indices such as Herfindhal, Theil or Gini based on exports data fail to capture the inter-industrial linkages. This paper builds on the literature up until 1990s that employed input-output-based models to study economic diversification, including Wundt and Martin (1993), Siegel et al. (1994, 1995a, 1995b) and Wagner and Deller (1998).

The structure of the paper is as follows. Section 2 undertakes a literature review around the resource curse theory, growth volatility, and diversification. In section 3, I define the indicator of diversification and present its properties. I also present some stylized facts by plotting the relations between volatility, growth, diversification and resource abundance. Section 4 explains the econometric model, estimation method, definitions of variables and data sources. Section 5 presents the estimation results of the model, before I conclude the findings of this paper in section 6.

2. Literature review

2.1 The resource curse theory

Scepticism about natural resources is not a recent trend in economic thinking. Early in 1950s, Hans Singer (1950) and Raul Prebisch (1950) – economists from the so called "structuralist school" – noted that natural resources lead to a decline in the terms of trade of commodity exporting countries over time, and this does not favour their economic development. They argued that the prices of commodities decrease in the long-term relative to the prices of manufactured goods because the demand for primary goods is inelastic with respect to world income. Therefore, countries that specialise in primary goods and import manufactured goods will experience a declining terms of trade and will miss the industrialisation opportunity.

Three decades later, Corden and Neary (1982) and Bruno and Sachs (1982) put forward the "Dutch disease" theory that attracted most attention. They based their analyses on the experience of the Netherlands in natural gas extraction in 1970s and argued that natural resources exploitation draws labour out of the manufacturing towards the extractive sector due to more attractive returns to labour supply. As a result, the manufacturing sector experiences shortage of labour and higher input costs. On the other hand, a rise in mining revenues leads the government to raise its spending which will partly be spent on non-traded goods such as construction and services. The prices of non-traded goods and services increase, and this leads to an appreciation of the real exchange rate. As a result, economic growth declines as manufacturing output and non-commodity exports drop due to both higher labour costs in manufacturing, and more appreciated real exchange rate that makes non-commodity exports more expensive and less competitive.

Subsequent studies in 1980s and later years evaluated the empirical validity of the Dutch disease effect. Gelb (1988) studied the economic performance of oil-exporting developing countries and found that these countries exhibited poor economic performance during the boom periods of 1970s and 1980s. Sachs and Warner (1995, 2001) were the first to initiate the econometric literature on the impact of resource abundance on economic growth. The authors used a data-set of 71 resource intensive countries for the period 1970-1990 and found that "economies with abundant natural resources have tended to grow less rapidly than natural-resource-scarce economies." Other studies such as Leite and Weidmann (1999), Gylfason et al. (1999), Auty (2001) and Sala-i-Martin and Subramanian (2003) also found similar results.

The "resource curse" theory, however, has not been limited to only poor economic performance. It has developed into a multi-dimensional phenomenon that takes into account developmental issues, institutional quality, and political economy considerations. A number of studies have linked resource abundance with poor development outcomes. For instance, Bulte et al. (2005) found that resource-intensive countries suffer lower levels of human development. Gylfason (2001) found that natural resources leave negative impact on the level of education and human capital. Ross (2003) confirmed that oil and non-fuel mineral economies exhibit worsened conditions for the poor.

Recent literature on natural resources has suggested that resource endowment affects economic growth and development through the institutional channel (Easterly and Levine, 2002; Sala-i-Martin and Subramanian, 2003; Isham et al., 2003; Bulte et al., 2005; Mehlum et al., 2006). Institutions may refer to governance, laws and regulations, enforcement mechanisms, property rights, judiciary system, social norms, etc. Sala-i-Martin and Subramanian (2003) found that natural resources, in particular oil and minerals, have a strong and negative impact on growth by weakening the institutional quality. Isham et al. (2003) noted that countries abundant in "point-source" natural resources (such as oil, minerals and plantation crops) have weaker institutional capacities and these are significant determinants of economic growth.

Another consequence of the resource curse is that agents engage in rent-seeking behaviour. In high-rent economies, non-cooperative powerful groups engage in a "redistributive struggle" and this will result in a greater share of resources being invested in non-taxable inefficient activities (Tornell and Lane, 1999). Ross (2001a) argues that resource windfalls encourage politicians to engage in "rent-seizing" activities; meaning state actors seek the rents that are held by state institutions. Robinson et al. (2006) explain that temporary resource booms lead to negative economic outcomes because political elites intend to maximise the rents that they can extract in the short-term, and thus they deviate from the socially efficient extraction path. On the other hand, permanent resource booms also lead to an increased misallocation of resources in the economy, because politicians will have an incentive to engage in inefficient redistribution of rents to influence elections. Auty (2001, 2006) argued that resource rents incite governments to capture and distribute the rents and thereby divert efforts away from promoting wealth creation in the economy through efficient activities. Leite and Weidmann (1999) empirically investigated the impact of natural resource abundance on corruption and found that natural resources are an important determinant of a country's level of corruption. Busse and Gröning (2011) also found similar results for the impact of resource abundance on corruption.

Other studies have focused on the link between natural resource abundance and political stability, regime type, democracy, and civil war. Wantchekon (1999) found that natural resources increase socio-political instability and have significant impact on the probability of authoritarian governments. Ross (2001b) found that oil and non-fuel mineral wealth impedes democracy; resource-rich countries tend to be less democratic than resource-poor countries. Collier and Hoeffler (1998, 2005) found that natural resource dependence increases both the probability and the duration of civil wars. Several explanations have, so far, been discussed in the literature on the link between natural resources and civil war. First, resource rents constitute an attraction for rebels wishing to capture the state and can thus motivate conflict in the country. Secondly, natural resources induce patronage politics. States with natural resources often have weak institutions and do not develop a democratic system based on electoral competition and civil rights. Third, resource rents are often used as a source of financing for civil wars, and therefore natural resource lengthens the periods of civil war in these conflict-prone countries. Collier and Hoeffler (1998, 2005) found, however, that the relation between natural resources and civil war was non-linear; natural resource wealth initially increased the risk of civil war but after a certain level of exports, it reduced the risk due to an increase in per capita income and an enhanced financial capacity of the government that enables it to defend itself against rebellion groups through military expenditure.

Despite the fact that there is considerable evidence on the notion of a resource curse, the arguments are by no means conclusive (Rosser, 2006). The econometric literature on the resource curse theory has still not reached a consensus; conceptual disagreements over the correct measure of resource abundance, as well as appropriate econometric technique to measure its impact are the ongoing sources of debate. Stijns (2000), Herb (2005) and Fearon (2005) emphasized that if natural resource abundance is measured alternately, the negative impact of natural resource abundance on growth, democracy and civil war disappears. Usually the resource curse literature has measured natural resource abundance in terms of the ratio of natural resource exports to GDP or to total exports. If resource abundance is measured in terms of levels of production, or percentage of rents in government revenues, the evidence for the resource curse theory disappears. On the other hand, some economists argue that not all types of natural resources are harmful for growth and development, but only abundance of particular types of resources (Rosser, 2006). Many researchers have found that only "point source" natural resources (oil and non-fuel minerals), and particularly "lootable" resources such as diamond and drugs, are problematic (Isham et al., 2002; Sala-i-Martin and Subramanian, 2003; Ross, 2003).

Davis (1995) studied the data on 22 mineral economies over the period of 1970-1991 and found no evidence of the recourse curse. Instead, he found that mineral economies outperformed non-mineral economies in certain development indicators. The author acknowledged that "the resource curse is, if anything, the exception rather than the rule." On the other hand, Alexeev and Conrad (2009) showed that the effect of an abundance in oil and other minerals on long-term growth is positive. The authors argued that the claims of the natural resource curse literature are due mostly to misinterpretation of the available data. Lederman and Maloney (2007b) adopted a panel data analysis to allow better control for unobserved fixed effects and endogeneity, and found that "several possible indicators of the incidence of natural resource exports seem to have a positive rather than a negative effect on subsequent economic growth." Manzano and Rigibón (2001) noted that natural resources per se are not responsible for the fact that resource-rich developing countries experienced slow growth since the 1970s. The authors explained that resource-rich economies accumulated large stocks of foreign debt in the 1970s when the prices of commodities were very high. When commodity prices declined in the 1980s, these countries experienced "debt overhang effects" that translated into an economic slowdown.

Despite considerable literature on the resource curse theory, the idea of natural resources being an advantage for growth and development has still not been abandoned. Traditional literature on the resource curse theory did not account for the dynamic patterns of trade specialisation and for the role of human capital and technological progress in their analysis. Recent studies, however, have treated resource endowment in a dynamic context alongside other structural elements of the economy. For instance, Gylfason (2001) and Bravo-Ortega and de Gregorio (2007) have found that resource endowment may lead to a decline in economic growth only in countries with low levels of human capital, whereas in countries with human capital above a certain threshold, resource abundance propels economic growth. Bravo-Ortega and de Gregorio (2007) argue that "it is difficult to explain the faster growth of Scandinavia compared with Latin America without highlighting the *educational gap that emerged between the two groups of countries over the period 1870-1910, and which remained large throughout the 20th century*" (emphasis by authors). The authors emphasize that if natural resources are coupled with the accumulation of human capital, they can be transformed into an engine of economic growth.

Furthermore, national "learning" capacity for technological adoption and tinkering is an important factor for a successful exploitation of natural resources. Technological progress increases productivity growth and creates dynamic industries in the country. Maloney (2007) explained that one of the reasons that Latin America missed the opportunities for resource-based growth, while other countries and regions such as Australia, Canada and Scandinavia enjoyed it, was their deficient national "learning" or "innovative" capacity, arising from low investment in human capital and scientific infrastructure. Therefore, it is not the inherent character of natural resources that matters for resource-based development, but "the nature of the learning process through which their economic potential is achieved" (Wright and Czelusta, 2007). In reality, natural resources require extensive investments before they become productive assets, and the required investments not only include physical capital and infrastructure, but also the acquisition of knowledge and adoption of technologies that make natural resources valuable.

2.2 The link between natural resources, volatility, and growth

Resource-rich countries tend to experience higher macroeconomic volatility. The structural characteristics of resource-intensive economies are such that they lead to increased volatility in growth, prices, and public spending. First, resource-rich countries tend to have greater export concentration which itself is strongly correlated with higher output volatility (Malik and Temple, 2009). Second, resource-rich countries are usually commodity exporters which are more prone to commodity prices shocks and terms-of-trade shocks (Blattman et al., 2004), while studies have found that terms-of-trade shocks account for significant portion of output fluctuations (Mendoza, 1995; Kose and Riezman, 2001). Third, resource-rich countries risk running pro-cyclical fiscal policies if rigorous fiscal discipline is not put in place. In absence of good fiscal management, resource rents tend to distort fiscal policy and lead to large fluctuations in fiscal indicators. Bleaney and Halland (2009) showed that resource-rich countries tend to have higher volatility of government spending and of aggregate growth. The authors argued that fiscal policy volatility is an important transmission channel for the resource curse.

Finally, weak institutions which are the symptoms of the resource curse in resource-abundant countries lead to increased macroeconomic volatility. Rodrik (1999) explained that, when institutions are weak, the volatility impact of exogenous shocks is magnified by the distributional conflicts that are induced in the society. Further, Acemoglu et al. (2003) argued that countries with worse institutions are much more likely to experience high volatility and severe economic crises. They explained that, in institutionally weak societies, elites and politicians find various ways of "expropriation" of resources. Economic cooperation is based on "trust," and contractual agreements are more imperfect. Shocks, in this case, may make it impossible to sustain cooperation and will lead to output collapses. Further, with weak institutions, entrepreneurs may choose sectors or activities from which they can withdraw their capital more quickly following a perceived shock, thus further contributing to the economic instability.

Hence, volatility is one of the main transmission mechanisms through which natural resources adversely affect economic growth. Van der Ploeg and Poelhekke (2009) explain that resource abundance indirectly affects economic growth by increasing volatility. They argued that any direct impact of natural resources on economic growth is, in fact, trumped by their *indirect* effect through volatility.

Macroeconomic volatility is not neutral. Empirical studies have found that macroeconomic volatility has significant costs in terms of decline in economic growth, loss in welfare, and increase in inequality and poverty (Aizenman and Pinto, 2005). In a seminal paper, Ramey and Ramey (1995) showed that volatility is not costless; it adversely affects economic growth. They showed that countries with higher volatility tend to have lower mean growth, even after controlling for other country-specific growth correlates. Hnatkovska and Loayza (2005) assessed the cost of volatility and estimated that a one-standard-deviation increase in growth volatility leads to 1.3

percentage-point drop in the growth rate. They also found that the adverse effects of volatility on growth is larger in countries that are poor, institutionally underdeveloped, undergoing intermediate stages of financial development, or are unable to conduct countercyclical fiscal policies.

Further, Laursen and Mahajan (2005) found that volatility negatively affects income inequality, and this relation is statistically significant and robust. The authors argued that macroeconomic volatility leads to high poverty rates by raising income inequality. On the other hand, a number of studies have shown that macroeconomic volatility has significant welfare costs. Though Lucas (1987) found that the welfare cost of economic fluctuations was small in the case of the United States, recent studies have suggested that the welfare cost of volatility is in fact much larger. Reis (2006) found that the cost of eliminating the uncertainty that induces macroeconomic volatility could be as large as 5 percent of per capita consumption. Pallage and Robe (2003) explained that the welfare costs of macroeconomic volatility are substantially larger in poor countries than in the United States. They argued that the median welfare cost of business cycles in low-income countries typically range from 10 to 30 times its estimate for the United States. Pallage and Robe also emphasized that for poor countries "the welfare gain from eliminating aggregate fluctuations may in fact be so large as to exceed that of receiving an additional 1% of growth forever."

2.3 Diversification and growth volatility

Many studies have suggested that less diversified economies face higher risk of external shocks. In a pioneering paper, Acemoglu and Zilibotti (1997) showed that less developed economies are more volatile because they are unable to *diversify* idiosyncratic risks. The authors noted that "better diversification opportunities enable a gradual allocation of fund to their most productive uses while reducing the variability of growth."

Koren and Tenreyro (2007, 2013) developed endogenous growth models to study volatility at different stages of development. The authors showed that sectoral diversification is a key determinant that explains the difference in growth stability between countries at different stages of development. Papageorgiou and Spatafora (2012) found that lower levels of diversification are associated with higher volatility and lower growth. Haddad et al. (2010), on the other hand, wrote that the effect of trade openness on growth volatility reduces with the degree of export diversification, both across products and markets. According to them, not only product diversification (number of goods exported) but also market diversification (number of destination markets) play an important role in moderating the volatility effects of trade openness on growth. Malik and Temple (2009) found that terms-of-trade volatility is strongly associated with lack of export diversification. Further, di Giovanni and Levchenko (2006) studied the risk content of a country's export pattern and estimated that increased specialisation contributes by 7.5 percent to output volatility.

Diversification in resource-rich countries has attracted renewed attention of academics and development institutions in recent years. Though recent discussions reflect on new approaches to industrialisation within a more complex model of development, the core argument remains unchanged to what the structuralist and neo-classical economists argued in the 20th century: diversification away from commodity exports into new industries is favourable to economic development.

Diversification is acknowledged as an optimal strategy for resource-rich countries in their development process. Murshed and Serino (2011) argued that "it is only specialization in unprocessed natural resource products that slows down economic growth, as it impedes the emergence of more dynamic patterns of trade specialization." Many economists have suggested that diversification can be seen as a way out of the resource curse (Hesse, 2008; Gelb and Grasmann, 2010; Murshed and Serino, 2011; Massol and Banal-Estañol, 2012). Diversification minimizes the risks that countries are faced with, lowers the negative impact of external shocks on the economy, prevents the Dutch disease from affecting the manufacturing or other traded sectors, and – above all – allows for a gradual allocation of resources to their most productive uses in the economy. Chile, Brazil, Malaysia, Mexico and Sweden represent some of the best examples of resource-rich countries that were able to diversify their economies.

For resource-intensive economies, an optimal strategy would be to diversify into processed natural resources, a strategy known as "resource-based industrialisation" (Gelb and Grasmann, 2010; Murshed and Serino, 2011; Massol and Banal-Estañol, 2012). It would require developing new industries for processing of natural resources, and strengthening the "links" between the mining and other sectors. The stronger the inter-industry links with the natural resources sector, the larger its growth impact. Resource rents could, in fact, be used to support the diversification process. They can be principally used in two major ways. First, resource rents can be used to finance large-scale public investments, as Lin (2011) puts it, in both "hard" and "soft" infrastructures. Hard infrastructure refers to roads, railway, port facilities, telecommunication systems, electricity grids and other public utilities. Soft infrastructure includes institutions, regulations, social capital[2], and other economic arrangements. Rodrik (2007) explains that diversification cannot take place without direct intervention of the government or other public action. Therefore, large-scale, simultaneous investments in upstream and downstream levels are necessary before natural resources turn into productive assets.

Second, resource rents can be allocated in different ways to support and encourage private investments in new industries, such as in downstream processing activities and/or upstream support activities. Rents, in this case, can be allocated for "horizontal" and "vertical" policies of the government. Horizontal measures refer to financing R&D activities across industries and economy-wide skills/technological upgrading measures. Meanwhile, vertical policies consist of promoting specific sectors and supporting specific businesses by provision of investment subsidies, public credit, tax holidays, or temporary tariff protections. These vertical policies are basically "industrial policy" measures which need to be carefully designed with the objective to support industrial upgrading, and should not lead the government to pick "winners" in the market (Aghion et al., 2011).

3. Indicator of diversification: methodology and stylized facts

Unlike other studies in the literature which use exports concentration indices, this paper defines a composite indicator to measure diversification using input-output data. As such, it enables us: (i) to measure diversification of the *production structure*, and not only of the exports structure; and (ii) to capture inter-sectoral linkages in the economy.

Production structure gives a more accurate sense of the level of economic diversification rather than the exports structure. A number of reasons could be highlighted in this respect. First, exports structure does not include information on *inter-sectoral linkages* which are key for the definition of diversification. Linkages define how industries interact and are positioned with respect to each other. Inter-sectoral linkages determine the extent to which shocks affect the economy; whether they are averaged out or are magnified at the aggregate level as they propagate across sectors. The larger the linkages, the stronger the transmission of shocks across sectors. Whereas exports mediate for the transmission of external shocks to the economy, the absorption or propagation of shocks depend on the structure of all industries present in the country. These inter-sectoral linkages and transactions (i.e., use and supply of both

[2] Social capital refers to social interactions, relations and norms between individuals in the society that have economic value and benefits. Economic theory has recently suggested that social capital contributes to economic growth.

goods and services) can only be captured and measured if one studies the production structure.

Second, the exports structure reflects only the structure of comparative advantage of the economy rather than the whole output structure (Linnemann et al., 1987). In most countries, and even in several advanced economies, not all industries are exporters, and many industries are supported by governments through different types of industrial policy instruments to exist and to survive. We have not yet reached a stage where all countries in the world would specialise in sectors where they have comparative advantage and import the remaining goods and services they need from the rest of the world. Thus, production structure and exports basket could have different levels of concentration in most countries. Nonetheless, what is more important is to have a picture of both the tradable and non-tradable sectors. Production structure captures both the traded and non-traded production processes and paints a more comprehensive picture of the economy (Papageorgiou and Spatafora, 2012).

Finally, while commodity prices shocks – which are transmitted through the exports channel – are a source of volatility in resource-rich countries, they are not the largest or the only source of it. Koren and Tenreyro (2010) showed that global sectoral shocks (which would include global commodity prices volatility) were a less source of volatility in the resource-rich countries in the Gulf. They found that idiosyncratic sectoral shocks (i.e., sectoral shocks that are different for each country) and country-specific shocks (e.g., policy, institutional and political changes) are in fact the largest sources of volatility in those countries. Hence, production structure could best capture idiosyncratic sectoral shocks, in addition to global sectoral shocks, compared to the exports structure.

The production structure is best presented by the input-output (IO) tables, from which large amounts of information can be extracted on the level, composition and dynamics of production. Input-output tables allow us to measure both the diversity of production and the inter-sectoral linkages in the economy. The use of input-output data to study economic diversification is not a new practice. Early in 1990s, economists attempted to study regional economic diversification using IO tables. A number of these studies used portfolio theory models (Wundt and Martin, 1993; Siegel et al. 1994, 1995a, 1995b), while others constructed *scalars* (Wagner and Deller, 1998) to measure diversity at regional levels. Recent development of large IO databases has made it more interesting to use input-output data in micro- and even macro-economic analyses. This paper uses the Eora MRIO (Multi-Region Input-Output) database, developed by Lenzen et al. (2012, 2013) which provides the time-series of high-resolution IO tables for 187 countries, covering the period from 1970 to 2011.

To measure productive diversification, I define a composite indicator based on the input-output data. While an input-output table presents information in the form of a *matrix*, we are interested to have the information synthesized in a uni-dimensional scale. To do this, I define a *scalar* to measure specific dimensions of information that are needed out of an input-output matrix. Once the scalars are derived, they are treated as *values* for further calculation of indices or indicators.

I define the indicator of diversification as shown in equation 1, composed of three elements: a modified Entropy index, named E_k ; a measure of production density, named DN_k ; and a penalty coefficient, named ϕ_k . The subscript k denotes the country.

$$DIV_k = E_k + DN_k \times \phi_k \qquad (1)$$

The first two elements of the indicator are computed based on the *Leontief inverse* matrix, also known as the *total requirements matrix*, because it captures the inter-industry and intra-industry transactions – including both *direct* and *indirect* transactions – in the economy. The direct transactions are the units of intermediate goods that are required for the production of a final product, while indirect transactions are the units of primary goods or commodities that are required to produce the intermediate product which is used in the production process of the final good. The Leontief inverse matrix L is defined as $L = (I - A)^{-1}$ where A is the technical coefficients or technology matrix.

Entropy index is traditionally used as a measure of income inequality and industrial concentration in economics. It is conventionally defined as:

$$E = \sum_{i=1}^{N} x_i \,.\ln\left(\frac{1}{x_i}\right) = -\sum_{i=1}^{N} x_i \,.\ln(x_i) \qquad (2)$$

where x_i is the sectoral share of economic activity with value between 0 and 1. If all economic activities are concentrated in a single sector, then $x_1 = 1$, and the value of the entropy index will equal zero. If economic activities are equally distributed among n sectors, then the entropy index will have its maximum value.

The entropy index can be applied without modification to a Leontieff inverse matrix, where x_i would be the elements of the matrix. The technical coefficients of a Leontieff inverse matrix are also between 0 and 1, which satisfies the condition that $0 < x_i < 1$. However, the constraint for applying the standard entropy index to an input-output matrix is that the entropy increases with the size of the matrix (i.e.

number of sectors). Entropy generates different values for countries that in reality are equally diversified but whose input-output tables have with different dimensions. In fact, countries do not have the same level of industrial disaggregation in their input-output tables, and thus the size of the IO tables differ considerably across countries. The number of sectors/industries in an input-output table does not reflect the true number of industries that exist in the country, rather it depends on the statistical capacity of the government to compile data for more disaggregated levels of industrial classification.

The standard entropy index does not respect the "*population principle;*" i.e., if the size of the population changes, while the distribution remains unchanged, the index should remain unaffected. To show this, let X be a square matrix whose all elements are equal to a constant θ, reflecting a perfect equality in distribution of economic activities across the sectors. The entropy for X would equal:

$$E = \sum_{i=1}^{n}\sum_{j=1}^{n} x_{ij} \,.\ln\left(\frac{1}{x_{ij}}\right)$$

$$= N\theta . ln\frac{1}{\theta} \qquad (3)$$

As demonstrated in equation 3, the entropy's value depends on the total number of matrix elements N. For instance, if X were a (2, 2) matrix (and hence a total of 4 matrix elements) and it is expanded to a (4, 4) matrix (as a result the number of elements increases fourfold to 16) with all elements equal to θ, the entropy equally increases by 4. Hence, the entropy fails to show similar level of equality for two matrices that have the same distribution of values across its elements but have different dimensions.

Hence, the entropy index needs to be corrected for this deficiency, so that it respects the population principle. I propose therefore a modified entropy index that partially respects the population principle. The modified entropy index is defined as:

$$\hat{E} = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} x_{ij}^{\frac{1}{n}} \,.\ln\left(\frac{1}{x_{ij}^{\frac{1}{n}}}\right) = -\frac{1}{n}\sum x_{ij}^{\frac{1}{n}} \,.\ln x_{ij}^{\frac{1}{n}} \qquad (4)$$

where $\mathrm{x_{ij}}$ denotes the elements of the Leontief inverse matrix $\mathrm{L} = (\mathrm{I}-\mathrm{A})^{-1}$, and n is the number of rows/columns in the matrix (i.e., the number of sectors in the IO table). If $\mathrm{Y} = \mathrm{x_{ij}}^{\frac{1}{\mathrm{n}}}$ is a Leontief inverse matrix (L) whose each element is raised by power $\frac{1}{\mathrm{n}}$, $\mathrm{Z} = \ln \mathrm{x_{ij}}^{\frac{1}{\mathrm{n}}}$ is a matrix with each element being the natural logarithm of the corresponding element in Y, and v is a scalar equal to $\frac{1}{\mathrm{n}}$, the entropy index could be expressed in the following matrix form:

$$\hat{E} = -v \sum (Y \circ Z)_{ij} = -v \cdot tr(Y\, Z^T) \qquad (5)$$

where the sign $\circ$ defines the element by element multiplication of matrices Y and Z, known as Hadamard product. Z^{T} is the transpose of matrix Z, and *tr* defines the trace of a matrix.

Though the modified entropy does not perfectly respect the population principle, it is significantly less sensitive to changes in the size of the matrix, compared to the standard entropy – which I call a *weak population principle.* To show this, let us suppose – similar to our previous demonstration for the standard entropy in equation 3 – a square matrix X whose all elements are equal to a constant θ. The modified entropy for X is written as:

$$\begin{aligned}\hat{E} &= \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} x_{ij}{}^{\frac{1}{n}} \,.\ln\left(\frac{1}{x_{ij}{}^{\frac{1}{n}}}\right)\\ &= \frac{1}{n}\,.N\theta^{\frac{1}{n}}\,.\ln\left(\frac{1}{\theta^{\frac{1}{n}}}\right)\\ &= -\frac{1}{n}\,.N\theta^{\frac{1}{n}}\,.ln\theta^{-\frac{1}{n}}\\ &= \frac{1}{n^2}\,.N\theta^{\frac{1}{n}}\,.ln\theta \qquad (6)\end{aligned}$$

where n is the number of rows or columns in the matrix and N is the total number of matrix elements. We know that $N = n{\times}n = n^2$. Hence, per equation 6, the modified entropy for X would equal:

$$\begin{aligned}\hat{E} &= \theta^{\frac{1}{n}}\,.ln\theta\\ &= -\,\theta^{1-\frac{1}{n}}\left(\theta.\,ln\frac{1}{\theta}\right) \qquad (7)\end{aligned}$$

Per equation 7, we observe that the modified entropy depends on the number of sectors n of the input-output matrix (or the number of rows or columns of the matrix) but the relation is very marginal. Compared to the standard entropy which increases proportionally to the total number of matrix elements N or n^2 (see equation 3), the modified entropy for X increases by only $-\theta^{1-\frac{1}{n}}$. As $0 > \theta \geq 1$, the change in the value of entropy would be between $|0|$ and $|1|$ for any changes in n. Hence, though the modified entropy does not perfectly respect the population principle, a partial adjustment towards this end is plausible for the purpose of our study.

The modified entropy also respects other main properties of the standard entropy. For instance, the lower limit of the index is zero. If all transactions in the economy are concentrated in one sector, the corresponding single element of the matrix will have the value 1, and the modified entropy will be 0. Further, the modified entropy respects the *Pigou-Dalton principle of transfers;* i.e. a *progressive* transfer from one element to another which reduces the difference in value between the two will result in an increase in the modified entropy, and, on the contrary, a *regressive* transfer from one element to another which increases the difference in value between the two will lower the modified entropy. Formally, let X be a square matrix with n dimension, in which x_{kk} and x_{ll} are two elements, and $\hat{E}$ denotes the modified entropy calculated on X. If $x_{kk} > x_{ll}$ and a progressive transfer δ occurs from x_{kk} to x_{ll} such that the difference in value between the two is reduced: $(x_{kk} - \delta) - (x_{ll} + \delta) < (x_{kk} - x_{ll})$, the modified entropy increases. On the other hand, if $x_{kk} > x_{ll}$ and a regressive transfer δ occurs from x_{ll} to x_{kk} such that $(x_{kk} + \delta) - (x_{ll} - \delta) > (x_{kk} - x_{ll})$, the modified entropy decreases.

The second component of the indicator is the *density* measure of total requirements matrix, which captures the degree of inter-industry linkages or transactions in the economy. A non-zero element in the Leontief inverse matrix indicates the purchase of an input from a local industry. The higher the density, the larger the purchase of locally produced inputs in the economy. The density measure is calculated as following:

$$DN_k = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} L_{i,j} \qquad (8)$$

The use of density measure and calculating a scalar based on an IO matrix in this paper is inspired by Wagner and Deller's (1998) work. Wagner and Deller constructed a scalar index to measure regional economic diversity in the United States based on regional input-output tables. However, the approach in this paper differs from Wagner and Deller (1998) in a number of areas. First, Wagner and Deller computed the density measure based on the Leontief matrix $(I - A)$, while I define the density measure for the Leontief inverse matrix $(I - A)^{-1}$. The reason for using the Leontief inverse matrix in this paper is that it captures the inter-industry and intra-industry transactions – including both *direct* and *indirect* transactions – in the economy, while the Leontief matrix includes only the direct transactions.

Second, the authors define their scalar indicator for each American state relative to the United States (as the base economy), while scalars in our indicator are not computed relative to any base economy. Third, I correct the density measure for the number of sectors (n) in the IO table. This is for the same reason as previously discussed under the modified Entropy index discussion; if not corrected for the number of industries, the density increases with the number of sectors in the IO table.

Finally, Wagner and Deller (1998) include in their index the condition number – defined as the ratio of the largest and smallest singular values of the matrix (with respect to the Euclidean norm) – as a measure of the inter-industry linkages in the economy. Their motivation for using the condition number is that it measures the linear independence between the column vectors of a matrix. However, the condition number is also – and usually – used to measure the sensitivity of a linear system to noise and inaccuracies in the data (Horn and Johnson, 1990; Leach). Matrices with large condition numbers are said to be *ill conditioned* or *poorly conditioned.* Hence, as the input-output tables are subject to a certain degree of data discrepancy and margin of error, particularly in the case of developing countries where data is often of poor quality, the use of condition number would expose the indicator to data noise and would provide less insight on inter-industry linkages of an economy.

The last component of the diversification indicator is a penalty coefficient. The diversification index is penalized if the export share of extractive commodities is larger than the sectoral share of mining in domestic output. The motivation behind introducing a penalty factor to the diversification indicator is based on dual purposes. First, resource-rich countries that have not diversified their economies tend to have an exports basket concentrated on commodities. Second, diversification in resource-rich countries requires developing linkages between mining and other industries in the economy. The theoretic underpinning behind the penalty function is not based on the argument that an *inward-looking policy* – the strategy that countries should develop local industries to process primary goods and avoid exporting commodities – is good for diversification. But it's rather based on the fact that resource-rich countries that diversify their economies develop new lines of export products that finally reduce the share of commodity exports in their total exports. The penalty coefficient is defined as:

$$\phi_k = \sqrt{\exp\left(\frac{q_m - x_m}{1 + q_m}\right)} \qquad (9)$$

where q_m is the share of mining sector output in total output of all sectors for domestic use, and x_m is the share of extractive commodities in total exports. q_m is calculated based on the intermediate consumption matrix T as following:

$$q_m = \frac{\sum_j^n T_{ij} \,|_{i=m}}{\sum_i^n \sum_j^n T_{ij}}$$

Since the intermediate consumption matrix includes supply of inputs for local industries and does not include production for exports, q_m covers mining sector linkages with the rest of the local industries in the economy. On the other hand, x_m is calculated on the vector of gross exports.

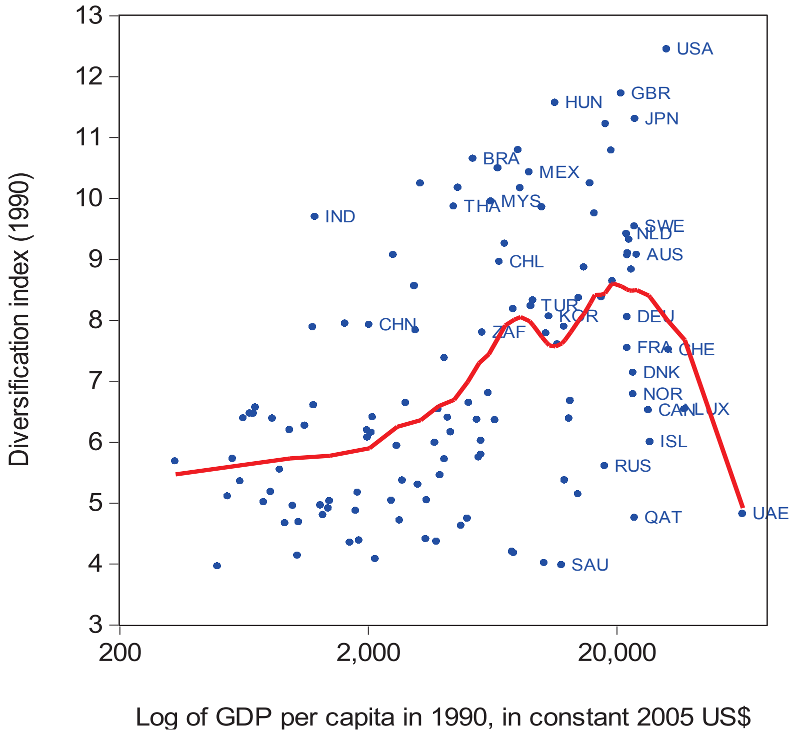
Per equation 9, if $x_m > q_m$, $\left(\frac{q_m - x_m}{1+q_m}\right)$ turns negative, and given the exponential function of the penalty coefficient, we will have $0 < \phi_k < 1$. With a multiplicative relation between the penalty factor and the density index, as defined in equation 1, the overall indicator will be penalized when $x_m > q_m$.

Justification for the denominator $(1 + q_m)$ is that we should differentiate between, for instance, a country with the share of commodity exports at 35 percent and its mining output representing 15 percent of its domestic production, and a country with the share of commodity exports at 21 percent while its share of mining output in total domestic output being only 1 percent. For both countries, the difference between their shares of commodity exports and mining output is 20 percent. Nonetheless, it is important to differentiate between the two resource-rich countries, because the former has significantly developed local downstream industries for extractive commodities, while in the latter the processing of extractive commodities represent only a tiny fraction of its domestic production. With the proposed denominator, the penalty coefficient will be much stronger for the second country and weaker for the first one.

The indicator of diversification is calculated using IO matrices provided by Eora MRIO database (Lenzen et al., 2012, 2013). Appendix B provides the dataset of the indicator for 123 countries in 1990.

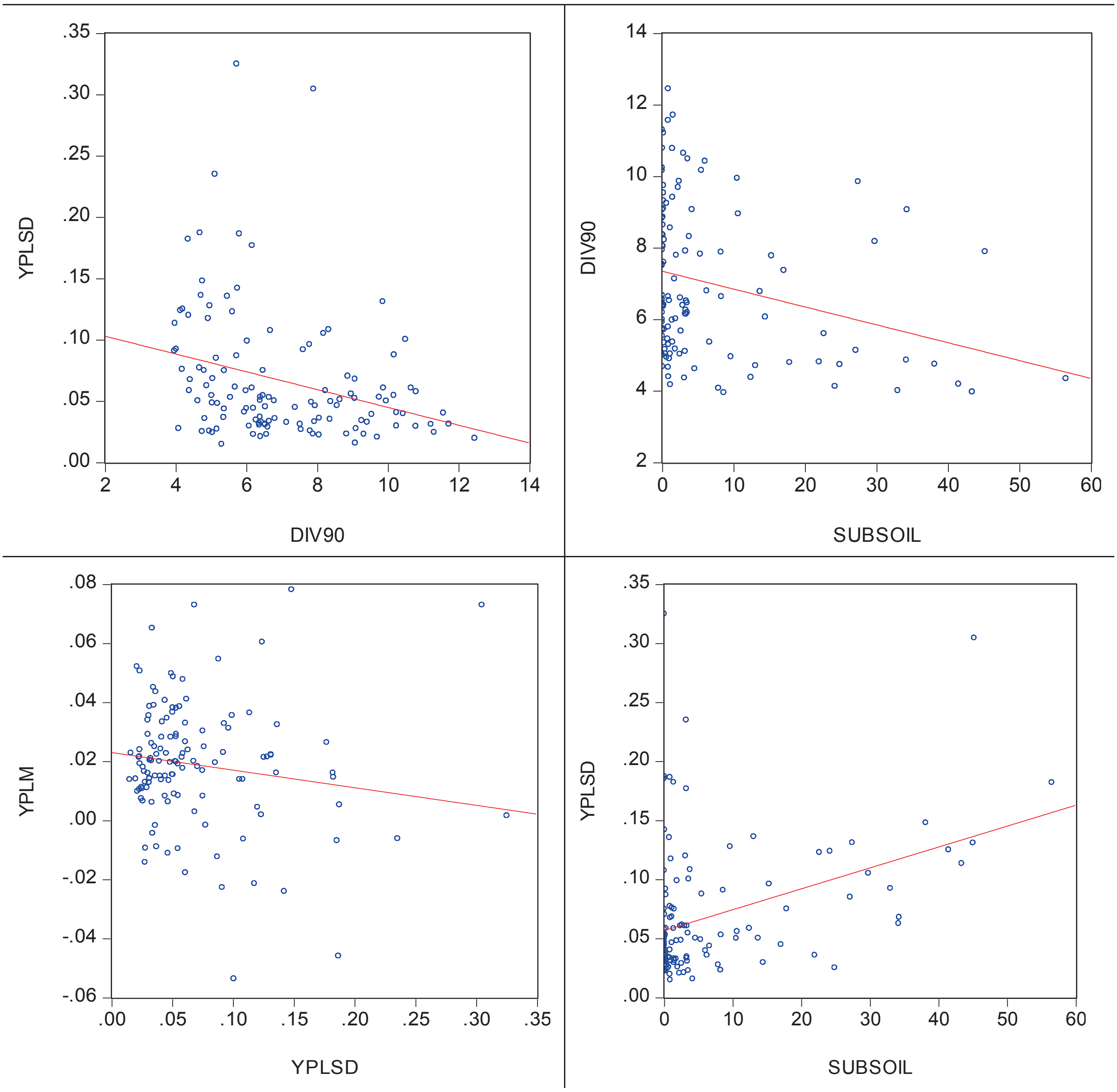
Plotting the diversification index against the level of income indicates that countries start off from a less diversified state of the economy, and they diversify as they move along their development path. Specialisation only takes place at a later stage when countries achieve a very high level of per capita income, but this could also be dependent on geographical and structural characteristics of countries. This is overall consistent with the findings of Imbs and Wacziarg (2003), Papageorgiou and Spatafora (2012) and Cadot et al. (2011). Imbs and Wacziarg (2003) explained that "countries diversify over most of their development path" and specialisation "occurs quite late in the development process and at a surprisingly robust level of income per capita." However, this paper cautions that specialisation at higher levels of income should be treated with some care, because it may well be driven by geographic (e.g. being a small and/or remote country) and structural (e.g. oil dependence) characteristics of countries.

Figure 1: *Scatterplot and estimated (nonparametric) curve between diversification and income level*



Using the same nonparametric regression method as Imbs and Wacziarg (2003), I plot the diversification index against the GDP per capita. The fitted line in Figure 1 is the estimated relationship by a nonparametric regression that fits local polynomials, known as *lowess technique* or *nearest neighbour fit.* The method is basically a locally weighted scatterplot smoothing which only use the subset of observations that lie in a neighbourhood of the point to fit the regression model. Figure 1 indicates that there is an inverse U-shaped relationship between diversification and level of income. As countries develop, they diversify their economies, and they only start specialising when they reach a significantly high level of income per capita. However, specialisation at higher levels of income may well depend on geographic and structural characteristics of countries. As seen in Figure 1, countries such as the United States, Great Britain and Japan remain the most diversified economies while being at the very highest levels of income. These countries have not departed for specialisation. On the other hand, a number of Gulf States such as the United Arab Emirates and Qatar, small countries such as Luxemburg, and remote countries such as Iceland have specialised as they reached high levels of income per capita. While these countries are not the only ones that have drawn downward the curve on the right – Russia, Canada, Norway, Denmark and Switzerland also appear towards the downward sweep of the curve – it would be difficult to explain specialisation as a general rule by disregarding the geographic and structural characteristics of countries.

Figure 2: *Scatterplots and estimated (linear) relationships between volatility, diversification, resource endowment and average growth*



DIV90: diversification index in 1990; YPLSD: standard deviation of growth in GDP per capita over 1990-2011 (measure of growth volatility); YPLM: average growth rate of GDP per capita over 1990-2011; SUBSOIL: average rents from subsoil resources in % of GDP over 1990-2011

Figure 2 plots the estimated relationships between different variables of interest using linear regression method. Reading the figures clockwise, the top-left figure indicates that less diversified economies experience higher growth volatility. However, countries that are more diversified are less prone to volatility. The top-right figure shows that resource abundant countries are usually less diversified, and these countries experience higher volatility compared to resource poor economies, as shown in the bottom right figure. Finally, countries that experience higher macroeconomic volatility tend to have lower economic growth compared to more stable economies (bottom left figure). All these data relationships are in accord with the findings of other empirical studies. The core question of this paper thus becomes more clarified: does diversification help reduce the adverse impact of resource abundance on growth by decreasing the volatility effects of natural resources?

4. Model and data

The econometric literature that studies the impact of volatility on growth, using cross-sectional data, traditionally uses the "standard deviation of growth" as an exogenous variable in a model in which the "mean growth" is regressed over a number of control variables. The biggest limit of such approach is that it fails to capture the time series effects of the process. It estimates the impact of the "average" level of volatility on the "average" level of growth for a country and does not capture the different impacts that shocks with different magnitudes could have on growth in different points in time.

A better method would be to employ models that can capture the time series effects of volatility on growth. Ramey and Ramey (1995) applied an ARCH-in-mean (ARCH-M) model to a panel data structure to study the impact of volatility on growth. The model was originally proposed by Engle et al. (1987) for time-series analysis of volatility in financial economics, which allows the conditional variance to be a determinant of the mean equation. Ramey and Ramey (1995) extended the model to pooled cross section data, with exogenous variables being constant over time but varying for countries in the cross section. Ramey and Ramey's (RR) model is, in fact, a special case of the original ARCH-M model where the autoregressive coefficients in the variance equation are set to zero.

Several studies have so far used RR's model to study the relationship between volatility and growth; including Imbs (2007), Edwards and Yang (2009), van der Ploeg and Poelhekke (2009), and Posch and Wälde (2011). Van der Ploeg and Poelhekke (2009) and Posch and Wälde (2011) also included exogenous control variables in the variance equation. Launov et al. (2012) have explained that in order for the model to produce unbiased and consistent estimates, relevant explanatory variables need to be included in the conditional variance equation.

The advantage of working with an ARCH-in-mean model are that it uses the standard deviation of "residuals" in the model as a measure of volatility. It thus allows volatility to be determined by a number of economic variables (i.e. conditional heteroskedasticity), and not to be merely the cyclical component of the growth series. Further, it captures the time series effects of the process, such that the impact of shocks with different magnitudes on growth is captured in the model. Hence, in-line with Ramey and Ramey (1995) and van der Ploeg and Poelhekke (2009), I specify the following econometric model for growth in per capita income:

$$\Delta \log(y_{it}) = X_{i\cdot}\theta + \lambda\sigma_{i\cdot} + \varepsilon_{it} \qquad where \quad \varepsilon_{it} \sim N(0, \sigma_{i\cdot}^2) \tag{10}$$

$$\log(\sigma_{i\cdot}^2) = \alpha + Z_{i\cdot}\beta \tag{11}$$

where y_{it} is GDP per capita in country i at period t, $X_{i\cdot}$ and $Z_{i\cdot}$ are vectors of exogenous variables for country i which are either for the initial year 1990 or the average over 1990-2011, $\sigma_{i\cdot}$ is the standard deviation of the residuals ε_{it} which is constant over time but different across countries, α is a constant, θ and β are vectors of coefficients, and λ is coefficient of volatility estimated simultaneously with θ. The dependent variable expressed in logarithmic first difference defines the *growth* in GDP per capita.

The model is, in fact, a system of simultaneous equations. Equation 10 is called the *mean equation*, in which volatility – defined as the standard deviation $\sigma_{i\cdot}$ of residuals – is an explanatory variable for growth in GDP per capita. $\sigma_{i\cdot}$ is in turn defined in the *variance equation* (Eq. 11). The variance $\sigma_{i\cdot}^2$ of the residuals ε_{it} is explained by a set of *relevant* exogenous variables, gathered in vector $Z_{i\cdot}$. These control variables are also part of the exogenous variables in the mean equation. Therefore, $Z_{i\cdot}$ can be a subset of $X_{i\cdot}$

The system of equations is estimated simultaneously using the maximum log-likelihood technique. The parameters θ, β, λ and α are estimated by maximizing the following log-likelihood function:

$$l(\theta,\lambda,\beta,\alpha) = -\frac{NT}{2}\log(2\pi) - \frac{T}{2}\sum_{i=1}^{N}\log(\sigma_i^2) - \sum_{i=1}^{N}\frac{1}{2\sigma_i^2}\sum_{t=1}^{T}(\Delta\log(y_{it}) - X_{i\cdot}\theta - \lambda\sigma_{i\cdot})^2 \tag{12}$$

$$= \sum_{i=1}^{N}\sum_{t=1}^{T}\left\{\log\phi\left(\frac{\Delta\log(y_{it}) - X_{i\cdot}\theta - \lambda\sigma_{i\cdot}}{\sigma_i}\right) - \frac{1}{2}\log(\sigma_i^2)\right\} \tag{13}$$

where the covariance matrix is defined as $\sigma_i^2 = \exp(\alpha + Z_{i\cdot}\beta)$, and $\phi(\cdot)$ is the standard normal density function.

To estimate the model by maximum log-likelihood technique, the initial values of parameters need to be supplied. Econometric software packages use iterative algorithm to find the maximum likelihood estimates, and, therefore, the choice of starting values is important. One approach is to first estimate the mean equation using Ordinary Least Squares (OLS), and then use the estimated coefficients as initial parameter values in the log-likelihood function. As for the variance parameter λ, the variance of the estimated OLS residuals can be chosen as the initial value.

Exogenous variables included in the mean and variance equations (Eq. 10 and 11) are those that are theoretically established to be important determinants for cross-country growth differences and for growth volatility. The initial level of GDP per capita (YPL90) is added in the mean equation to test for convergence between poor and rich countries; countries at lower levels of income per capita tend to grow faster than advanced economies. Thus a negative sign for GDP per capita in 1990 should validate existence of convergence. Population growth, according to the augmented Solow growth model, negatively affects the growth, as also found by Mankiw, Romer and Weil (1992) and other empirical studies. Hence, the average growth of population over 1990-2011 (GN) is included in the mean equation. Average share of investment in GDP (INV) is used as an indicator for changes in capital stock. Initial level of human capital (HC90) is added in the mean equation as it is argued to be an important determinant of growth, as suggested by the endogenous growth theory.

Trade openness and financial development are controlled in both the mean and variance equations. More trade openness is expected to increase growth, as it allows for more productivity gains through lower input costs, transfer of technology and access to larger global markets. On the other hand, trade openness also exposes countries to terms-of-trade shocks and engender growth volatility. Hence, average trade-to-GDP ratio over 1990-2011 (TRADE) is added in both the growth and variance equations. Further, while financial deepening is believed to facilitate the growth process, as it provides funds for investment, it may also increase vulnerabilities in the economy as Aghion, Banerjee and Piketty (1999) and Aghion, Bacchetta and Banerjee (2004) have argued. Domestic credit to private sector is used as a proxy for financial development (FIN) and is included in both equations.

There is a growing literature on how institutions and ethnic fractionalisation affect growth. Institutional quality (INS) is argued to directly impact growth as it provides the enabling environment for efficient resource allocation. Ethnic fractionalisation (ETHFRAC) is argued to adversely affect growth and to increase fluctuations in the economy, because in fractionalized societies economic agents engage in redistributive struggle and larger share of resources is invested in non-taxable inefficient activities (Rodrik, 1999; and Tornell and Lane, 1999). In fractionalized societies, the cost of exogenous shocks are hence magnified by the distributional conflicts that are triggered. Ethnic fractionalisation is thus controlled in both the growth and volatility equations.

Geographic predispositions are important determinants for growth and volatility. Landlocked countries, as they have greater coastal distance, tend to have more concentrated exports and thus experience larger volatility. Landlockedness increases both the input costs and transportation costs for exports and can thus result in lower growth outcome for the country. The dummy variable for landlockedness (DLL) is hence included in both the mean and variance equations. Further, endowment in natural resources could have potential implications for growth and volatility. While the exact nature of the natural resources impact on growth is an area of debate, this paper attempts to contribute to the economic literature and further clarify the implications of natural resources for growth and volatility. The average rents of subsoil resources in percent of GDP (SUBSOIL) is thus included in both equations. Finally, the initial level of diversification (DIV90) is controlled in the model to assess whether countries that started off more diversified experienced lower volatility. The exact definition of variables and their respective data sources are presented in Appendix A.

A sample of 123 countries has been selected for the empirical test. The list of these countries is provided in Appendix B along with the diversification index computed in this paper. The sample covers the period of 1990 to 2011, resulting in a panel of 2583 observations. Regressions are based on the period 1991-2011 after adjustment for lagged data.

5. Estimation results

The estimation results of the model have been documented in tables 1 and 2. In all regressions regardless of the set of control variables included, the volatility coefficient σ_i is statistically significant. In regressions 1 to 5, in which diversification is not controlled for, the volatility coefficient is negative. This indicates that volatility exerts adverse effect on economic growth. Countries that experience higher volatility are likely to achieve lower growth.

According to the estimation results, countries that start off with lower levels of income per capita tend to grow faster than richer economies – hence the negative sign

Table 1: Estimation results (regressions 1-7)

Dependent variable: DLOG(YPL)
Method: Maximum log likelihood (Marquardt)
Observations: 2583 (123 cross sections, and 21 periods: 1991-2011)

	1	2	3	4	5	6	7 (core)
Mean equation:							
constant	0.1168***	0.1025***	0.1258***	0.1525***	0.1177***	0.1350***	-0.0023
	(0.0218)	(0.0238)	(0.0276)	(0.0257)	(0.0248)	(0.0259)	(0.0648)
log(ypl90)	-0.0086***	-0.0101***	-0.0133***	-0.0132***	-0.0125***	-0.0129***	-0.0781***
	(0.0023)	(0.0025)	(0.0032)	(0.0031)	(0.0030)	(0.0031)	(0.0025)
gn	-0.0036**	-0.0034**	-0.0035**	-0.0023	-0.0036***	-0.0033**	-0.0085***
	(0.0015)	(0.0015)	(0.0015)	(0.0016)	(0.0014)	(0.0015)	(0.0011)
inv	0.0007***	0.0007***	0.0007***	0.0007***	0.0010***	0.0008***	0.0038***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
hc90	0.0016**	0.0016**	0.0015*	0.0016**	0.0012	0.0010	-0.0034***
	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0007)
trade	0.0002***	0.0001**	0.0001*	0.0002***	0.0001**	0.0002***	0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
fin	-0.0002***	0.0001	0.0001	-0.0002***	-0.0001***	-0.0002***	0.0005***
	(0.0001)	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
fin^2		-0.0001**	-0.0001*				
		(0.0001)	(0.0001)				
subsoil	0.0023***	0.0018***	0.0018***	0.0021***	0.0016***	0.0024***	0.0019***
	(0.0003)	(0.0004)	(0.0004)	(0.0003)	(0.0003)	(0.0003)	(0.0003)
inst			0.0064***	0.0063**	0.0092***	0.0068**	0.0492***
			(0.0032)	(0.0032)	(0.0031)	(0.0032)	(0.0028)
ethfrac				-0.0117**			
				(0.0050)			
dll				-0.0100**			
				(0.0046)			
div90						**0.0019***	
						(0.0007)	
vol (σ_i)	**-0.8869*****	**-0.5446***	**-0.4558***	**-0.7149*****	**-0.3660*****	**-0.7991*****	**3.6584*****
	(0.1446)	**(0.2383)**	**(0.2437)**	**(0.1724)**	**(0.1129)**	**(0.1637)**	**(0.5490)**
trade	0.0107***	0.0098***	0.0099***	0.0104***	0.0084***	0.0103***	0.0060***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0008)	(0.0002)	(0.0003)
fin	-0.0165***	-0.0166***	-0.0165***	-0.0164***	-0.0134***	-0.0165***	-0.0074***
	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0005)	(0.0004)	(0.0004)
subsoil	0.0294***	0.0295***	0.0292***	0.0294***	0.0379***	0.0296***	0.0049***
	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0009)	(0.0008)	(0.0008)
ethfrac					-0.1637***		
					(0.0484)		
dll					0.9294***		
					(0.0352)		
div90							**0.0501*****
							(0.0062)
constant	-5.5800***	-5.5091***	-5.5173***	-5.5692***	-5.7533***	-5.5548***	-4.8544***
	(0.0239)	(0.0247)	(0.0246)	(0.0246)	(0.0440)	(0.0245)	(0.0579)
Log likelihood	3200.18	3203.42	3205.61	3208.36	3275.87	3207.89	-2304.59
Avg. Log likelihood	1.2389	1.2402	1.2410	1.2421	1.2682	1.2419	-0.8922

*Values in parentheses are standard errors; *** for p<0.01, ** for p<0.05, and * for p<0.1*

for YPL90. This indicates that, ceteris paribus, all countries should eventually converge in terms of income per capita. The model results also indicate that population growth has negative impact on economic growth. This is aligned with the augmented Solow growth theory and findings of other empirical studies. Further, capital accumulation or investment is a strong determinant of growth. The variable INV remains positive and statistically significant with 99 percent confidence level in all regressions, regardless of the set of exogenous variables accounted for in the model. Human capital (HC90) is also positive in most regressions, but is not statistically significant and/or does not remain stable.

The model provides interesting results for trade openness and financial development. The coefficient for trade is statistically significant and positive as long as diversification is not controlled for. When diversification is controlled in the model, the trade coefficient either becomes statistically insignificant or turns negative. This indicates that trade openness favours economic growth in general, but its impact on growth could be ambiguous in countries that are not well diversified. On the other hand, the estimated coefficient for financial development is negative in regression 1. This is not surprising. A number of empirical studies have found that the relation between financial development and growth is not monotonic. Financial depth increases growth up to a certain level, after which the impact of more financial deepening on growth becomes negative. Arcand et al. (2012), Cecchetti and Kharroubi (2012) and Samargandi et al. (2015) have found that there is an inverted U-shaped relationship between financial development and growth; excessive financial development becomes a drag on economic growth after certain level. To test this quadratic relationship, regressions 2 and 3 include the square of the variable financial development. The results show that after accounting for this quadratic relationship, the estimated coefficient for FIN becomes positive – though it is not statistically significant – and the coefficient for FIN^2 has a negative sign.

Trade and financial development are strong determinants of volatility too, as observed from the estimated coefficients in the variance equation. Higher trade and more openness increase volatility, as confirmed by Razin et al. (2003), Loayza and Raddatz, (2006), di Giovanni and Levchenko (2006) and Malik and Temple (2009). Financial development, on the other hand, reduces macroeconomic volatility as it provides insurance mechanisms against exogenous shocks.

Regression 4 indicates that there is a positive relation between growth and institutional quality, while ethnic fractionalisation (ETHFRAC) adversely affects growth as explained by Rodrik (1999) and Tornell and Lane (1999). Geographic location also affects growth: lack of coastal access or landlockedness results in lower growth outcomes. Landlocked countries not only experience lower growth but also increased volatility, as also found by Malik and Temple (2009). The dummy variable DLL is statistically significant in the variance equation to explain growth volatility.

The estimation results provide valuable insights around the resource curse theory. The estimation results suggest that resource abundance *per se* is not a drag on economic growth; it adversely impacts growth through the *volatility* and *low diversification* channels. As the model controls for volatility, the results indicate that resource-rich countries tend to have *higher* economic growth compared to resource-scarce countries with comparable levels of growth volatility. The coefficient for resource abundance is positive and statistically significant – as long as resource abundance is introduced as one of the determinants of volatility in the variance equation. However, if resource abundance is not controlled for in the variance equation (see regression 10), the coefficient for SUBSOIL turns negative even despite having diversification as one of the control variables. This indicates that the adverse effects of natural resources on growth take place through the volatility channel. When resource abundance is not included as one of the explanatory variables for volatility, its coefficient in the growth mean equation is negative. This also explains the reason why some studies in the resource curse literature have found evidence for a negative growth impact of natural resources; they have missed to control for the volatility triggering effects of natural resources.

However, the indirect effects of natural resources on growth through the volatility channel may hamper the positive direct effects of resource endowment on growth, for countries with the same level of diversification. Looking at the results for regression 2, the estimated coefficient for SUBSOIL in the variance equation is 0.0295, while the estimated volatility coefficient is -0.5446. The indirect effect of natural resources on growth would therefore be 0.0295* -0.5446 = -0.0161. This is much greater than the positive direct effect of natural resources as captured by the estimated coefficient for SUBSOIL in the mean equation (i.e., 0.0018). The overall "net" effects of natural resources on growth will only be positive if diversification is controlled for (see regression 7).

The most important result of the model is that diversification offsets the adverse impact of resource abundance and trade openness on growth which takes place through the volatility channel. Both trade openness and natural resources increase growth volatility, as demonstrated by their positive coefficients in the variance equation. Volatility, in its turn, hampers growth and it therefore has a negative sign in

Table 2: Estimation results (regression 8-13)

Dependent variable: DLOG(YPL)
Method: Maximum log likelihood (Marquardt)
Observations: 2583 (123 cross sections, and 21 periods: 1991-2011)

	8	9	10	11	12	13
Mean equation:						
constant	0.1447***	0.0079	0.0395	0.1198***	0.1397***	0.1405***
	(0.0260)	(0.0446)	(0.0271)	(0.0122)	(0.0261)	(0.0268)
log(ypl90)	-0.0137***	-0.0475***	-0.0391***	-0.0643***	-0.0125***	-0.0130***
	(0.0031)	(0.0026)	(0.0024)	(0.0013)	(0.0030)	(0.0031)
gn	-0.0018	-0.0023	-0.0018	-0.0023***	-0.0027*	-0.0031**
	(0.0016)	(0.0015)	(0.0012)	(0.0006)	(0.0015)	(0.0015)
inv	0.0007***	0.0021***	0.0040***	0.0025***	0.0008***	0.0008***
	(0.0002)	(0.0002)	(0.0002)	(0.0001)	(0.0002)	(0.0002)
hc90	0.0012	-0.0047***	-0.0049***	-0.0001	0.0014*	0.0009
	(0.0008)	(0.0006)	(0.0005)	(0.0003)	(0.0008)	(0.0008)
trade	0.0002***	-0.0007***	-0.0002**	-0.0008***	0.0002***	0.0002***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
fin	-0.0002***	0.0002	-0.0001	0.0007***	-0.0002***	-0.0002***
	(0.0001)	(0.1798)	(0.0001)	(0.0007)	(0.0001)	(0.0001)
subsoil	0.0023***	0.0004	-0.0006***	0.0001	0.0023***	0.0022***
	(0.0003)	(0.0006)	(0.0001)	(0.0003)	(0.0004)	(0.0003)
inst	0.0062**	0.0414***	0.0153***	0.0339***	0.0072**	0.0083***
	(0.0032)	(0.0027)	(0.0026)	(0.0013)	(0.0032)	(0.0031)
ethfrac	-0.0123**	-0.0082**			-0.0150***	
	(0.0051)	(0.0040)			(0.0053)	
dll	-0.0091**	-0.1026***	-0.1212***		0.0176	
	(0.0046)	(0.0043)	(0.0045)		(0.0121)	
div90	**0.0019*** **					**0.0005**
	(0.0007)					**(0.0007)**
vol (σ_i)	**-0.7567*** **	**3.5098*** **	**2.6981*** **	**4.3408*** **	**-0.6913*** **	**-0.6946*** **
	(0.1759)	**(0.4319)**	**(0.2412)**	**(0.1307)**	**(0.2294)**	**(0.1607)**
trade	0.0103***	0.0087***	0.0088***	0.0062***	0.0089***	0.0098***
	(0.0002)	(0.0003)	(0.0002)	(0.0001)	(0.0003)	(0.0002)
fin	-0.0164***	-0.0081***	-0.0103***	-0.0133***	-0.0131***	-0.0145***
	(0.0004)	(0.0003)	(0.0003)	(0.0001)	(0.0005)	(0.0005)
subsoil	0.0295***	0.0188***		0.0459***	0.0385***	0.0299***
	(0.0008)	(0.0008)		(0.0004)	(0.0009)	(0.0008)
ethfrac					-0.1208***	
					(0.0480)	
dll					0.9395***	
					(0.0349)	
div90		**0.0118*** **	**-0.0448*** **			**-0.0763*** **
		(0.0034)	**(0.0048)**			**(0.0111)**
log(div11/ div90)				-0.7057***		
				(0.0284)		
constant	-5.5620***	-5.1053***	-4.7027***	-5.1920***	-5.8311***	-5.0825***
	(0.0250)	(0.0379)	(0.0389)	(0.0142)	(0.0436)	(0.0604)
Log likelihood	3212.60	-899.00	-535.18	-8267.4	3280.84	3215.29
Avg. Log likelihood	1.2437	-0.3480	-0.2072	-3.2007	1.2702	1.2448

*Values in parentheses are standard errors; *** for p<0.01, ** for p<0.05, and * for p<0.1*

regressions 1 to 6. However, when diversification is controlled for in the variance equation in regression 7 or in regressions 9 and 10, the volatility coefficient (σ_i) turns positive. This means that if countries start off diversified, they will enjoy the positive effects of resource abundance and trade openness on economic growth. Failure to have initially diversified, these countries will experience higher volatility which will result in lower growth in the long-run. Thus, diversification provides an optimal strategy for resource-rich countries to offset the negative impact of natural resources on growth and reap the benefits of their resource endowment.

While many studies have attempted to study the patterns and nature of diversification in different resource-rich countries and regions in the world (Hesse, 2008; Diop et al., 2012; Kaplinsky et al., 2012), we still lack a clear understanding of how diversification affects growth in these countries and through which specific channels. This paper is a small contribution into better understanding these mechanisms and focuses on the volatility channel. Studies show that *successful* resource-rich countries diversify into higher value-added products in resource-based sectors, and they use resource rents to develop other industries in which they have comparative advantage. Theoretically it is argued that diversification lowers the negative impact of shocks on the economy, allows for a gradual allocation of resources to their most productive uses in the economy, and prevents the Dutch disease from affecting the manufacturing and other non-tradable sectors because there will exist other dynamic sectors in the economy which reduce concentration around the mining sector.

What the findings of this paper confirm is that diversification minimizes growth fluctuations that result from natural resources production. This could be taking place through a number of ways. First, from a portfolio theory perspective, as the economy is more diversified, opportunities for risk diversification through sectorally-diversified investment is stronger and hence output variance is minimized. Second, depending on the substitutability of inputs, diversification makes it possible for firms to substitute inputs of one sector with those of another. This is mostly the case when inputs are used to produce final goods or services. However, in cases where inputs are used to produce other sets of intermediate goods, substitutability is usually low. Overall, diversity of industries limits propagation of shocks in the economy. This is applicable to both external shocks and domestic sectoral shocks affecting the economy. Third, in concentrated economies, as there are limited number of industries operating, linkages between industries are denser and stronger, i.e. transactions between two industries are higher. Shocks to one sector transmit strongly to another, depending on the share of intermediate goods in output and on the degree of complementarity of inputs in the production process. However, in diversified economies, these linkages are more diversified; one sector receives input from several other sectors and is not entirely dependent on inputs from a single sector. Diversification thus limits propagation of shocks and reduces the impact of shocks on aggregate output volatility.

This paper also finds that not only the initial level of diversification (DIV90) determines the impact of resource abundance and trade openness on growth, but also the pace and speed of diversification is important – represented by the variable *log(div11/div90)* which measures changes in the level of diversification between 1990 and 2011. If the initial level of diversification is replaced with the change in diversification over 1990-2011 in regression 11, we obtain the same results. This means that even if countries start off less diversified, they can still enjoy the positive impact of trade openness and resource abundance by pursuing a diversification and industrialisation strategy. The speed or pace with which countries diversify is an important determinant, but estimating the optimal pace of diversification is a question out of the scope of this study.

The impact of diversification on volatility-growth link is statistically significant if diversification is controlled for only in the variance equation. If diversification is included both in the mean and in the variance equations, it does not alter the negative volatility-growth link (see regression 13). One reason could be that as diversification exerts positive effect on growth while generating a negative impact on volatility, the overall impact turns ambiguous in the model. One could measure the impact of diversification on the « resource abundance – volatility – growth » link only if diversification is added in the variance equation. Other variables – if controlled in the variance equation – do not alter the negative sign of the volatility parameter (see regression 11).

The effects of diversification on the « resource abundance – volatility – growth » link would only be fully captured if diversification of the production structure of the economy is taken into account. Exports diversification does not offset the negative impact of volatility on growth. To show this, I test the model using the exports concentration measure (Theil index) calculated by Cadot et al. (2011) on 4,991 product lines for the period 1988-2006. The estimation results are shown in Table 3. Since an increase in Theil index indicates less diversification (higher concentration), the coefficient for theil is negative in the mean equation – which indicates a positive relation between diversification and growth. On the other hand, the theil coefficient in the variance equation shows that diversification reduces volatility. However, in none of the specifications does the theil index render the volatility parameter negative or at least statistically insignificant. Hence, while export diversification has a positive impact on growth, it does not impede the negative impact of natural resources on growth through the volatility channel. Diversification should occur on the production structure as a whole so that it could diversify idiosyncratic risks in the country.

Table 3: Estimation results (regression 14-16)

Dependent variable: DLOG(YPL)
Method: Maximum log likelihood (Marquardt)
Observations: 2583 (123 cross sections, and 21 periods: 1991-2011)

	14	15	16
Mean equation:			
constant	0.1753***	0.1583***	0.1763***
	(0.0275)	(0.0249)	(0.0261)
log(ypl90)	-0.0165***	-0.0151***	-0.0177***
	(0.0032)	(0.0029)	(0.0030)
gn	0.0005	-0.0019	0.0008
	(0.0019)	(0.0015)	(0.0019)
inv	0.0007***	0.0008***	0.0008***
	(0.0002)	(0.0002)	(0.0002)
hc90	0.0024***	0.0016**	0.0022***
	(0.0008)	(0.0008)	(0.0008)
trade	0.0001**	0.0002***	0.0001**
	(0.0001)	(0.0001)	(0.0001)
fin	-0.0001***	-0.0002***	-0.0001***
	(0.0001)	(0.0001)	(0.0001)
subsoil	0.0021***	0.0021***	0.0019***
	(0.0003)	(0.0003)	(0.0003)
inst	0.0083***	0.0083***	0.0094***
	(0.0032)	(0.0029)	(0.0029)
theil	**-0.0063*** **		**-0.0051*** **
	(0.0015)		**(0.0020)**
vol (σ_i)	**-0.4531** **	**-0.7330*** **	**-0.3980** **
	(0.1949)	**(0.1243)**	**(0.1708)**
trade	0.0103***	0.0116***	0.0110***
	(0.0001)	(0.0003)	(0.0003)
fin	-0.0164***	-0.0133***	-0.0128***
	(0.0001)	(0.0005)	(0.0005)
subsoil	0.0295**	0.0201***	0.0185***
	(0.0001)	(0.0011)	(0.0012)
theil		**0.1671*** **	**0.1909*** **
		(0.0124)	**(0.0126)**
constant	-5.5627***	-6.5439***	-6.6217***
	(0.0253)	(0.0898)	(0.0909)
Log likelihood	3212.47	3237.20	3242.31
Avg. Log likelihood	1.2437	1.2533	1.2553

Values in parentheses are standard errors;
**** for p<0.01, ** for p<0.05, and * for p<0.1*

The estimation results of the model are not sensitive to the use of alternate definitions for key variables, such as the variable for resource endowment. In precedent regressions, the average rents of subsoil resources (including minerals, oil and gas) in percent of GDP were used as the variable for resource abundance. To assess the robustness of the model, I use "the average share of mining in total gross output" (denoted MINSH) as the alternate definition. The results of robustness tests are presented in Appendix C. Considering regression 7 as the core regression, the estimation results for regression 20 show that the broad results of the model do not change if an alternate measure of resource abundance is used; natural resources continue to have a positive effect on growth and, having controlled for diversification in the variance equation, the impact of volatility on growth turns positive. On the other hand, in-line with other studies that suggested that not all types of resources are bad for growth (Isham et al, 2002; Sala-i-Martin and Subramanian, 2003; Ross, 2003), regression 21 finds that oil exerts negative impact on economic growth. However, diversification plays the same role in oil-rich countries; it offsets the volatility triggering effects of natural resources on growth. Further to the robustness tests against sensitivity to alternate definitions, regressions 9 and 17-20 also indicate that the broad results of the model remain unchanged when variables are excluded from or added into the model. Hence, the model is fairly robust with respect to using different compositions of explanatory variables.

6. Conclusion

This paper looked at the « natural resources – volatility – growth » link by evaluating the role of economic diversification. It attempted to address a question that has remained unexplored in the literature: does diversification help offset the adverse effects of natural resources on economic growth by reducing volatility? Similar to Ramey and Ramey (1995), this paper employed an Arch-In-Mean model applied to panel structure to study the impact of volatility on growth, while controlling for diversification in the model. The study is innovative in two aspects. First, it focuses on 'productive diversification' – diversification of the *production* structure of the economy, – instead of 'export diversification' which is commonly used in the literature. Second, it constructs an indicator of diversification that is computed on input-output data. Unlike other studies that employ export concentration measures, this paper also incorporates the density of inter-industry linkages in the diversification indicator.

The study found that natural resources exert negative impact on growth through the volatility channel. While the direct effects of resource abundance on growth are positive, the adverse indirect effects of natural resources through volatility could be larger. However, these results should not be interpreted as if natural resources *per se* are detrimental to growth. The results show that resource-intensive countries tend to have higher economic growth compared to resource-scarce countries for the same level of output volatility. The reason why other studies have found negative relation between resource abundance and economic growth is likely that they have missed to control for the volatility triggering effects of natural resources.

The results show that diversification offsets the adverse impact of resource abundance and trade openness on growth, which take place through the volatility channel. Countries that start off diversified are likely to enjoy the positive effects of their resource endowment. Further, it's not only the initial level of diversification which matters but also the process of diversification throughout the development process. Resource-rich countries that neither start with a diversified production base nor diversify their economies as they develop are more likely to experience lower growth and to suffer from the "resource curse." Nonetheless, it is *productive* diversification that is important. Export diversification, by its own, cannot be helpful, unless the country diversifies its production structure as a whole.

The policy implication of this study is that diversification provides an optimal strategy for resource-intensive economies to offset the negative impact of natural resources on growth and to avoid falling into the resource curse. Diversification helps countries reduce their exposure to external shocks, diversify idiosyncratic risks in the economy, and finally offset the volatility triggering effects of natural resources on growth. For resource-intensive economies, an optimal strategy would be to diversify into processed natural resources, a strategy known as "resource-based industrialisation." It would require developing new industries for processing of natural resources, and diversifying away from commodity production towards high value-added goods in resource-based sectors. Resource rents should be used, therefore, to support the diversification process; both to support private investments in downstream processing activities and upstream support industries, and to fund large-scale, simultaneous public investments through vertical and horizontal interventions to turn natural resources into productive assets.

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Appendix A: Data definitions and sources

Variable	Definition	Source of data
GDP per capita (YPL)	Real GDP per capita in PPPs, in constant 2005 prices	PWT 7.1 and PWT 8.0 for GDP, and WDI for population numbers
Population growth (GN)	Average population growth between 1990 and 2011	World Development Indicators (WDI)
Investment (INV)	Share of Gross Capital Formation in GDP, at current PPPs, average 1990-2011	PWT 7.1 and PWT 8.0
Human capital (HC90)	Average years of total schooling in 1990	Barro and Lee (2013)
Trade (TRADE)	Total exports and imports, in percent of GDP, average 1990-2011	WDI
Financial development (FIN)	Domestic credit to private sector, in percent of GDP, average 1990-2011	WDI
Institutions (INST)	Average of World Governance Indicators, average 1996-2011	World Governance Indicators
Ethnic fractionalisation (ETHFRAC)	An index that measures the probability that two randomly selected individuals from a population belong to different ethnic groups.	Alesina et al. (2003)
Landlockedness (DLL)	Dummy variable that takes 1 if a country is landlocked	UNCTAD; list of informally accepted landlocked countries by UN member states
Resource abundance (SUBSOIL)	Rents of minerals, oil and natural gas in percent of GDP, average 1990-2011	Wealth of Nations dataset and WDI
Resource abundance (MINSH)	Share of mining sector output in gross total output, average 1990-2011	This paper – using MRIO database (Lenzen et al., 2012, 2013)

Diversification (DIV90)	Indicator of economic diversification in 1990	This paper – using MRIO database (Lenzen et al., 2012, 2013)
Exports concentration index (Theil)	Theil index calculated on export product lines of each country; average for 1990-2006	Cadot et al. (2011)

Appendix B: Diversification index dataset for 1990

		ENT	DN	φ	DIV
1	Albania	4.4248	1.5927	1.0875	6.1568
2	Algeria	4.7417	1.4166	0.0000	4.7417
3	Argentina	7.7465	4.2491	0.5704	10.1704
4	Armenia	4.2167	1.5446	0.8017	5.4551
5	Australia	7.9383	4.1253	0.2750	9.0726
6	Austria	6.4002	2.6628	1.0964	9.3198
7	Bahrain	4.4695	1.4245	0.4724	5.1425
8	Bangladesh	4.3017	1.7002	1.3522	6.6007
9	Belgium	6.1269	3.5449	0.7619	8.8276
10	Benin	4.2775	1.5638	0.4285	4.9475
11	Bolivia	5.7462	2.7937	0.1167	6.0721
12	Botswana	4.4771	1.4816	1.0399	6.0178
13	Brazil	6.2912	3.8404	1.1343	10.6474
14	Bulgaria	3.7211	2.2218	0.2050	4.1765
15	Burundi	4.2827	1.7336	0.8300	5.7215
16	Cambodia	4.1368	1.6910	1.3280	6.3824
17	Cameroon	4.0783	1.7667	0.0003	4.0787
18	Canada	5.7721	1.5437	0.4864	6.5230
19	Central African Republic	4.2639	1.6832	0.4427	5.0091
20	Chile	6.5602	2.8292	0.8462	8.9542
21	China	6.1521	2.1235	0.8327	7.9203
22	Columbia	5.9737	3.1622	0.2612	6.7997
23	Congo	4.3426	1.5657	0.0011	4.3444
24	Costa Rica	4.1949	1.7640	1.2259	6.3575
25	Cote d'Ivoire	4.1919	1.7237	1.1358	6.1497
26	Croatia	4.1320	1.7723	0.6987	5.3703
27	Cyprus	4.4948	1.4914	1.2675	6.3852
28	Czech Republic	6.0184	3.0791	0.8516	8.6405
29	Denmark	6.7816	1.6761	0.2108	7.1350
30	Dominican Republic	4.3249	1.6320	1.3530	6.5330
31	DR Congo	3.9307	1.9278	0.0139	3.9575
32	Ecuador	6.9617	0.4647	0.8888	7.3748
33	Egypt	4.2019	1.7340	0.1037	4.3818
34	El Salvador	4.5762	1.4257	1.3963	6.5668
35	Estonia	6.0430	2.7932	0.6224	7.7815
36	Fiji	4.3495	1.5912	1.4395	6.6400
37	Finland	5.6277	3.6577	0.9391	9.0627
38	France	5.8184	3.2178	0.5358	7.5426
39	Gabon	4.1964	1.7094	0.0000	4.1964
40	Germany	6.2724	1.6327	1.0894	8.0510
41	Ghana	4.3193	1.5668	0.4534	5.0296
42	Greece	6.6959	2.7600	0.6036	8.3618
43	Guatemala	4.0684	1.7194	0.7144	5.2967

44	Guyana	3.9946	1.8854	0.7284	5.3680
45	Honduras	4.0759	1.8546	0.5167	5.0342
46	Hungary	5.1064	5.8637	1.1019	11.5674
47	Iceland	4.1354	1.7737	1.0512	5.9999
48	India	7.0897	3.2611	0.7984	9.6935
49	Indonesia	6.3199	1.7055	0.1865	6.6380
50	Iran	8.7284	2.2765	0.1493	9.0682
51	Ireland	6.9491	2.4699	1.1340	9.7499
52	Israel	7.7197	3.2538	1.0751	11.2178
53	Italy	5.6744	3.7132	0.9218	9.0973
54	Jamaica	4.1170	1.7488	1.3037	6.3970
55	Japan	8.2580	2.7318	1.1142	11.3018
56	Jordan	4.1980	1.6805	0.1215	4.4022
57	Kazakhstan	8.2247	1.5857	1.0267	9.8528
58	Kenya	7.3831	2.5303	0.2206	7.9414
59	Kuwait	6.6440	1.4425	0.8651	7.8920
60	Kyrgyzstan	7.8392	2.1131	1.2545	10.4902
61	Laos	4.2382	1.5405	1.3168	6.2668
62	Latvia	6.3140	2.7410	0.1310	6.6732
63	Lesotho	4.6116	1.3740	0.6789	5.5444
64	Liberia	4.6129	1.4651	0.3361	5.1054
65	Lithuania	6.4166	2.2210	0.5338	7.6021
66	Luxembourg	5.4955	1.3812	0.7507	6.5323
67	Malawi	4.1291	1.7917	1.3057	6.4684
68	Malaysia	7.8432	4.1226	0.5102	9.9466
69	Mali	4.2821	1.6640	1.3109	6.4634
70	Mauritania	4.5663	1.4469	0.1614	4.7998
71	Mauritius	7.2982	2.3034	1.2448	10.1654
72	Mexico	7.8374	2.3910	1.0830	10.4269
73	Moldova	5.1589	1.0850	0.5397	5.7445
74	Mongolia	3.8940	2.0508	0.3989	4.7120
75	Morocco	4.1437	1.7988	0.5001	5.0432
76	Mozambique	4.4470	1.4644	0.8406	5.6779
77	Namibia	4.3928	1.5384	1.0344	5.9841
78	Nepal	4.1571	1.7586	1.1579	6.1934
79	Netherlands	6.2154	3.3365	0.9583	9.4126
80	New Zealand	7.1098	3.8827	0.9455	10.7810
81	Nicaragua	4.2082	1.6648	1.3205	6.4065
82	Niger	4.4643	1.6120	0.5501	5.3510
83	Norway	5.9093	3.0237	0.2895	6.7846
84	Pakistan	4.0774	1.8637	1.1349	6.1925
85	Panama	4.2045	1.6730	1.2895	6.3618
86	Papua New Guinea	4.1938	1.7005	0.3971	4.8692
87	Paraguay	5.7499	3.2668	1.3743	10.2396
88	Peru	4.5717	4.7507	0.6863	7.8320
89	Philippines	6.0949	2.2813	1.0801	8.5588

90	Poland	6.3794	2.6975	1.0652	9.2528
91	Qatar	4.7514	1.3599	0.0000	4.7514
92	Russia	5.6011	1.7304	0.0002	5.6014
93	Rwanda	4.2187	1.7519	0.2652	4.6833
94	Saudi Arabia	3.9793	2.0015	0.0000	3.9793
95	Senegal	4.1694	1.8625	0.5347	5.1653
96	Sierra Leone	4.4585	1.6688	0.2705	4.9100
97	Slovakia	6.9388	2.1810	0.8822	8.8628
98	Slovenia	6.0111	2.7557	0.8592	8.3788
99	South Africa	5.0780	6.6067	0.4115	7.7964
100	South Korea	5.3371	2.3496	1.1580	8.0580
101	Spain	5.4359	4.3927	1.0944	10.2432
102	Sri Lanka	4.5617	1.4668	0.9352	5.9334
103	Swaziland	4.7129	1.3608	0.7377	5.7168
104	Sweden	6.9384	2.5853	1.0051	9.5368
105	Switzerland	5.1634	3.0736	0.7646	7.5135
106	Syria	4.1299	1.8307	0.0000	4.1299
107	Tajikistan	4.0067	1.8017	0.9915	5.7929
108	Tanzania	4.1433	1.8094	0.5707	5.1759
109	Thailand	7.4550	2.0413	1.1801	9.8640
110	Togo	4.2776	1.6689	0.2316	4.6642
111	Trinidad and Tobago	4.0123	1.8341	0.0000	4.0123
112	Tunisia	4.1542	1.8011	0.2591	4.6209
113	Turkey	7.1380	2.1919	0.4980	8.2295
114	UAE	4.8169	1.3334	0.0000	4.8169
115	Uganda	4.1721	1.6968	1.3060	6.3881
116	UK	8.0777	4.6388	0.7849	11.7187
117	Ukraine	6.2642	2.3231	0.8857	8.3217
118	United States	7.3618	5.0467	1.0075	12.4466
119	Uruguay	9.0095	1.9405	0.9179	10.7906
120	Venezuela	7.7883	2.5994	0.1507	8.1800
121	Vietnam	7.7746	1.5739	0.0686	7.8825
122	Zambia	4.1694	1.6806	0.4696	4.9585
123	Zimbabwe	4.1642	1.7428	0.1140	4.3628

Appendix C: Robustness tests (regressions 17-21)

Dependent variable: DLOG(YPL)
Method: Maximum log likelihood (Marquardt)
Observations: 2583 (123 cross sections, and 21 periods: 1991-2011)

	7 (core)	9	17	18	19	20	21
Mean equation:							
constant	-0.0023	0.0079	0.0365	-0.0880**	-0.0059	-0.4260***	0.2348***
	(0.0648)	(0.0446)	(0.0232)	(0.0387)	(0.0496)	(0.0231)	(0.0291)
log(ypl90)	-0.0781***	-0.0475***	-0.0422***	-0.0567***	-0.0786***	-0.0281***	-0.0876***
	(0.0025)	(0.0026)	(0.0023)	(0.0015)	(0.0022)	(0.0008)	(0.0017)
gn	-0.0085***	-0.0023	-0.0005	0.0004	-0.0012	0.0061***	0.0005
	(0.0011)	(0.0015)	(0.0012)	(0.0009)	(0.0010)	(0.0005)	(0.0008)
inv	0.0038***	0.0021***	0.0030***	0.0039***	0.0045***	0.0007***	0.0021***
	(0.0002)	(0.0002)	(0.0002)	(0.0001)	(0.0002)	(0.0001)	(0.0001)
hc90	-0.0034***	-0.0047***	-0.0031***	-0.0037***			-0.0001
	(0.0007)	(0.0006)	(0.0005)	(0.0004)			(0.0004)
trade	0.0001	-0.0007***	-0.0007***	0.0001	0.0001		-0.0010***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)		(0.0001)
fin	0.0005***	0.0002	0.0001**	0.0008***	0.0006***	0.0001	0.0003***
	(0.0001)	(0.1798)	(0.0308)	(0.0001)	(0.0001)	(0.9312)	(0.0001)
subsoil	0.0019***	0.0004	0.0001	0.0029***	0.0028***		
	(0.0003)	(0.0006)	(0.0004)	(0.0003)	(0.0003)		
minsh						0.0122***	
						(0.0008)	
oil							-0.0029***
							(0.0008)
inst	0.0492***	0.0414***	0.0184***		0.0418***		0.0526***
	(0.0028)	(0.0027)	(0.0023)		(0.0025)		(0.0017)
ethfrac		-0.0082**					
		(0.0040)					
dll		-0.1026***	-0.0967***				
		(0.0043)	(0.0046)				
vol (σ_i)	**3.6584*** **	**3.5098*** **	**2.8674*** **	**3.3449*** **	**3.4433*** **	**3.9972*** **	**4.8457*** **
	(0.5490)	**(0.4319)**	**(0.2030)**	**(0.3482)**	**(0.4197)**	**(0.3048)**	**(0.3407)**
trade	0.0060***	0.0087***	0.0083***	0.0063***	0.0061***		0.0070***
	(0.0003)	(0.0003)	(0.0002)	(0.0002)	(0.0003)		(0.0001)
fin	-0.0074***	-0.0081***	-0.0095***	-0.0091***	-0.0081***	-0.0038***	-0.0079***
	(0.0004)	(0.0003)	(0.0002)	(0.0003)	(0.0003)	(0.0001)	(0.0002)
subsoil	0.0049***	0.0188***	0.0232***	0.0117***	0.0073***		
	(0.0008)	(0.0008)	(0.0008)	(0.0006)	(0.0007)		
minsh						0.0640***	
						(0.0007)	
oil							0.0559***
							(0.0006)
div90	0.0501***	0.0118***	-0.0581***	0.0219***	0.0441***	-0.0591***	-0.0151***
	(0.0062)	(0.0034)	(0.0045)	(0.0035)	(0.0052)	(0.0040)	(0.0018)
constant	-4.8544***	-5.1053***	-4.6832***	-4.9900***	-4.9073***	-4.2513***	-5.1431***
	(0.0579)	(0.0379)	(0.0373)	(0.0363)	(0.0544)	(0.0245)	(0.0178)
Log likelihood	-2304.59	-899.00	-1799.89	-4322.38	-2826.49	-9497.58	-6269.83
Avg. Log likelihood	-0.8922	-0.3480	-0.6968	-1.6734	-1.0943	-3.6769	-2.4273

*Values in parentheses are standard errors; *** for p<0.01, ** for p<0.05, and * for p<0.1*

Appendix D: Matrix Algebra for Input-Output Tables

Let $\mathrm{A} = \mathrm{a_{ij}}$ denote a square matrix with n dimension, in which each element represents the input of sector i into the production of sector j per unit of output of sector j.

$Y = \begin{pmatrix} y_1 \\ \vdots \\ y_n \end{pmatrix}$ is the vector of final demand for inputs supplied by sector i

$X = \begin{pmatrix} x_1 \\ \vdots \\ x_n \end{pmatrix}$ is the vector of gross output of sector i

The system of the economy can be written as:

$$X = AX + Y \qquad (14)$$

$$\begin{pmatrix} x_1 \\ \vdots \\ x_n \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ & & \vdots & \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix} \begin{pmatrix} x_1 \\ \vdots \\ x_n \end{pmatrix} + \begin{pmatrix} y_1 \\ \vdots \\ y_n \end{pmatrix} = \begin{pmatrix} a_{11}x_1 + \cdots + a_{1n}x_n \\ \vdots \\ a_{n1}x_1 + \cdots + a_{nn}x_n \end{pmatrix} + \begin{pmatrix} y_1 \\ \vdots \\ y_n \end{pmatrix}$$

where AX is the vector of intermediate consumption for sector i. This vector simply corresponds to sectoral outputs and is derived from the matrix of intermediate consumption T:

$$T\,1 = AX = a_{ij}x_i$$

T is a matrix with n dimension, and 1 is a column vector with all elements equal to 1. The column vector is used as a summation operator for the rows in matrix T. In other words, each element $(AX)_i$ of vector AX corresponds to the sum of all rows $T_{i.}$ of the matrix T.

A is the matrix of technical coefficients or technology matrix, whose each element A_{ij} is calculated by dividing the elements T_{ij} of matrix T by the gross output x_j of sector j.

Equation (14) could then be written as:

$$(I - A)X = Y \qquad (15)$$

$$X = (I - A)^{-1}Y \qquad (16)$$

where $(I - A)$ is the Leontief matrix and $(I - A)^{-1}$ is the Leontief inverse which is denoted by L in this paper. The Leontief inverse matrix is also called the “total requirements matrix”. The elements of the Leontief inverse matrix are interpreted as the direct and indirect transactions between two sectors. For example, the direct transactions are the units of intermediate goods that are required for the production of a final product, while indirect transactions are the units of primary goods or commodities that are required to produce the intermediate product which is used in the production process of the final good.

The input-output tables are produced in the following form:

Figure 3: An illustration of Input-Output table

		Intermediate Consumption						Final Demand			
		X1	X2	Xj	…	Xn		H	G	K	X
Sectors or Industries	X1										
	X2										
	Xi										
	:										
	Xn										
Income Account	H										
	G										
	K										
	M										

X_i : output sectors, H : household, G : government, K : capital (gross fixed capital formation), X : exports, M : imports

In figure 3, the first block in the top left is the matrix of intermediate consumption, called T. The second block in the right-hand side is the vector of final demand, Y. Finally, the third block in the bottom left corresponds to the gross value-added of output sectors x_j . This block is also defined as an income account which records the wages and salaries received by households, revenues collected by the government, taxes and interests paid by the firms in sectors x_j or the operation surplus of these firms, and payments for imports. As a summary, reading through the columns of the input-output table – and across the rows – the numbers are interpreted as "expenditures", and reading through the rows the numbers are defined as "sales" in the economy.

Appendix E: EViews 8 command references

1) *Matrix operations:*

Entropy index:

Per method defined in equation 4:

```
matrix M = @epow(L, 1/@rows(L))
scalar Le = -@sum(@emult(M, @log(M))) / @rows(M)
```

Per method defined in equation 5:

```
matrix M = @epow(L, 1/@rows(L))
scalar v = 1/@rows(M)
scalar Le = -v * @trace(M * @transpose(@log(M)))
```

Density (equation 8):

```
scalar Ld = @sum(L) / @rows(L)
```

2) *Model estimation:*

Equations 10 and 11, per equation 13 (maximum log-likelihood function):

```
@logl mvl1
res = dlog(y) - c(1) - c(2) * x1 - c(3) * x2 - c(4) * x3 - c(5) * x4 - c(6) * @sqrt(var)
var = @exp( c(7) + c(8) * x3 + c(9) * x4 )
mvl1 = log(@dnorm(res/@sqrt(var))) - log(var)/2
```

How should resource-rich countries diversify? Estimating forward-linkage effects of mining on productivity growth

Abstract

Resource-rich countries willing to diversify their economies are faced with dual policy options; to either develop resource-based industries, or diversify their economies as a whole and invest into new activities that are not necessarily resource-dependent. Not only the economic theory fails to provide a consensual guidance on this issue, empirical evidence is also lacking. This paper empirically assesses which of these two patterns of diversification is associated with higher productivity growth outcomes for resource rich countries. Using panel data for 50 resource-abundant countries over 1970-2010, I find that stronger downstream linkages to mining and extractives do not lead to productivity enhancements. Broadening and diversifying the production structure as a whole offers potentials for productivity growth at higher levels of income.

1. Introduction

There is a number of ways for resource-rich countries to escape the "resource curse." One best option is to diversify (Gelb and Grasmann, 2010; Murshed and Serino, 2011; Ahmadov, 2014; Massol and Banal- Estañol, 2014; Joya, 2015). Diversification limits propagation of shocks in the economy, reduces output volatility by diversifying idiosyncratic risks, allows for a gradual allocation of resources in the economy to their most productive uses, and prevents the Dutch Disease from affecting the manufacturing and other non-tradable sectors. Murshed and Serino (2011) wrote that "it is only specialization in unprocessed natural resource products that slows down economic growth, as it impedes the emergence of more dynamic patterns of trade specialisation." Joya (2015) showed that diversification offsets the adverse effects of natural resources on growth, which take place through the volatility channel.

Countries that start off with a diversified production structure or diversify their economies as they develop tend to have better growth performances.

For resource-rich countries, diversification means moving away from commodity exports, because commodity exporters are directly exposed to global prices shocks, they often run procyclical fiscal policy with respect to their terms of trade and are likely to experience larger growth fluctuations. Diversification away from commodity exports can be achieved either by: (i) processing the minerals and extractives domestically and then exporting the intermediate and final goods, or (ii) developing new industries that are not necessarily connected to the resources sector. The former basically means pursuing a *resource-based industrialisation* strategy which consists of developing resource-based sectors at upstream and downstream activities, while the latter means pursing a *broad-based diversification* strategy and discovering new industries that would have enough low costs for the country to be profitable.

Economic theory diverges on which of the two patterns of diversification is productivity-enhancing for resource-rich countries. The debate hovers around the question whether the comparative advantage of resource-intensive economies is defined by their factor endowments or by their idiosyncratic elements. Should resource-rich countries automatically diversify into *processed* natural resources because they are easily accessible for them and it would allow them to benefit from gains in economies of scale? Or, can these countries reshape their production structure and develop *new* industries that could have higher productivity potentials?

The neoclassical trade theory suggests that factor endowments shape the comparative advantage of a country (Costinot, 2009). Leamer (1984) showed that the pattern of trade specialisation across countries is determined by the Heckscher-Ohlin theorem, which states that a country with balanced trade will export the commodity that uses intensively its relatively abundant factor and will import the commodity that uses intensively its relatively scarce factor. Leamer classified traded products into 10 commodities and factors of production into 11 resources, and showed that the distribution of resource endowments across countries defined the global pattern of trade in commodities. More recently, Harrigan and Zakrajsek (2000) found that the pattern of industrial specialisation across countries can be explained by relative factor endowments. Hence, in this perspective, resource-rich countries have a comparative advantage in the resources sectors due to their “fundamentals” (i.e., physical and human capital, labour, land, and natural resources) and, hence, they should diversify into resource-based industries. Resource-rich countries can only gain from global trade if they specialise in the resources sectors, because this is where their potentials for productivity growth lie.

A different perspective in economic literature, however, holds that specialisation patterns are not entirely determined by factor endowments, but also – and more importantly – by country characteristics and their "idiosyncratic elements" (Hausmann, Hwang and Rodrik, 2007; Lederman and Xu, 2007). Lederman and Xu (2007) found that the sectoral patterns of net exports are associated with international differences in country characteristics such as schooling, knowledge, infrastructure, information and communications technology, and institutional quality. This line of literature argues that some industries are successful in some countries and fail in others due to the idiosyncratic characteristics of countries which are shaped by their historical events and public policies (Hausmann, Hwang and Rodrik, 2007). The comparative advantage of countries can thus alter as their idiosyncratic elements and characteristics evolve over time.

To find out which industries entail higher productivity gains for a country – in other words, what a country is good at producing – would require significant diversification (Hausmann and Rodrik, 2003). Government policies to provide enough incentives for entrepreneurs to *discover* new activities with higher productivity levels are critical. In fact, some industries are associated with higher productivity levels than others, and, therefore, countries that diversify into higher productivity sectors perform better. In this perspective, resource-based sectors are *not necessarily* the sectors with higher productivity levels. It could well be possible that resource-rich countries discover new industries that entail higher productivity gains for them.

Diversification engenders a structural change in the country. The earliest theories in economic development held that countries that diversify away from agriculture and other traditional sectors and move towards modern economic activities would experience a rise in their productivity and income levels. Different patterns of diversification means different structural transformations and thus different productivity levels. The empirical literature that has studied structural changes in countries often focus on productivity differentials, for instance McMillan and Rodrik (2014), because productivity growth best captures the performance of countries throughout their development path. This paper similarly uses productivity growth as a measure to identify successful development performances of resource-rich countries.

While diversification patterns are difficult to be measured quantitatively, one option is to look at industrial linkages that are formed in the economy. Inter-industry linkages show how sectors within an economy trade with each other. For instance, a country specialised in agro-processing industries has denser and stronger linkages between agriculture and manufacturing industries, because sales of agriculture commodities as inputs to agro-processing industries are higher. On the contrary, a commodity exporter would have weaker inter-industry linkages because it exports most of its minerals and extractives abroad.

This paper uses the indicator of forward-linkages to mining and extractives to measure the extent to which downstream processing industries have been developed in the economy. Forward linkages to mining basically capture transactions between mining and other sectors, which involve purchase of inputs supplied by the resources sector. Countries that embark on resource-based industrialisation have stronger forward-linkages to mining and extractives. On the contrary, in countries that pursue a broad-based diversification strategy, one should expect a diversified production structure as a whole and not necessarily denser forward linkages to mining and extractives sector alone.

I therefore explore in this paper the pattern of diversification in resource-rich countries that is associated with productivity enhancements, by examining the relation between forward linkages to extractives and productivity growth. If a positive relation between productivity growth and forward linkages to mining is confirmed, it would indicate that resource-based industrialisation is associated with higher productivity growth rates. Further, I examine whether diversification – as measured by the Theil index of exports concentration – is associated with higher productivity growth rates. This would allow us to discuss whether a broad-based diversification strategy in resource-rich countries is otherwise productivity-enhancing.

The rest of the paper is structured as following. Section 2 explains the methodology employed in this paper and describes definitions and data sources. Section 3 presents the results of the model, before section 4 concludes the findings of this paper.

2. Model and data

I employ a panel econometric model to study the relation between productivity growth and forward linkages to mining and extractives. The indicator of forward linkages captures the extent to which resource-based industries are developed in the economy. In fact, when a country develops downstream industries to process and transform natural resources, forward linkages to mining and extractives become stronger and denser. On the contrary, if a country develops other new industries that are not necessarily connected to the resources sector, linkages around mining and extractives are weaker. In this case, however, the level of (broad-based) diversification in the economy can be captured through the conventional indicators of exports concentration.

Using a panel of 50 countries for the period 1970-2010 (with a five-year period-average series), I regress productivity growth over a set of productivity determinants and control variables, including forward linkages to the resources sector. The sample consists of middle- and high-income countries whose natural resource rents equal 1 percent of their GDP or higher. The time series include a time span of 5-year averages to avoid transitory effects such as short-term business-cycle effects and to provide enough time for structural and dynamic adjustments. A static model and a dynamic model have been specified as the following:

$$PG_{it} = \grave{X}_{it}\beta + \grave{Y}_{it}\delta + \alpha_i + \varepsilon_{it} \quad (1)$$

$$PG_{it} = \gamma PG_{i,t-1} + \grave{X}_{it}\beta + \grave{Y}_{it}\delta + \alpha_i + \mu_t + \varepsilon_{it} \quad (2)$$

Dependent variable PG_{it} is labor productivity growth, $\grave{X}_{it}$ is a vector of explanatory variables known to be important determinants of productivity growth, and $\grave{Y}_{it}$ is a vector of three control variables which are explained in the subsequent paragraph. In the static model, α_i is country fixed effect which includes unobserved variables that affect productivity growth cross-sectionally but do not vary over time, and ε_{it} is the error term. In the dynamic model, I assume that productivity in a given year also depends on the level of last year's productivity. Hence, PG_{t-1} denotes previous year's labor productivity growth, and μ_t is time-specific effect common to all countries.

In both models, the first control variable is the subsoil resource rents – differentiated for mineral rents (*minrents*) and oil rents (*oilrents*) – which is used as a measure of the level of resource endowment in sample countries. The second control variable is an indicator of exports concentration, measured by the *Theil* index (Theil, 1967, 1972), calculated on 2970 product lines for each country. The Theil index captures the level of diversification in the economy, because more diversified economies also tend to have diversified exports baskets. The Theil index can inform us the extent to which resource-rich countries in our sample have diversified their economies as a whole, basically to have pursued a *broad-based diversification* strategy.

The third control variable is an index of forward linkages to mining and extractives sector (*fwdlink*) which captures the level of *resource-based industrialisation*. Forward linkages were originally proposed in 1950s by Rasmussen (1957) and

Hirschman (1958). Rasmussen originally named the index 'sensitivity of dispersion', which measured the increase in output of industry i driven by a unit increase in the final demand for all industries in the economy. Hirschman further expanded the concept of sectoral linkages and focused on causal relations between industries and on linkage effects. Nonetheless, the forward and backward linkages have since been widely used in input-output analysis to study the 'pattern' of industrial interdependence (Drejer, 2002).

Jones (1976) refined Rasmussen's original measure of forward linkages in an attempt to better operationalise Hirschman-linkages in an input-output setting. Jones proposed to use Ghosh's supply side input-output matrix – known as the *output inverse* matrix – to calculate forward linkages, instead of using the demand-side Leontief inverse matrix. In this sense, the index of forward linkages measures the increases in output for all industries as a result of increased output of industry i brought about by a unit of primary input into this industry.

I therefore calculate the forward linkage based on the Ghosh inverse matrix, as suggested by Jones (1976), with a slight different specification where the original index is normalized for the number of industries in order to control for the differences in matrix dimension across countries. In fact, input-output tables produced by countries have different number of industries based on the level of data disaggregation. The number of industries in IO matrices does not reflect the true number of industries that exist in the economy rather the capacity of the governments to compile data for certain level of industrial classification. Hence, the index of forward linkages increases with the size of the IO matrices, unless a uniform classification is employed across all countries. To correct for this problem, the index is divided by the number of industries in the IO matrix and is defined as follows:

$$fwdlink = \frac{\sum_i B_{ij}}{\frac{1}{n}\sum_{ij} B_{ij}} \times \frac{100}{n} \qquad (2)$$

where B_{ij} are the elements of Ghosh inverse matrix and $\sum_i B_{ij}$ would thus represent the row sum of the Ghosh inverse matrix that corresponds to the mining and extractives sector. n is the number of industries in the IO matrix.

Explanatory variables included in the static and dynamic models are those that have been theoretically established to be important determinants of productivity growth. Neoclassical growth models have traditionally held that accumulation of physical capital per worker (*dkpw*) directly impacts productivity. Further, recent theories of economic growth have broadened the concept of capital and consider accumulation of human capital an important determinant of growth. Inspired by Mincer (1974), I estimate human capital accumulation (*hcl*) by the following function:

$$hcl = L\, e^{edu} \qquad (3)$$

where L is the labor force and edu is an index of years of schooling and returns to education developed by Feenstra et al. (2015) in the Penn World Table.

Productivity is also impacted by the demographics. According to the Solow growth model, population growth (*gn*) reduces productivity because it lowers the capital-labour ratio. Further, trade is argued to increase economies of scale, facilitate technology spillovers and expands the scope for learning-by-doing externalities, and hence it contributes to productivity growth (Aghion and Howitt, 2009). Based on the endogenous growth theory, one could also argue that productivity is impacted by institutions, because *good* institutions (i.e., effective regulatory framework, protection of property rights, contract enforcement, etc.) would support a more efficient allocation of resources in the economy and provide an enabling environment for innovation and technological progress. Hence, an indicator of legal system and property rights (*inst_legal*) and an indicator of regulatory quality (*inst_regul*) have been included as explanatory variables.

Finally, dual-economy models argue that there is a productivity gap between agriculture and non-agriculture sectors of the economy. Recent empirical studies confirm the productivity gap between agriculture and non-agriculture activities, though the gap between the two behaves non-monotonically during economic growth (McMillan and Rodrik, 2014). To account for this phenomenon, the share of agriculture in GDP (*agri*), the share of manufacturing in GDP (*manf*) and the share of services in GDP (*serv*) have been included in the vector of exogenous variables. *manf* excludes however the shares of other industries such as mining, construction and electricity. Hence, *agri, manf* and *serv* can be used altogether without running into the problem of full collinearity between the three.

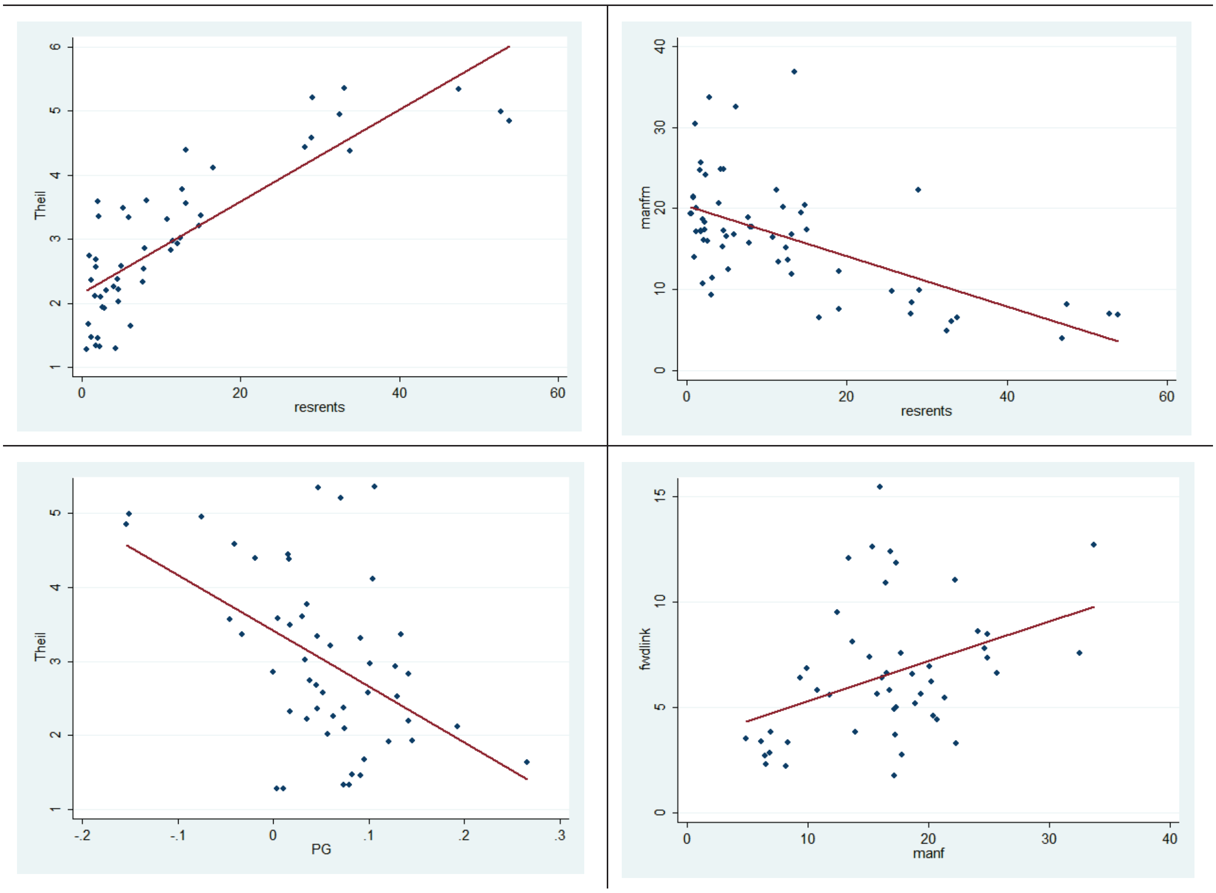
The labour productivity data is based on The Conference Board's (2015) Total Economy Database. The exports data for calculation of the Theil concentration index come from The Observatory of Economic Complexity (Simoes and Hidalgo, 2011). The input-output tables, used for calculation of the indicator of forward linkages, is based on the Eora multi-region IO database (Lenzen et al., 2013). Appendix A details the definition and sources of data for all variables employed in the model.

Table 1 presents the descriptive statistics for a number of key variables. The linear relationship between these variables are shown in the scatterplot matrix (Figure

Table 1: Descriptive statistics of selected variables

Variable	No. of Obs.	Mean	Std. Dev.	Min	Max
PG	534	0.055	0.205	-1.040	1.298
minrents	567	0.937	2.733	0.000	35.921
oilrents	567	11.070	17.155	0.000	83.058
fwdlink	442	6.530	3.365	1.613	17.705
Theil	435	3.040	1.223	0.418	5.820

Figure 1: Scatterplot matrix with estimated (linear) relationships for selected variables, based on average values over 1965-2010



RESRENTS: Resource rents, in percent of GDP; THEIL: Theil index of exports concentration; MANF: Share of manufacturing in GDP; FWDLINK: Index of forward linkages to mining & extractives; PG: Productivity growth. All variables are in "average" values calculated over 1965-2010.

1). The two graphs in the top row indicate that countries with higher levels of resource rents tend to have higher exports concentration (higher values for Theil) and smaller manufacturing base. The graph in the bottom-right shows that in countries with smaller manufacturing base, the size of the forward linkage indicator for mining and extractives is also smaller. Given that all countries in our sample are resource-rich, with various sizes of the resource economy, it seems that those which move towards industrialisation – meaning those that develop manufacturing industries for the processing of minerals and extractives – naturally develop stronger forward linkages in their economy with the mining sector. This validates the key assumption that we posed as part of our empirical strategy, i.e. using forwarding linkage indicator as a proxy for the level of resource-based industrialisation. Finally, the graph in the bottom-left shows that countries with more concentrated exports basket tend to experience, on average, lower productivity growth rates. In other words, diversification in general – and not necessarily diversification around the mining sector – is associated with higher productivity growth rates. Of course, these are two-way estimated relationships which do not control for other variables.

The reason for specifying two sets of model is to add a layer of robustness checks into the results, and to ensure that the principal results of the model are not sensitive to the estimation methods and to the assumption whether or not productivity depends on its previous year's level. The static model is estimated using fixed effect estimator with cluster-robust standard errors. This method is particularly appropriate when the number of cross-sections (*N*) is large and the number of time observations (*T*) is small – which is the case with our panel data (*N*: 50, *T*: 9). Further, when heteroscedasticity and serial correlation are both present in the model, "clustering" produces asymptotically valid inference (Wooldridge, 2010). A modified Wald test and LM Wooldridge test respectively confirmed presence of heteroscedasticity and serial correlation in our panel. Last but not least, the Breusch-Pagan LM test did not conclude for the presence of significant random effect in panel data, and the Hausman test also resulted in preferring the fixed effect specification.

The dynamic model is estimated using Generalized Method of Moments (GMM) system estimator (Arellano and Bover, 1995; Blundell and Blond, 1998). The system GMM is particularly appropriate when the model risks running into endogeneity and omitted variables problems. The model is estimated using two-step system GMM with Windmeijer-corrected robust standard errors (Windmeijer, 2005). The instruments include the first lag of the dependent variable, and the first lags of *minrents*, *inst_legal*, *fwdlink*, *trade*, and *theil* as predetermined variables.

3. Estimation results

Estimation results for the static model show that physical capital accumulation increases labour productivity. The relation is statistically significant and is robust to different sets of exogenous variables being included in the model. Human capital accumulation seems to positively impact productivity only with a time lag. Estimation results show that the relation between human capital accumulation and productivity is negative over the same time period, but it is not robust and turns statistically insignificant under different specifications. One reason could be that it is difficult to produce accurate estimates of human capital accumulation. Data on years of schooling – which is the most commonly-used proxy for human capital – is subject to statistical errors for many countries and does not measure human capital in its true sense. Finally, in-line with the Solow growth model predictions, population growth adversely affects productivity growth.

Our results do not show robust evidence for the dual-economy argument. While the estimated coefficients for manufacturing and services are positive and statistically significant in regressions 1-4, they are not robust across all specifications. Further, we do not find robust results whether resource-rich countries are likely to experience higher productivity growth. The estimated coefficients for both *minrents* and *oilrents* are not statistically significant in all regressions.

Effective regulatory institutions, which include regulations for credit market, labour and business environment, have a statistically positive effect on productivity growth. The results are robust across different specifications and estimations techniques. However, the indicator of legal system and property rights does not have a statistically positive effect on labour productivity growth.

The results also show that more open resource-rich countries experience lower productivity growth. One explanation could be that trade openness in resource-rich countries means larger commodity exports, which is not necessarily the type of trade that creates technology spillover and learning-by-doing externalities. The adverse relation between trade openness and productivity growth in resource-rich countries should not come as a surprise. McMillan and Rodrik (2014) also found that trade liberalisation did not lead to productivity enhancements in many resource-rich countries, particularly in Latin America and Sub-Saharan Africa. They explain that as globalisation promotes specialisation according to comparative advantage, trade liberalisation in countries endowed with natural resources and primary goods "reduces incentives to diversify toward modern manufactures and reinforces traditional specialization patterns." Nonetheless, the adverse relation between trade openness and productivity growth is not robust to alternative estimation techniques and specifications. The results turn statistically insignificant (and positive) in the dynamic model estimated using system GMM.

The main finding of this study is that resource-based industrialisation does not lead to productivity enhancements, even after controlling for the level of diversification. The estimated coefficient for the forward linkage is negative and statistically significant. Countries that developed downstream industries for

Table 2: Estimation results (regressions 1-6)

Dependent variable: DLOG(YPL)
Method: Fixed effect, Cluster-robust estimator
Observations: 328 (no. of cross-sectional groups: 43)

	1	2	3	4	5	6
constant	-0.3676	-0.6310**	-0.4057**	-0.3961**	-0.1683	-0.0859
	(0.2385)	(0.2399)	(0.1651)	(0.1637)	(0.1825)	(0.1319)
dkpw	0.1033**	0.1326***	0.1362***	0.1277***	0.1346***	0.1302***
	(0.0433)	(0.0402)	(0.0429)	(0.0341)	(0.0481)	(0.0456)
hc	-2.91e-07**	-2.38e-07**	-2.42e-07**		-2.05e-07*	-1.04e-07
	(1.33e-07)	(1.10e-07)	(1.17e-07)		(1.16e-07)	(1.10e-07)
hc(-1)	2.82e-07**	2.33e-07**	2.25e-07*		1.99e-07*	1.30e-07
	1.32e-07	(1.10e-07)	(1.15e-07)		(1.14e-07)	(1.25e-07)
gn	-0.0075**	-0.0076**	-0.0065*	-0.0073**	-0.0069*	-0.0080**
	(0.0035)	(0.0032)	(0.0033)	(0.0033)	(0.0037)	(0.0038)
minrents	0.0098**	0.0088**	0.0058	0.0066*	0.0045	0.0057
	(0.0038)	(0.0040)	(0.0040)	(0.0037)	(0.0038)	(0.0038)
oilrents	0.0037	0.0025			-0.0008	
	(0.0026)	(0.0023)			(0.0018)	
agri	0.0025	0.0027			-0.0002	
	(0.0029)	(0.0031)			(0.0025)	
manf	0.0092*	0.0133***	0.0076**	0.0077**	0.0012	
	(0.0052)	(0.0048)	(0.0037)	(0.0035)	(0.0022)	
serv	0.0051**	0.0061***	0.0039**	0.0035**		
	(0.0023)	(0.0022)	(0.0017)	(0.0016)		
inst_legal	0.0012					
	(0.0089)					
inst_regul	0.0389**	0.0396**	0.0281	0.0361**	0.0373**	0.0394***
	(0.0170)	(0.0169)	(0.0169)	(0.0170)	(0.0171)	(0.0144)
fwdlink	**-0.0162***	**-0.0149***	**-0.0158***	**-0.0146***	**-0.0145**	**-0.0141***
	(0.0088)	**(0.0081)**	**(0.0086)**	**(0.0079)**	**(0.0087)**	**(0.0083)**
trade	-0.0014**	-0.0013**		-0.0012**		-0.0010*
	(0.0006)	(0.0006)		(0.0005)		(0.0005)
theil		0.0519***	0.0556***	0.0596***	0.0498**	0.0427*
		(0.0187)	(0.0204)	(0.0211)	(0.0206)	(0.0228)
R-square within	0.2203	0.2412	0.2168	0.2275	0.2008	0.2259

*Values in parentheses are Cluster-robust standard errors; *** for p<0.01, ** for p<0.05, and * for p<0.1*

processing of minerals and extractives experience, on average, lower productivity growth. This suggests that resource-based industries are not necessarily those with the highest productivity growth potentials.

Export diversification is found to be inversely associated with productivity growth. The estimated coefficient for the Theil concentration index in the fixed effect model is positive and statistically significant, implying a negative relation between

Table 3: Estimation results (regressions 7-12)

Dependent variable: DLOG(YPL)
Method: Fixed effect, Cluster-robust estimator
Observations: 335 (no. of cross-sectional groups: 43)

	7	8	9	10	11	12
Constant	-0.0773	-0.0734	-0.0226	-0.0113	-0.0153	-0.0030
	(0.1303)	(0.1283)	(0.1222)	(0.1169)	(0.1205)	(0.1158)
dkpw	0.1225**	0.1179**	0.1307***	0.1304***	0.1333***	0.1191**
	(0.0465)	(0.0460)	(0.0440)	(0.0444)	(0.0449)	(0.0447)
hc	-1.06e-07	-1.19e-07	-8.80e-08	-8.25e-08	-9.00e-08	-9.75e-08
	(1.14e-07)	(1.12e-07)	(1.08e-07)	(1.07e-07)	(1.11e-07)	(1.08e-07)
hc(-1)	1.33e-07	1.46e-07	1.13e-07	1.07e-07	1.16e-07	1.23e-07
	(1.29e-07)	(1.25e-07)	(1.23e-07)	(1.22e-07)	(1.26e-07)	(1.22e-07)
gn	-0.0080**	-0.0075**	-0.0083**	-0.0084**	-0.0083**	-0.0079**
	(0.0038)	(0.0037)	(0.0037)	(0.0038)	(0.0038)	(0.0037)
minrents	0.0051	0.0051	0.0055	0.0057	0.0050	0.0054
	(0.0039)	(0.0037)	(0.0037)	(0.0035)	(0.0038)	(0.0036)
inst_regul	0.0398***	0.0420***	0.0408***	0.0406***	0.0411***	0.0429***
	(0.0146)	(0.0143)	(0.0138)	(0.0138)	(0.0083)	(0.0137)
fwdlink	**-0.0139**	**-0.0129**	**-0.0149***	**-0.0156****	**-0.0147***	**-0.0145***
	(0.0083)	**(0.0086)**	**(0.0083)**	**(0.0079)**	**(0.0083)**	**(0.0081)**
trade	-0.0014**	-0.0001	-0.0013**	-0.0013**	-0.0016***	-0.0002
	(0.0006)	(0.0009)	(0.0005)	(0.0005)	(0.0005)	(0.0008)
trade*LMC	0.0015				0.0014	
	(0.0009)				(0.0009)	
trade*UMC		-0.0011				-0.0010
		(0.0009)				(0.0009)
trade*HIC		-0.0032***				-0.0029***
		(0.0011)				(0.0011)
theil	0.0383	0.0396*	-0.0026	0.0906***	-0.0062	0.0853***
	(0.0228)	(0.0227)	(0.0275)	(0.0259)	(0.0271)	(0.0231)
theil*LMC			**0.0935****		**0.0921****	
			(0.0380)		**(0.0363)**	
thei*UMC				-0.0749		-0.0695
				(0.0468)		(0.0459)
theil*HIC				**-0.1194*****		**-1.1150*****
				(0.0394)		**(0.0379)**
R-square within	0.2311	0.2375	0.2422	0.2440	0.2469	0.2540

*Values in parentheses are Cluster-robust standard errors; *** for p<0.01, ** for p<0.05, and * for p<0.1*

diversification and labour productivity. Given that most empirical studies have found a non-monotonic relation for diversification with respect to growth and productivity, I investigate if the relation between export diversification and productivity growth varies for the different income levels. I introduce dummy variables for the income groups of lower middle-income, higher middle-income and high-income countries, and allow interaction between the dummy variables and the Theil concentration index.

Results show that export diversification leads to lower productivity growth in lower middle-income countries, while it is likely to increase productivity growth in high-income economies. The results are statistically significant in the fixed effect model. A number of other studies also find an inverse relation between export diversification and productivity growth in lower income groups. Weinhold and Rauch (1999) found a positive (negative) relation between specialisation (diversification) and manufacturing productivity growth in less developed countries. Bagci (2011) found that export concentration is likely to lead to improvements in productivity growth in low and lower middle income countries in certain industries.

A number of reasons for the inverse relation between diversification and productivity growth in developing countries have been discussed in the literature. First, in developing countries, large productivity gaps exist between the traditional and modern sectors of the economy due to allocative inefficiencies (McMillan and Rodrik, 2014). The diversification process initially reduces the productivity gap in developing countries, which may show lower growth in the economy-wide productivity. Second, the effect of misallocation of resources on productivity in developing countries can be amplified through the input-output structure of the economy (Jones, 2011). Misallocation associated with microeconomic distortions not only affects directly sectoral productivities, but also indirectly through the inter-industry linkages. In more diversified economies, as the input-output structure is larger, resource misallocation would reduce economy-wide productivity more so than in less diversified economies. Finally, variations in sectoral composition across countries also explain the differences in aggregate productivity performances. Sectoral reallocation associated with structural transformation could generate episodes of acceleration or slowdown in economy-wide productivity growth even if sectoral productivities are growing (Herrendorf et al., 2014).

These results are robust to different specifications and estimation techniques. The estimated coefficients for the forward linkage index and the interaction between the Theil index and the high-income group dummy remain statistically significant in the dynamic model estimated using system GMM (see Table 4). System GMM is particularly appropriate when there are concerns for endogeneity in the model.

To summarize, these results suggest that a resource-based industrialisation, as measured by the forward linkages around the mining sector, is associated with lower rates of productivity growth. Developing downstream processing industries for

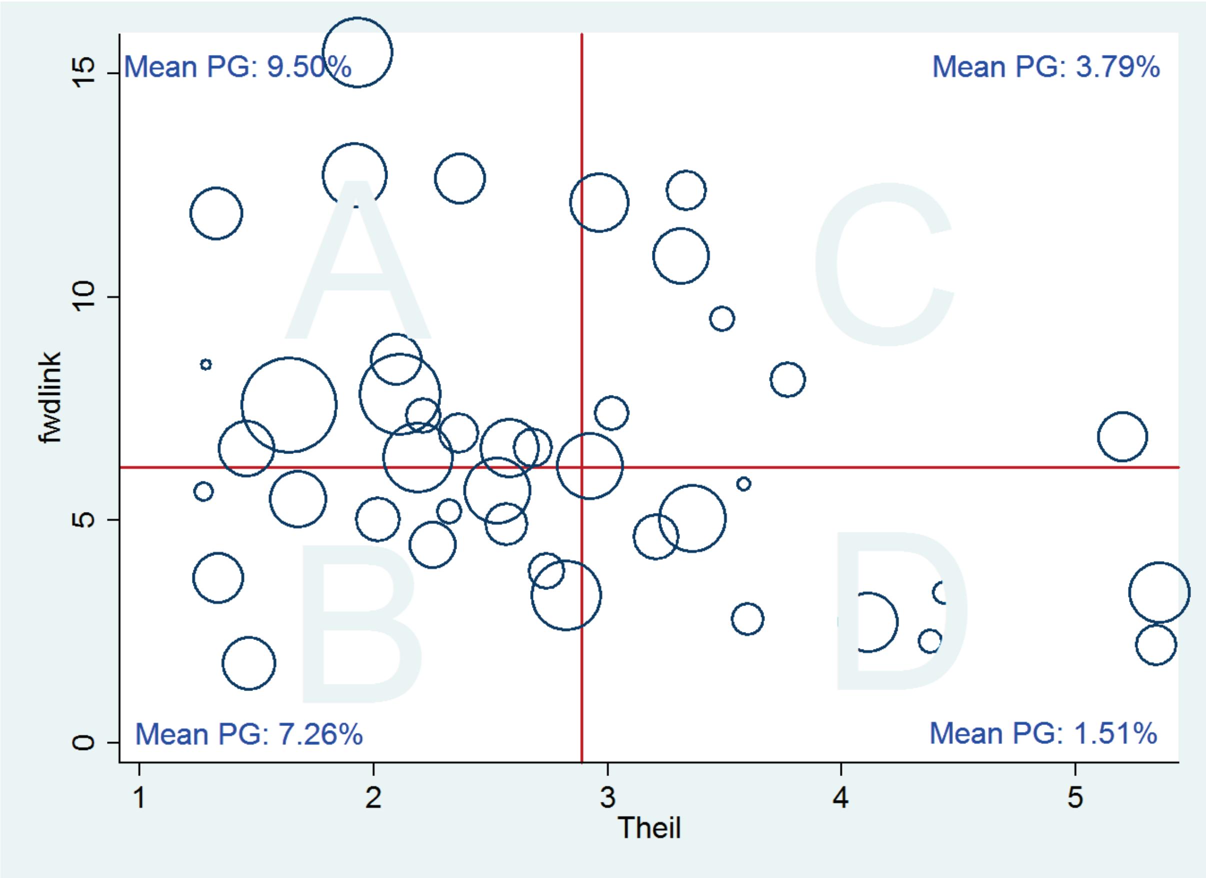
Table 4: Results with alternative estimation method (regressions 13-18)

Dependent variable: DLOG(YPL)						
Method: GMM System, with two-step WC-robust estimator						
Observations: 335 (no. of cross-sectional groups: 43)						
	13	14	15	16	17	18
Constant	-0.0915	-0.0804	-0.0557	-0.2401	-0.1181	-0.1691
	(0.0884)	(0.0928)	(0.0907)	(0.3155)	(0.0968)	(0.1267)
DYPL(-1)	0.1701*	0.1657*	0.1821*	0.1694	0.1362	0.1519
	(0.0972)	(0.1010)	(0.1002)	(0.1152)	(0.0883)	(0.1147)
dkpw	0.1554**	0.1268**	0.1417***	0.1688*	0.1513***	0.1153***
	(0.0638)	(0.0567)	(0.0441)	(0.0874)	(0.0531)	(0.0379)
hc	-3.69e-08		-2.42e-08	-7.99e-08	-3.43e-08	-2.47e-07
	(1.46e-07)		(1.31e-07)	(1.68e-07)	(1.50e-07)	(2.48e-07)
hc(-1)	4.23e-08		2.77e-08	6.30e-08	3.42e-08	2.72e-07
	(1.59e-07)		(1.45e-07)	(2.01e-07)	(1.62e-07)	(2.81e-07)
gn	-0.0071**	-0.0077***	-0.0063**	-0.0076**	-0.0060**	-0.0071***
	(0.0029)	(0.0030)	(0.0029)	(0.0038)	(0.0025)	(0.0026)
minrents	-0.0019	-0.0021			0.0003	-0.0032
	(0.0023)	(0.0021)			(0.0026)	(0.0042)
Agri				-0.0015		
				(0.0023)		
Manf				0.0044		
				(0.0059)		
inst_regul	0.0298***	0.0296***	0.0285***	0.0387*	0.0370***	0.0333**
	(0.0111)	(0.0105)	(0.0102)	(0.0214)	(0.0108)	(0.0166)
fwdlink	**-0.0067***	**-0.0086****	**-0.0092****	**-0.0080****	**-0.0086**	
	(0.0039)	**(0.0044)**	**(0.0044)**	**(0.0040)**	**(0.0057)**	
Trade	0.0002	0.0001	0.0004	0.0001	0.0004	0.0007
	(0.0006)	(0.0001)	(0.0005)	(0.0007)	(0.0005)	(0.0005)
Theil	0.0135	0.0195	0.0022	0.0347	0.0307	0.0403
	(0.0199)	(0.0178)	(0.0169)	(0.0437)	(0.0279)	(0.0324)
theil*LMC					-0.0381	-0.0341
					(0.0265)	(0.0261)
thei*UMC						
theil*HIC					**-0.0431***	**-0.0551****
					(0.0252)	**(0.0271)**
AR2(p)	0.5795	0.5059	0.6601	0.2886	0.4857	0.6182

*Values in parentheses are WC-robust standard errors; *** for p<0.01, ** for p<0.05, and * for p<0.1*
AR2(p) shows Arellano-Bond second order autocorrelation test.

minerals and extractives does not help the resource-rich countries to achieve higher levels of labour productivity. A broad-based diversification, however, offers potentials for productivity enhancement, but at later stages of development. Diversification leads to higher productivity growth when countries reach the high-income group level.

Figure 2: Scatter plot showing productivity growth outcomes for various degrees of resource-based industrialisation (fwdlink) and broader economic diversification (theil), average 1970-2010



PG: Productivity growth; FWDLINK: Forward linkages to mining & extractives; THEIL: Theil index of exports concentration. All variables are in "average" values over 1970-2010. Higher values for fwdlink indicate higher levels of resource-based industrialisation. Higher values for theil indicate lower levels of economic diversification (or higher concentration). The size of the circle/ bubble shows average productivity growth of the country. The red reference lines are the "median" of the respective variables.

In terms of policy guidance to resource-rich countries, it should not be inferred that developing countries should not develop resource-based industries at all and/or not diversify until they reach the status of high-income countries. In fact, it is only specialisation in mining alone and the fact of remaining a commodity exporter which substantially lowers productivity growth. As shown in Figure 2, resource-rich countries with smallest forward linkages to mining (i.e., those with smallest resource-based industries) and higher exports concentration (i.e., least diversified) have experienced lowest average productivity growth at 1.5 percent over 1970-2010. Countries that have developed resource-based industries but have not diversified their economies as a whole have had an average productivity growth of 3.8 percent. Conversely, countries that have diversified their economies as a whole have experienced highest average productivity growth rates between 7 and 9 percent on average. Thus, a broad-based diversification can potentially help countries achieve higher productivity growth outcomes over time.

Countries endowed with natural resources are not destined to remain commodity exporters and/or specialise uniquely into resource-based industries. These countries have the option to reshape their production structure and discover new industries that would have enough low costs for them to be profitable. The examples of such countries are not rare. Advanced economies such as the United Kingdom, the United States, and Sweden, which started off as resource-rich countries in 18th and 19th centuries, diversified extensively their economies towards modern activities, sophisticated products and high-tech industries (see Blomström and Kokko (2007) for an overview of Swedish experience). More recent examples of developing resource-rich countries include Malaysia, Mexico and South Africa, whose production structures are not limited anymore to mining and resource-based industries. Chile and Brazil have also diversified in recent years into fishery, horticulture and other agriculture products.

A broad-based diversification is not necessarily exclusive of resource-based industrialisation. Broadening the production structure in a resource-rich country does not mean that it should avoid mineral processing while looking for other productive industries to develop. The core concept of a broad-based diversification is that a resource-abundant country should not uniquely rely on activities that are based on natural resources. With a more diversified economic structure, potentials for minimizing growth volatility that result from natural resources production are higher and opportunities for productivity enhancements are larger.

4. Conclusion

Resource-rich countries willing to diversify their economies, in order to escape the *resource curse*, are faced with dual policy options. The first option is to develop downstream processing industries for minerals and extractives – a strategy known as *resource-based industrialisation* – while the other is to develop *new* industries and broaden the production structure as a whole. From a neoclassical trade perspective, the comparative advantage of resource-rich countries would lie in the resources sector, and thus a resource-based industrialisation is the most sensible option. Recent thinking in the economic literature, however, argues that comparative advantage is not solely defined by factor endowments, but also – and more importantly – by country characteristics and idiosyncratic elements. Hence, there could well be other potential industries in resource-rich countries, which could offer better opportunities for productivity growth.

This paper explored which of the two patterns of diversification engenders a productivity-enhancing structural change in resource rich countries. Using a panel data for 50 middle- and high-income resource-rich countries for the period 1970-2010 (with a five-year period-average series), I studied the relation between productivity growth and forward linkages to mining and extractives. As forward linkages capture the transactions related to downstream processing of minerals, they show stronger and denser inter-industry linkages for countries that embark on a resource-based industrialisation. On the contrary, countries which pursue a broad-based diversification strategy, have a diversified production structure as a whole and not necessarily denser forward linkages to mining and extractives sector.

The results show that resource-based industrialisation does not lead to productivity enhancements. Countries that develop industries at downstream level for processing of minerals and extractives are likely to experience *lower* productivity growth. However, a broad-based diversification increases labour productivity when countries reach higher income levels. Nonetheless, a broad-based diversification seems to be the most feasible option for resource rich countries, regardless of their income level; I find that countries that have diversified their economies as a whole have experienced highest average productivity growth rates between 7 and 9 percent on average over 1970-2010, compared to 3.8 percent for countries that developed resource-based industries but did not diversify their economies as a whole. Countries endowed with natural resources are not destined to remain commodity exporters and/or specialise uniquely into resource-based industries. These countries have the option to reshape their production structure and discover new industries that may entail productivity enhancements.

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Appendix A: Data definitions and sources

Variable	Definition	Source of data
Labor productivity growth (*dlog(lp)*)	Growth in labor productivity per person employed in 1990 US$ (converted at Geary Khamis PPPs)	The Conference Board (2015)
Change in capital stock per worker (*dkpw*)	Capital stock at current PPPs	PWT 8.1 for capital stock, and The Conference Board for number of persons employed
Human capital (*hc*)	$hc = L\, e^{edu}$ where L is the labor force and hc is an index of years of schooling and returns to education	PWT 8.1 for years of schooling and returns to education, and The Conference Board for workforce
Population growth (*gn*)	Growth in mid-year total population	The Conference Board (2015)
Mineral resources rents (*minrents*)	Rents of minerals, in percent of GDP	Wealth of Nations and World Development Indicators
Oil rents (*oilrents*)	Rents of oil and gas, in percent of GDP	Wealth of Nations and WDI
Exports concentration (*theil*)	Theil index of concentration, calculated based on 2970 product lines per SITC4	Observatory of Economic Complexity (Simoes and Hidalgo, 2011)
Forward linkages (*fwdlink*)	Indicator of forward linkages for minerals and extractives sector	This paper – using Eora MRIO database (Lenzen et al., 2013)
Trade openness (*trade*)	Total exports and imports, in percent of GDP	United Nations Statistics Division (UNSD) National Accounts Database
Agriculture (*agri*)	Share of agriculture value added in GDP	UNSD's National Accounts Database
Manufacturing (*manf*)	Share of manufacturing value added in GDP	UNSD's National Accounts Database
Services (*serv*)	Share of services value added in GDP	UNSD's National Accounts Database

Institutions: indicator of legal system and property rights (*inst_legal*)	*See* Gwartney et al. (2014)	Economic Freedom of the World index (Gwartney et al., 2014)
Institutions: indicator of regulatory quality (*inst_regul*)	*See* Gwartney et al. (2014)	Economic Freedom of the World index (Gwartney et al., 2014)

Appendix B: List of sample countries

List of countries, with the value of forward linkage indicator for mining and extractives

Developing countries						*Developed countries**		
1	Albania	6.642	21	Jamaica	8.410	40	Australia	15.687
2	Algeria	2.727	22	Jordan	3.041	41	Bahrain	4.452
3	Angola	2.024	23	Malaysia	3.388	42	Canada	4.713
4	Argentina	6.826	24	Mexico	5.325	43	Denmark	1.809
5	Bolivia	6.072	25	Morocco	3.947	44	Kuwait	3.521
6	Brazil	9.619	26	Nigeria	2.955	45	Netherlands	11.937
7	Bulgaria	5.779	27	Peru	7.761	46	New Zealand	7.039
8	Cameroon	2.860	28	Philippines	6.864	47	Norway	8.226
9	Chile	13.276	29	Romania	13.027	48	Qatar	2.978
10	China	7.912	30	Russian Federation	3.984	49	United Kingdom	5.620
11	Colombia	11.296	31	Saudi Arabia	2.583	50	United States	2.209
12	Cote d'Ivoire	6.569	32	South Africa	4.755			
13	Croatia	6.131	33	Syria	2.259			
14	Ecuador	8.628	34	Thailand	7.605			
15	Egypt	4.537	35	Tunisia	3.717			
16	Ghana	6.247	36	Ukraine	7.939			
17	India	15.317	37	Venezuela	10.931			
18	Indonesia	6.869	38	Vietnam	5.313			
19	Iran	6.603	39	Zambia	3.479			
20	Iraq	3.132						

** countries classified as "high-income" in 2010*

Does greater diversification lead to lower volatility? A production network perspective

Co-authored with Eric Rougier.

Abstract

Productive diversification is generally considered a volatility-reducing strategy. Yet, recent theoretical contributions have shown that, in strongly diversified economies, idiosyncratic shocks could translate into aggregate volatility via the network of inter-industry linkages. This paper explores the impact of sectoral shocks on aggregate output volatility during the 2008 Great Recession. Exploiting exogenous cross-country and cross-sector variations in demand shocks, we find that both the location of a sector within the network economy and its influence on other sectors condition the transmission of idiosyncratic shocks to aggregate volatility. Sectors that are located in dense parts of the network in which shocks are smeared out over a large number of alternative paths of propagation due to substitution effects, have a mitigating effect on aggregate volatility. Conversely, sectors that are more influential and central in a strongly asymmetrical network economy generate aggregate fluctuations through contagion effects and inter-sectoral linkages. We also find that shocks to service sectors are more likely to channel the latter effect and that developing countries are more vulnerable to shock contagion than advanced countries because their productive network features more structural holes.

1. Introduction

Does greater diversification lead to lower volatility? This is an important question because volatility in output growth is costly for an economy. Volatility reduces long-run growth (Ramey and Ramey, 1995), leads to significant welfare loss and increases in inequality and poverty (Aizenman and Pinto, 2005) and increases asset risk premia. The myriad ways in which output volatility impacts an economy places it high on the priority list of both academic economists and policymakers.

The early answer to the question of whether greater diversification leads to lower output volatility was in the affirmative. The answer relied on the argument that only aggregate shocks — shocks that affect many economic sectors in the same way — are important. In diversified economies, shocks to individual sectors are unimportant because as the number of independent and identically distributed shocks increases in an economy, each independent sectoral shock would become inconsequential according to the law of large numbers (Lucas, 1977). However, a more nuanced answer to the question was provided by recent work having demonstrated the importance of independent sectoral shocks for aggregate output. One recent path-breaking paper by Acemoglu et al. (2012) has derived theoretical conditions under which firm-level or sector-level shocks can have aggregate implications in a network macroeconomic model. The authors show that in such a network model, highly diversified economies can be buffeted by aggregate volatility emanating from independent sector shocks. Therefore, greater productive diversification does not always immunize economies from higher volatility for sectoral shocks satisfying the theoretical conditions described in Acemoglu et al. (2012).

While the theoretical result in Acemoglu et al. (2012) is important and insightful, a deeper understanding of the relationship between diversification and output volatility requires the theory to be taken to the data. This paper does so and contributes to our understanding of sectoral shocks in network economies in two ways. First, unlike other studies which have relied on simulations of theoretical models calibrated usually on the US economy, we use an econometric model to study how inter-sectoral linkages determine the impact of idiosyncratic shocks on aggregate volatility and derive empirical results from a *real-world* network of a multi-country global economy. Second, we are the first to identify the causal impact of various network features on various measures of output volatility. Establishing causality from observational data is extremely challenging. We overcome this challenge by utilizing the natural experiment of the Global Financial Crisis of 2007-8. This natural experiment provides plausible exogenous variation in sectoral shocks to the countries in our sample.[1] In addition, our country-sector panel set-up allows us to control for a variety of observed – including the difference in size and intensity of the shock – and unobserved sector-based determinants of aggregate volatility. Establishing causality is a considerable

[1] Similar to various recent papers (Bems et al., 2011, 2012; Garbellini et al., 2014; Nguyen, 2015), we use the 2008-2009 Great Recession episode as a 'natural experiment' of exogenous demand shock with varying intensities across sectors. In addition, we ensure that the sectoral shocks are, at the same time, heterogeneous and exogenous by computing a shift-share instrument to adequately capture the exogenous part of the cross-sectoral variation in final demand impelled by the global recession and trade collapse between 2007 and 2009.

achievement because the previous empirical analysis based on conditional correlations or matching moments to the data may be spurious. Moreover, our results are robust to the choice of estimator and sample changes.

Our main empirical result is easy to state: Both the location of a sector within the network economy, and its influence on other sectors determine its importance in transmitting idiosyncratic shocks to aggregate output.[2] In other words, not every sectoral shock can generate aggregate fluctuations, but this capacity rather depends on the two distinct topological characteristics of the sector, namely its 'local density' and 'centrality'. More specifically, we can say that, everything else equal, we may expect a 4 to 7 percentage point increase in aggregate volatility after a one unit increase in the intensity of shock for sectors with very high centrality (the top 1% of PageRank centrality distribution), and a 5 to 10 percent point decrease in aggregate volatility after a one unit increase in the intensity of shock for sectors with high local density (the top 40% of the "average degree of neighbours" distribution).

Our results thus suggest that sectors that are located in dense parts of the network where shocks fade out over a large number of alternative paths of propagation due to substitution effects, have a mitigating effect on aggregate volatility. Conversely, those sectors that are more influential and central in a strongly asymmetrical network economy generate aggregate fluctuations through contagion effects and inter-sectoral linkages.

To gain some intuition for what density, centrality, and asymmetry mean, think of the global economy as a production network where the sectors are nodes and the links joining the sectors represent the flow of inter-industry goods from one sector to another. Density indicates the extent to which sectors in the network are connected to each other. The closer the number of actual links to the potential number of links, the denser the network. Centrality indicates the 'importance' of a node in terms of (i) having the shortest distance to all other nodes in the network, and (ii) being located in a central position in the network where it plays a mediating role in the transmission of flows. In an economy, sectors that are large input suppliers or large input purchasers would have higher centrality. Asymmetry means that the input-output linkages are unequally distributed in the economy, where some sectors are larger input suppliers to the rest. These measures are shown in simple networks in Figure 1.

[2] This result can be viewed as the empirical counterpart to the theoretical conditions established in Acemoglu et al. (2012) for the cases where independent sectoral shocks lead to aggregate output.

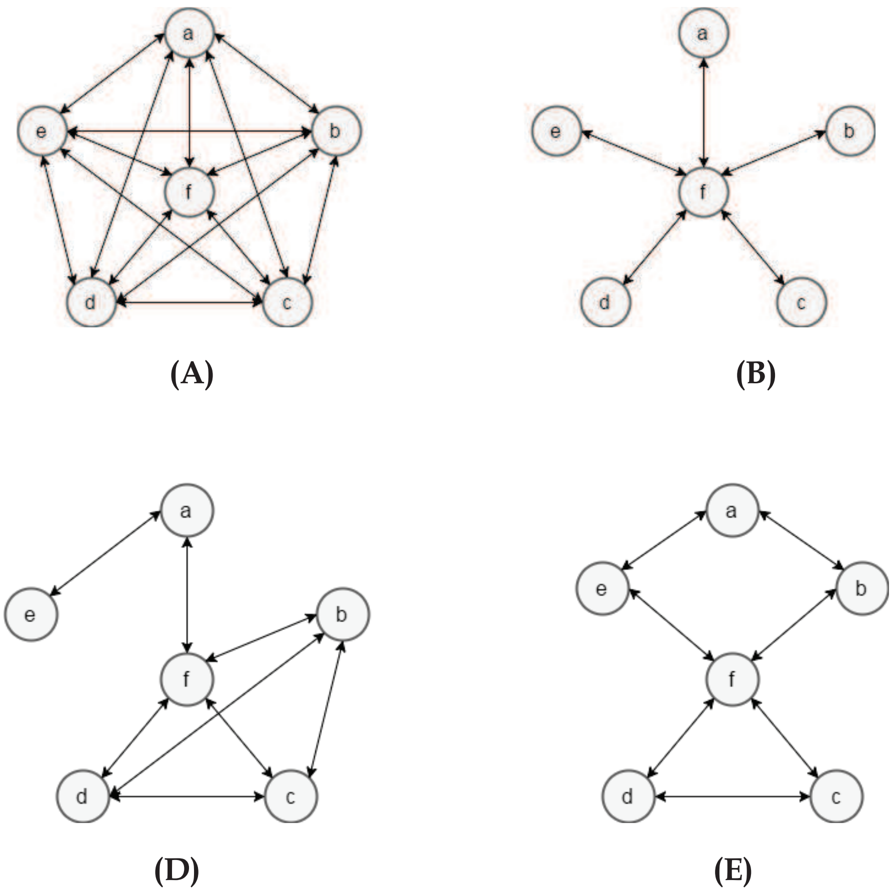


Figure 1: Network illustrations of asymmetry, density and centrality

Graph (A) represents a symmetric network where the links are equally distributed, meaning that every sector relies on all other sectors in the economy. It is also a densely connected network. Graph (B) shows a perfectly asymmetric network where one sector (f) is the input supplier and purchaser for all other sectors in the economy. It is also a sparse network. Graph (D) illustrates a network with a dense subgraph (the neighbourhood of b, c, d and f), while there are 'structural holes' (missing links) between a and b, and between e and d. In graph (E), sector f has a higher centrality because it is closer to or reachable by all other sectors, and it mediates the flow of goods between the subgraph comprising a, b and e, and the subgraph comprising c and d.

Looking more closely at sectors' average levels of centrality and local density, we get some interesting illustrations of our results.[3] Surprisingly, the automobile

[3] Figure A1 in Appendix V shows the average values of centrality and local density for all 35 sectors in our sample of 40 countries, as included in the World Input-Output Database. As illustrated in the upper panel, examples of sectors located in a dense part of the production absorbing shocks are mining and quarrying, air and water transport, and sale and repair of vehicles. Mining often has organised downstream industries, but mostly with few industries only, and hence it shows dense linkages. The automobile sector (i.e., sale of vehicles) is a complex industry which exhibits large densities around the sectors which supply inputs to it. Conversely, construction exhibits limited local density, meaning that this sector is not located in a dense part of the network. In the lower panel, examples of sectors with high centrality and therefore high potential for volatility transmission to the rest of the economy are construction, food manufacturing, health services, manufacturing of transport equipment, and public administration and social security. It is unsurprising to see construction on the top of the list, as this

industry, as it is located at the intersection of many sectors like metal, chemistry or service industries, shows a high degree of local density and, according to our estimations, has a high potential for substitution effects and therefore low potential for shock transmission. On the contrary, the construction sector, as it is simultaneously associated with potentially low substitution effects but very high contagion effects, is likely to be most conducive to shock propagation and aggregate volatility. Service sectors such as health, public administration and financial intermediation also appear to have higher-order degrees since they are suppliers to a large number of sectors in the economy. Our econometric estimation confirms the stronger capacity of service industries for the transmission of shocks to aggregate volatility through contagion effects.

Our paper is related to various recent strands of literature. First, a sizeable literature has supported the assumption that *sectoral diversification* (i.e., expansion in the number of sectors) reduces economic volatility. This assumption relies on two different theoretical mechanisms. First, a series of papers inspired by the financial portfolio theory have established that the pooling of risk across firms, notably through financial tools, ensures that aggregate and firm-level volatility follow inverse relation (Saint-Paul, 1992; Obstfeld, 1994; Acemoglu and Zilibotti, 1997). Second, models based on trade diversification (Koren and Tenreyro, 2007; di Giovanni and Levchenko, 2009; Cuberes and Jerzmanowski, 2009) also find that increased trade specialization, in more volatile export sectors, raises aggregate volatility. Indeed, empirical papers have essentially provided evidence supporting the prediction that sectoral diversification of export or output reduces aggregate volatility (di Giovanni and Levchenko, 2006; Malik and Temple, 2009; Haddad et al., 2010; Joya, 2015). By shifting the focus of our empirical research from *sectoral* to *technological* diversification, the present paper does better than simply showing that volatility increases with output concentration. By taking into account both the sectors *and* their linkages, we are able to identify which patterns of linkage distribution are more conducive to volatility reduction and which are to volatility increases.

Second, the analysis in this paper is closely related to the 'granular' hypothesis, put forward by Gabaix (2011), which states that shocks to individual firms or sectors can fail to average out when the distribution of firm shares of sales is sufficiently

sector shows strong upstream and downstream linkages to other influential sectors, not only to manufacturing and quarrying industries, but also to most other service industries.

leptokurtic, meaning that it features a small number of highly influential units.[4] Acemoglu et al. (2012) translate the granular assumption in a network model of input-output linkages where nodes are firms or sectors, and inter-firm or inter-sectoral linkages are edges. They identify higher-order interconnections, i.e. indirect linkages between suppliers and chains of downstream sectors, as the main driver of the propagation of productivity shock from one sector to the whole economy through *cascade* effects. They conclude that whereas the "sparseness" of the input-output matrix is not related to aggregate fluctuations, sizable aggregate volatility can be generated by idiosyncratic shocks to highly influential upstream sectors, that is sectors that are input suppliers to a large number of other downstream sectors.[5] In this paper, we compute two different sets of network metrics at node level for a panel dataset combining 35 sectors in 40 developing and industrialised countries, enabling us to adequately capture the asymmetry patterns of production networks described by Gabaix (2011) and Acemoglu et al. (2012). More specifically, by measuring higher-order interconnections through the *PageRank* score, our result supports the *cascade* theory, as it shows that shocks to sectors whose input demand is concentrated on other highly influential sectors trigger aggregate volatility.

By analysing the distribution of intersectoral input-output linkages, the present paper is also close to Koren and Tenreyro's (2013) *technological diversification* concept. They show that the diversification of inputs or productive technologies, which can be used as substitutes by each individual firm, is key in reducing aggregate volatility subsequent to idiosyncratic productivity shocks. They conclude that firm's adoption of increased number of input varieties provides diversification benefits against variety-specific shocks and reduces aggregate volatility.[6] To our knowledge, this paper is the first to take technological diversification to the data by *empirically* identifying the impact of structural properties of production networks on output volatility for a broad

[4] We should highlight that although Gabaix argues that the granular hypothesis might hold at strongly disaggregated levels, our results show that it applies even if the aggregation level of sectoral shocks is high and the number of sectors is limited (i.e., aggregated at 35 sectors).

[5] Acemoglu et al. (2016) generalize this result to demand shocks and for downstream and upstream networks and find evidence of substantial propagation of these shocks through the input-output network.

[6] In the own words of Koren and Tenreyro (2013: 379): "if a significant number of firms adopts an input that is already widely used by other firms, the economy as a whole may then become highly technologically concentrated and hence exposed to shocks to that particular input, leading to episodic surges in volatility." Note that *technological concentration*, that is a significant number of firms or sectors adopting input varieties that are widely used by other firms, is very much akin to the production network asymmetry. Acemoglu et al. (2012) describes production network asymmetry by the presence of firms/sectors highly influential in the production network, particularly when they are suppliers of inputs to a large number of other sectors. Importantly, in Acemoglu et al. (2012), influential firms/sectors drive aggregate volatility.

cross-section of countries.[7] Koren and Tenreyro's (2013) main finding is that the co-movement of firm-level and aggregate level volatility vanishes as countries develop and the inputs used by firms get more diversified. In this paper, we find that not all patterns of technological diversification are conducive to lowering aggregate volatility, since aggregate volatility is increased by the concentration of input demand on a small number of influential sectors. We also find evidence for the contagion effect but no evidence of the substitution mechanism for the sub-sample of developing and emerging economies, suggesting that these economies are more vulnerable to external shocks because: (1) their productive system features more structural holes than in developed economies, meaning that their productive system is not sufficiently diversified around the sectors that are more vulnerable to external shocks, and (2) they usually have large influential sectors. The present paper therefore constitutes an innovative contribution to the diversification-volatility debate by providing disaggregated empirical evidence for a large cross-section of 40 developed and developing countries, suggesting that the impact of *technological diversification* is not linear.

This paper is also linked to a number of recent papers which have studied the spillover effects of final demand shocks to international trade in intermediate goods during the Great Recession of 2008-09, and which also use global input-output data. Levchenko et al. (2010), Bems et al. (2011, 2012), and Garbellini et al. (2014) used global IO data to quantify the impact of final demand shock on trade collapse and other outcomes during the 2008 global crisis. These studies, however, have not studied the impact of diversification in the spillover process of shocks. Our theoretical framework is, nevertheless, closer to Bems et al. (2011) which use a Leontief, demand-driven model as the basis of their empirical test. Kireyev and Leonidov (2015) developed a network model for international spillover of demand shocks, albeit without looking at the diversification aspect of output.

It is worth mentioning that the debate on whether inter-sectoral linkages magnify aggregate volatility is not recent, as it can be traced back to the real business cycle theory, notably the multisector model *à la* Long and Plosser (1983). Using a similar model, Horvath (1998) demonstrated that the rate at which the law of large numbers applies is controlled by the rate of increase in the number of full rows in the input-output matrix (i.e. number of input-output relations or inter-industry linkages)

[7] The bulk of existing contributions to the network approach of aggregate volatility, including Carvalho (2010), Acemoglu et al. (2012, 2015), Contreras and Fagiolo (2014) and Roson and Sartori (2016), have essentially provided quantitative simulations of theoretical models calibrated with IO data for a single country, frequently the United States.

rather than by the rate of increases in the total number of sectors. Using I-O matrix for the US, Horvath (1998) shows that the number of full rows increases much slower than the total number of rows upon disaggregation, with the result being that aggregate volatility from sectoral shocks declines at less than half the rate implied by the law of large numbers. Put differently, what matters most for explaining aggregate volatility is *technological diversification*, i.e. the increase in the number of full rows, and not the mere increase in the number of rows, which we called *sectoral diversification*. Early simulations by Horvath (1998) also point to the possibility that a sizable portion of aggregate volatility in the U.S. growth rates (as much as 80%) could be caused by small and independent shocks to 2-digit SIC code (Standard Industrial Classification) sectors. This figure is consistent with more recent estimations based on simulations also using the US input-output matrix (Shea, 2002; Foerster et al., 2011; Carvalho and Gabaix, 2013; Atalay, 2014) finding that around 50–70% of the variability in US aggregate growth rates is associated with sector-level idiosyncratic shocks.

A series of recent contributions have also focused on exporting firms' heterogeneous characteristics to connect idiosyncratic shocks to aggregate fluctuations, through inter-firm I-O linkages and international business cycle co-movements. Using data on French firms for the period 1990– 2007, di Giovanni et al. (2014) find that the contribution of firm-specific component to aggregate sales volatility is similar in magnitude to that of shocks that are common across firms within a sector or country. They also find evidence that the effect of shocks emanating through input-output linkages are as large as three times the direct effect of shocks to individual firms. In this paper, we assess how the impact of a sectoral global demand shock on aggregate volatility is conditioned by the pattern of inter-sectoral linkages. We find evidence supporting the assumption that the impact of sectoral trade shocks on aggregate fluctuation is either smoothed or magnified by the characteristics of this sector in the production network. However, we are not interested in international business co-movements produced by large firms in sectors, but instead we focus instead on domestic fluctuations.

Lastly, some paper's findings indirectly relate to the nascent literature on industrialisation through Global Value Chains (GVCs). Over the past two decades, the global economy has become much more interconnected; demand and productive sectoral shocks are increasingly synchronized across countries as a consequence of production-sharing and vertical specialization (Di Giovanni and Levchenko, 2010; Di Giovanni et al., 2014). Increased uncertainty and small shocks to trade costs have become potential drivers of global trade busts hitting many economies through the channel of international supply chains (Grossman and Meissner, 2010). Our findings suggest that developing economies are more vulnerable to external shocks because their productive systems are insufficiently diversified in the neighbourhood of the sectors that are more vulnerable to external shocks. Such structural holes around the neighbouring trading and influential sectors may be another consequence of the vertical specialisation through GVCs which prompt the expansion of a few exporting sectors featuring only limited forward and backward linkages to the rest of the economy (Srholec, 2007).

The rest of the paper is structured as follows. In Section 2, we discuss in detail the theoretical arguments of the portfolio and network approaches, and we present a simple theoretical framework formalizing how the effects of a final demand shock on aggregate output volatility may be conditioned by production network characteristics. Section 3 then explains our empirical strategy and defines the network measures used in our empirical test, while section 4 describes the data sources and their descriptive statistics. In Section 5 and 6, we present and discuss our estimation results. Section 7 undertakes robustness checks before we conclude our findings in section 8.

2. Diversification and aggregate volatility: Theoretical framework

2.1 Sectoral diversification, technological diversification and aggregate volatility

Two contrasting views on the impact of diversification on aggregate volatility can be found in the literature. For convenience, we call the two approaches by *sectoral* diversification and *technological* diversification in the rest of the paper.

The *sectoral diversification* approach focuses on the diversification of output, or, put simply, it looks at the diversity of sectors and products in the economy. Based on this approach, the argument holds that developing countries should diversify their production and exports structures in order to reduce their economy's reliance on few volatile sectors, generally commodities, in order to hedge against fluctuations in the prices of these commodities (Koren and Tenreyro, 2013). As underlined by Koren and Tenreyro (2007), this approach assumes that output deviations are uncorrelated across the different sectors, and consequently any idiosyncratic shock to a given sector in a diversified productive structure will be averaged out over all other active sectors, leaving no impact on aggregate output (Lucas, 1977). Very much akin to *sectoral* diversification, *financial* diversification provides firms and economic units with enhanced opportunities for risk spreading across projects (Acemoglu and Zilibotti, 1997).

In addition to the concepts of *sectoral* and *financial* diversification, Koren and Tenreyro (2013) proposed to think of diversification as an expansion in the varieties of inputs, which they labelled as *technological* diversification. In an endogenous growth model with expanding varieties of inputs, with each input variety being associated with specific risks of productivity shocks, they show that any expansion in the number of varieties might reduce the risk of aggregate volatility. Similar to the Lucas effect based on the law of large numbers, as the number of input varieties increases, productivity and output will become less volatile because each individual input will matter less in the production process. However, technological diversification also waives volatility through the behavior of firms adjusting the use of other varieties of inputs in order to partially offset any idiosyncratic shock on a particular input. For Koren and Tenreyro (2013), the *substitution effect* between different technologies incorporated into the variety of inputs primarily explains why idiosyncratic shocks have no impact on aggregate volatility.

The substitution effect, however, can only be envisaged if the productive system is analysed as a collection of uncorrelated, or imperfectly correlated, sectors among which compensation is possible. In more complex models of productive economies, with sectors being linked through backward and forward linkages, the substitution effect may not apply anymore since output or productivity change may be correlated across sectors via inter-sectoral demand or supply effects. As opposed to the *sectoral* diversification approach, the *technological* diversification approach considers that sectoral output deviations are potentially cross-correlated via the network structure of input-output linkages. In this set-up, a more diversified distribution of input linkages will not automatically preclude an idiosyncratic sectoral shock from translating into aggregate volatility.

Two path-breaking papers by Gabaix (2011) and by Acemoglu et al. (2012) have recently established the conditions under which inter-firm or inter-sectoral linkages may condition the transmission of idiosyncratic shocks to aggregate volatility. They show that in highly asymmetric production networks, i.e. networks where some sectors or firms are larger input suppliers to the rest of the economy or the distribution of firm sizes is strongly leptokurtic, idiosyncratic shocks to these sectors or firms can prompt aggregate output fluctuations through *contagion* effects across the network of inter-sectoral linkages. Importantly, these results hold for economies comprising a large number of sectors.

As the technological diversification approach focuses on the distribution of inter-industry linkages in the economy, the conclusions drawn from this approach are not straightforward. This approach notably imposes to identify how the structure of the production network affects the diffusion of sectoral shocks across sectors and towards the whole economy. In *balanced* production networks, where sectors play equal roles as input suppliers and purchasers, greater diversity of inter-sectoral linkages should average out sectoral shocks and therefore reduce aggregate volatility risk. The portfolio argument will hold in this case, because economies that feature more diversified inter-industrial ties also exhibit more alternative input-output routes between sectors over which risk can spread out. A demand or supply shock to one sector will thus propagate more slowly to other sectors than in economies with less diversified input linkages. When a shock affects a sector that is an input supplier, other purchasing sectors will switch to alternative suppliers, depending on the possibility of input substitution for the goods or services they produce. At the sub-network level, this pattern is well characterized by high densities of linkages in the *neighbourhood* of the sector. In other words, being situated in a denser part of the network is important for the effects of the shock to be averaged out. The assumption of a *substitution* effect, i.e. substitution between different supply or demand linkages, is central to this view.

However, strictly balanced production networks are uneasy to find in the real world where economies tend to be specialised. Most economies actually feature asymmetric production networks where few sectors are larger input suppliers to the rest of the economy than the others. A series of important contributions have recently provided formal demonstrations of a *contagion* effect in unbalanced production networks, with idiosyncratic shocks translating into aggregate volatility if the sector affected by the shock plays an asymmetrical role as supplier or demander in the whole economy (Carvalho, 2010; Acemoglu et al., 2012, 2015). More specifically, the status of the sector hit by the shock within the whole network structure of inter-industry linkages, or in other words whether this sector is central and influential in the network or not, determines the magnitude of the *contagion* effect. Acemoglu et al. (2012) have notably insisted on the role of second-order degrees, that is the influence of a sector over the whole network through its linkages with other influential sectors as they share common suppliers or purchasers. Put differently, *technological* diversification may well covey *contagion* effects if volatility propagates to the whole productive system through strongly influential sectors. In short, the theoretical impact of technological diversification on aggregate output volatility is rather uneasy to be predicted, since it depends on the network properties of the sector that is affected by a shock. Identifying whether the *substitution* or *contagion* effect dominates requires assessing how the local production network structure drives volatility transmission from one sector to the rest of the economy.

2.2. I-O networks and the decomposition of aggregate volatility: An illustrative framework

In this subsection, we show how the empirical specification we are interested in can be derived from basic economic relationships inspired by the theory of real business cycles *à la* Long and Plosser (2003).[8] More specifically, we develop a theoretical set-up illustrating how the structural properties of a production network affect the transmission of an idiosyncratic demand shock to the aggregate level.

Following Bems et al. (2011), we assume that all changes in output and in final demand are in real terms, and that the quantity shares of our variables are equal to their value shares. To simplify model annotations, we consider a closed economy with n output sectors which all trade among each other. All these sets of assumptions are consistent with the type of data that we are using for our empirical exercise in the next section.

We define total gross output (Q) in the economy as the sum of all x_i sectoral outputs $Q_t = \sum_i^n x_i$. In terms of percentage changes, aggregate growth in year t will be the weighted sum of sectoral output growth rates, as following:

$$\tilde{Q}_t = \sum_i^n w_{i,t0} \tilde{x}_{i,t} \qquad (1)$$

where the accent ~ shows the percentage change in a variable, and $w_{i,t0}$ is the output share of sector i in the aggregate output at the beginning of the period.

Each sector x_i produces differentiated goods that are either used as an intermediate input by other sectors or are used to satisfy final demand. Let the intermediate goods from sector i used in production of output in sector j be x_{ij}^m and the final goods produced to satisfy final demand be x_i^d . The sectoral output is given by: $x_i = \sum_j x_{ij}^m + x_i^d$. The percentage change in sectoral output will therefore be:

$$\tilde{x}_i = \sum_j \left(\frac{x_{ij}^m}{x_i}\right) \tilde{x}_{ij}^m + \left(\frac{x_i^d}{x_i}\right) \tilde{x}_i^d \qquad (2)$$

The quantity of intermediate goods can be expressed as: $x_{ij}^m = a_{ij} x_j$ where $a_{ij} = \frac{x_{ij}^m}{x_j}$ is a technical coefficient measuring the share of intermediate goods from sector i used in the production of final goods by sector j. Similar to Leontief's assumption for the production function, we assume that flows of intermediate goods from sector i to

[8] For a more complete account of dynamic models of growth decomposition, see Malysheva and Sarte (2011).

j depend entirely on changes in the total output of sector j , which leads us to suggest that: $\tilde{x}_{ij}^{m} = \tilde{x}_j$. Equation (2) can thus be re-written as:

$$\tilde{x}_i = \frac{1}{x_i}\left(\sum_j a_{ij}x_j\tilde{x}_j + x_i^d\tilde{x}_i^d\right) \qquad (3)$$

For all sectors, Equation 3 can be expressed in the following matrix form:

$$[diag(x)]\,\tilde{X} = A[diag(x)]\tilde{X} + [diag(d)]\,\widetilde{D} \qquad (4)$$

where $[diag(x)]$ is an $(n{\times}n)$ diagonal matrix with elements x_i on the diagonal, $\tilde{X}$ is an $(n{\times}1)$ vector of output changes in each sector *i*, *A* is a technical coefficients matrix with elements a_{ij} , $[diag(d)]$ is a diagonal matrix with elements x_i^d on the diagonal, and $\widetilde{D}$ is a vector of final demand changes. With some matrix operations on Equation 4, we get:

$$\tilde{X} = M\,\widetilde{D} \qquad (5)$$

with $M = [diag(x)]^{-1}\,[I-A]^{-1}\,[diag(d)]$

The matrix $[I-A]^{-1}$ is the Leontief inverse matrix, also called total requirements matrix, which captures both direct and indirect transactions in the economy. Direct transactions refer to the units of intermediate goods that are required for production of a final good, while indirect transactions are the units of additional intermediates, primary goods or commodities that are required to produce the intermediate goods in the first place.

Equation 5 shows that changes in output directly relate to changes in final demand. However, the impact of final demand variability on output depends on the structure of the $(n{\times}n)$ matrix *M*. This matrix captures both direct and indirect inter-industry flows in the economy, as well as the shares of sectoral output and sectoral final demand. It thus captures the interconnectedness and linkages across sectors in the economy.

Per equation 5, the output growth for a given sector i would be: $\tilde{x}_i = \sum_j m_{ij}\tilde{x}_i^d$ where m_{ij} is an element of matrix *M*. Replacing this in equation 1, we obtain the expression for aggregate output growth $\tilde{Q}$:

$$\tilde{Q}_t = \sum_i^n\left(w_{i,t0}\sum_j m_{ij}\tilde{x}_{i,t}^d\right) \qquad (6)$$

or, in the matrix form, as following:

$$\tilde{Q} = W\,M\,\widetilde{D} \qquad (7)$$

where W is the $(1 \times n)$ vector of sectoral shares $w_{i,t-1}$.

We can now easily derive the aggregate output volatility. The variance for aggregate output growth $\tilde{Y}$ would therefore be:

$$\sigma_{\tilde{Q}}^2 = (WM)\, \Omega_{\tilde{D}\tilde{D}}\, (WM)^T \qquad (8)$$

with $\Omega_{\tilde{D}\tilde{D}}$ being the variance-covariance matrix of sectoral demand changes. Two observations can be made here.

First, equation 8 shows that aggregate output volatility depends on the distribution of sectoral shares, as captured by vector W. If sectoral demand volatility is symmetric across sectors, contributions to aggregate output volatility would be larger for those sectors that have higher weights in aggregate output, and smaller for smaller sectors. This goes in the same spirit as Gabaix (2011). Eq. 8 is also in conformity with the real business cycle theory which suggests that the distribution of sectoral shares matters for contribution of a sector to aggregate variability (Malysheva and Sarte, 2011).

Second, in conformity with Long and Plosser (1983), Horvath (1998) and Acemoglu et al. (2012), input-output linkages – as captured by M – also play a key role in aggregation of sectoral variability to country-level output volatility. In our theoretical model as presented here, these sectoral variabilities are final demand changes. Thus, the effect of a change in final demand to a given sector on aggregate output will depend on its linkages with all other sectors in the economy.

Another way to interpret matrix M is to define it as an *adjacency matrix* that depicts the input-output network of the economy. An adjacency matrix, in graph theory, is a mathematical representation for a network. In our case, M would depict a *weighted, directed network*, meaning that it not only captures the existence of linkages across sectors, but also the direction and strength of inter-industry flows. Each element m_{ij} in the adjacency matrix $M = (m_{ij})$ represents the weight of the edge (link) from node (sector) *i* to node *j*. Given that the input-output data actually capture *money flows* across industries (which go in the opposite direction of the flow of goods), m_{ij} thus measures the volume of money flows from node *j* to node *i*.

Per Eq. 8, the M matrix determines how sectoral demand variability contributes to aggregate output volatility through input-output linkages. The contribution of sectoral demand volatility into aggregate output volatility depends on the distribution of sectoral shares and on inter-industry linkages in the economy, which equation 8 bore a confirmation for.[9] The distribution of inter-industry linkages, their strengths, the position (importance) of a sector within the network, the average distance (paths) across sectors, existence of hubs and clusters, and other network features determine how a shock to a sector percolate across the network. In the next section, we discuss a number of relevant network measures at the node (sector) level.

3. Empirical strategy and identification

3.1 Empirical strategy

An empirical assessment of Eq. 8 would suggest measuring growth volatility at the aggregate level (left-hand side of the equation), while the structural properties of the production network are best captured at node-level, that is at sector-level (right-hand side). In order to consistently use cross-sectoral data for both variables, we had to find a method permitting to recompose disaggregated sector-level data into aggregate volatility. We therefore had to consider that a sector can either *directly* contribute to aggregate volatility, or *indirectly* induce aggregate fluctuations through its linkages with other sectors in the economy. In the rest of the paper, we therefore call *direct* impact, the impact of a shock through sector i's own relative contribution to aggregate volatility, and *indirect* impact, the impact of a shock through other sector's relative contributions to aggregative volatility.

A sector's direct contribution to aggregate volatility can be easily derived by using the *marginal risk contribution* measure employed in portfolio risk budgeting (Litterman, 1996; Davis and Menchero, 2010). Starting from Eq. 1, we define the contribution of sector i in country c's aggregate growth volatility as:

$$r_{ic} = \sigma_{\tilde{x}_{ic}} \, corr(\tilde{x}_{ic}\,, \tilde{Q}_c) \qquad (9)$$

where $\sigma_{\tilde{x}_{ic}}$ is the standard deviation of output growth $\tilde{x}_{ic}$ in sector i in country c between 2007 and 2009, and $corr(\tilde{x}_{ic}\,, \tilde{Q}_c)$ is the correlation coefficient between sectoral output growth ($\tilde{x}_{ic}$) and aggregate output growth ($\tilde{Q}_c$) in country c. Equation 9 therefore measures a sector's direct contribution to aggregate volatility. Appendix I shows how this measure is derived from Eq. 1.

In this paper, however, we are particularly interested in the transmission of a shock to all other sectors through inter-industry linkages, and we thus focus on the

[9] Note that the variance-covariance matrix $\Omega_{\tilde{D}\tilde{D}}$ can be further decomposed into diagonal and off-diagonal elements, which would respectively show the direct contributions of individual sector volatilities into aggregate output volatility, and comovements across sectors. Shea (2002) shows that most of aggregate volatility can be attributed to the latter due to input-output linkages and inter-industry complementarities.

indirect impact of a shock on aggregate volatility which pass through all other (non-*i*) sectors. Therefore, we compute the cumulative contributions of all non-*ic* sectors to aggregate volatility. To measure the sum of volatility contributions, we need to express the standard deviation in an additive function. The standard deviation can be additive of all individual sectors' contributions if their respective marginal contributions are weighted by their respective degrees of exposure (i.e. their shares in output), as shown in equations *(v)* and *(xii)* in Appendix I. We thus define the dependent variable as:

$$y_{non-ic} = \sum_{i \neq k} w_{ic}\, r_{ic} = \sum_{i \neq k} w_{ic}\, \sigma_{\tilde{x}_{ic}}\, corr(\tilde{x}_{ic}\,, \tilde{Q}_c) \qquad (10)$$

If we accept that in an *N*-sector economy, the volatility contribution of the *N*-1 non-*i* sectors is a good proxy of the aggregate volatility, then we can safely suggest that the impact of a shock to sector *i,c* on all *N*-1 sectors' contributions to output volatility, as done in equation 10, is a convenient proxy of the impact of this shock on aggregate volatility.

In order to respond to the central question of our paper, that is how the structural characteristics of the production network condition the transmission of sectoral volatility to the whole productive system, we therefore regress the contribution of all non-*i* sectors to aggregate volatility on the interaction of the shock intensity with network characteristics for sector *ic*, as well as other determinants, as in Equation 11:

$$y_{non-ic} = \propto_0 + \propto_1 D_{ic} + \propto_2 M_{ic} + \propto_3 D_{ic}\, M_{ic} + \grave{Z}_{non-ic} \propto_4 + \tau_c + \varepsilon_i + u_{ic} \qquad (11)$$

where $y_{non-i,c}$ is the sum of the contributions of all non-*i,c* sectors in the aggregate volatility between 2007 and 2009 as defined in Eq. 10, D_{ic} is the Bartik indicator of final demand shock for sector i in country c between 2007 and 2009 defined in Equation 12 below, M_{ic} is a measure of network properties for sector *i,c* in the base year (i.e., 2007) for which we will test different types of network measures alternately in the model, $\grave{Z}_{non-i,c}$ is a vector of average observed characteristics for non-*i,c* sectors, including changes in capital stock and changes in employment, τ_c and ε_i are country and sector fixed effects, and $u_{i,s}$ is the error term.

In Equation 11, the estimated direct impact of an exogenous demand shock in sector *i* on all non-*ic* sectors' contribution to the aggregate volatility is identified by the term $\propto_1$. We are interested in the *indirect* volatility impact of a sectoral shock, that is the impact channeled by inter-sectoral linkages transmitting volatility from one sector to the rest of the economy. In eq. 11, the sum of estimated coefficients $\propto_1 + \propto_3$ measures the average impact of a shock in the global final demand for each sector's output or volatility risk, conditional on the average population value of the network characteristic of the sector. Put differently, we can identify whether a sector's sensitivity to global demand shock is magnified or smoothed by various features describing the pattern of its linkages to the whole production network.

We first use panel data Fixed Effect estimator to estimate Equation (11). Data is first stratified by country c and then by sector i. Sectoral fixed effects are systematically included in order to account for unobservable factors explaining volatility, like technology or supply chains. There is no time dimension since the dependent variable and D_{ic} account for variations between 2007 and 2009.[10] Two controls for non-i sectors are also included: Labor and capital growth. We also estimate Equation 11 by Generalized Estimating Equations method in the robustness section. As GEE accounts for correlations between records within the same cluster, it produces improved standard errors and more efficient parameter estimators (Liang and Zeger, 1986; Burton et al., 1998). Yet, it has reservations on the distribution of variables and on the covariance matrix and is therefore a less general estimator than the FE estimator (see section 6).

Lastly, it is worth being emphasized that the present article does not explicitly address how sectoral co-movements, i.e. correlated shocks across sectors, impact aggregate volatility, chiefly because our empirical design based on sectors does not allow us to do so.[11] Still, sectoral co-movements are included as a component of the dependent variable (sector contribution to volatility) in our model, and the influence of sectoral co-movements within the same country is accounted for by the simultaneous inclusion of country fixed effects and by clustering errors by country in the robustness check's estimations reported in section 6. The potential influence of co-movements across countries for specific sectors is also controlled for by sector fixed effects.

3.2 Identification issues: Exogenous demand shock

We now seek to put the theoretical relation expressed in Equation 8 into an empirical test, as translated in Equation 11. To do so, we have chosen to focus on the 2008-2009 global crisis since we think it provides a convenient natural experiment set-up.

Indeed, when envisaging to assess the causal impact of sectoral shocks on aggregate volatility, we were conscious of two potential concerns. First, in the medium run, the level of final demand in a given sector that is captured by the national accounts

[10] Other recent studies which use similar panel setting, without a time variable, are Rajan and Subramanian (2011) and Chauvet and Ehrart (2015), among others.
[11] See Foerster et al. (2011) for a recent study accounting for these co-movements.

data might reflect the equilibrium level of demand in that sector rather than the actual level of demand. Empirically it can therefore be tricky to capture the actual demand irrespective of the supply conditions, because what the national statistical agencies collect *a posteriori* or what we observe empirically is the result of market clearing. Symmetrically, in case of supply shortage in the short run, the actual demand in a sector could well be higher than what was effectively supplied and is measured at equilibrium, biasing the measure of shocks and volatility.

Second, along a crisis episode, final demand shock to some sectors may well be endogenous to aggregate volatility. The credit crisis in 2008 rapidly transformed into a trade-induced demand crisis, with all sectors being symmetrically affected. Global trade collapsed faster than world incomes and the trade decline was highly synchronized across countries, albeit with different intensities across sectors (Grossman and Meissner, 2010). Hence, there can be a two-way effect, with aggregate volatility prompted by a limited set of sectors initially hit by shock, like finance or trade, drives in turn sectoral fluctuations of demand to other sectors.

With these two issues in mind, we define our variable for final demand shock as following:

$$D_{ict} = \frac{x^d_{ic,t0}}{X^d_{i,t0}}\left(\frac{X^d_{i,t}}{X^d_{i,t0}} - 1\right) = w^d_{ic,t0}\,\Delta D_{i,t} \qquad (12)$$

where $w^d_{ic,t0}$ is the share of sector i in country c in the global production of goods for final demand in the base year (i.e. 2007), and ΔD_i is the change in the global final demand for sector i between 2007 and 2009.

The main idea behind this definition is to isolate the exogenous component of the final demand shock, making the variable D_{ic} exogenous to the dependent variable (volatility contribution to aggregate volatility). The intuition behind Eq. 12 is that if final demand for a particular industry rises or drops at the global level, the main effects from that change will be observed most in the countries in which the relevant local industry has a higher share in the global sector output. Our definition for D_{ic} is inspired by the "shift-share instrument" initially proposed by Bartik (1991) and extensively employed in the empirical literature on labor. However, our definition is different from the predominant specification of the instrument, because the Bartik instrument is principally used to capture labor demand changes for a "region" (usually counties or municipalities) which consists of several operating local industries, while we would like to capture the demand changes for a “sector” in a given region (i.e., country).[12]

Since we rely on Leontief accounting methods, one restrictive condition of our strategy is that the shock might not be too large to change the very structure of a national economy, meaning that the proportions of all input into any productive process remain fixed. The short time period we use and the fast recovery after the 2008 global demand shock both plead for the fixity assumption. Another crucial assumption concerns the divisibility or indivisibility of the shock. Since divisible shocks split up for each transaction until vanishing, they tend to smear out immediately in such densely connected networks as in an I-O network (Blöchl et al. 2011). If the initial shock’s fractional effect accumulates in all sectors of the economy and quickly reaches a steady state level, then, as Blöchl et al. (2011) argue, “the frequencies that nodes are visited by an indivisible shock can be understood as a proxy for the steady state distribution of a divisible one.”

3.3 Measurement of sector-level network characteristics

In equation 11, we alternately use different measures for the network variable in order to test for various topological properties of the network at node/sector level. Consistently with the theoretical literature discussed in section 2, three dimensions must be considered: (1) first-order degrees with simple measures of sector’s centrality (in-degree and out-degree), (2) more complex measures of centrality considering second-order and higher-order degrees (Random Walk centrality and PageRank centrality) and (3) local density indicators focusing on productive diversification around the node/sector (local clustering coefficient and average degree a node’s neighbours). Asymmetries and second-order degrees put forward by Gabaix (2012) and Acemoglu et al. (2012, 2015) as the crucial dimensions of the network influence on the diffusion of volatility are best proxied by the second set of indicators.

The first group of these metrics measure the *centrality* of a sector in terms of its direct or indirect linkage with all other sectors in the network. In this category, a very basic measure is the ‘first-order degree’, which is the number of adjacencies for a node/sector, i.e. the number of links that a node has (Freeman, 1979). For weighted, directed graphs, i.e. in our case for input-output data, the in-degree (C_i^{id}) and out-degree (C_i^{od}) centralities are defined as the weighted sum of, respectively, incoming and outgoing links for a given node (Segarra and Ribeiro, 2016):

[12] See Beaudry et al. (2014) for a recent application of the Bartik instrument in labor economics.

$$C_i^{id} = \sum_{j\,|(j,i)\in E} w_{(j,i)} \quad ; \qquad C_i^{od} = \sum_{j\,|(i,j)\in E} w_{(i,j)} \tag{13}$$

where $w_{(j,i)}$ is the weight of the link coming from j to i, $w_{(i,j)}$ is the weight of the link going from i to j, and E is the set of directed edges/links in the network. Degree centrality is usually labeled as a node's *strength.*

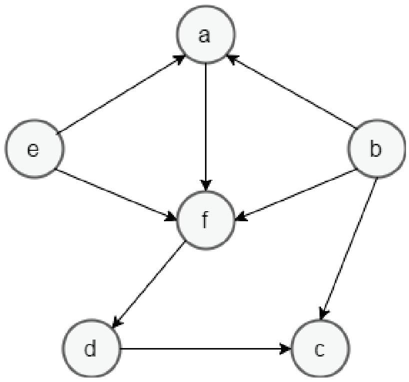


Figure 2: An illustration of a directed network. Node f has the highest in-degree centrality, while node b has the highest out-degree centrality.

Another class of centrality indicators measure 'higher-order centrality' and is particularly relevant for our analysis. As input-output networks are directed, and almost completely connected, with strong self-loops (intra-industry transactions sometimes account more than 50 percent of the sum of a sector's edges), centrality indicators based on shortest paths are in fact meaningless. For instance, "closeness centrality" defined as the mean distance from a node to all other nodes in the network (Freeman, 1979) would make little sense in the case of densely connected networks like input-output graphs, and they usually tend to ignore self-loops (i.e., intra-industry transactions).

Blochl et al. (2011) have proposed an indicator of centrality, based on random walk process, which measures how quickly or how frequently a node is visited during the process of propagation of shocks in the economy. Borgatti (2005) found that movement of goods between sectors is best characterized as a random walk. Blochl et al. (2011) emphasize that the random walk (RW) centrality is particularly fitted to quantify the response of sectors to an economic shock, that is a change in an exogenous variable that has repercussions on the endogenous variables under analysis, with final demand being one possible source of such exogenous shocks. A node is central if it is (1) close to all other nodes, meaning that a shock will arrive more quickly and frequently to it, or (2) located in a central position among other nodes for which it plays a mediating role in the propagation of flows. Blochl et al.'s RW centrality focuses on the first dimension, namely by defining centrality as the frequency and the speed with which it is visited during a random walk process:

$$RWC_i = \frac{n}{\sum_j H(j,i)} \qquad (14)$$

where $H(j,i)$ is the mean first passage time (MFPT), i.e. the expected number of steps a random walker which starts at node j takes to reach i for the first time. If we consider a supply side shock that occurs with equal probability in any sector, then a higher random walk centrality means that the sector is more sensitive to supply and demand conditions anywhere in the economy.

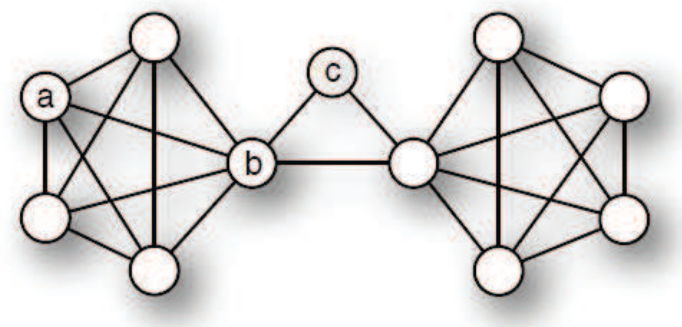


Figure 3: The network is taken from Blochl et al. (2011). Node *b* has a higher Random Walk centrality than *a* and *c*, because any shock originating in the left sub-network and traveling to the right sub-network would more generally pass through *b*. Node *c* has a higher RW centrality than node *a*, but lower than *b*.

PageRank centrality is another centrality measure which results from a random walk of the network (Brin and Page, 1998). It is of particular interest to us, because it coincides with the Acemoglu et al (2012)'s "influence vector" capturing higher-order interconnections (Carvalho, 2012). Cerina et al. (2015) already used PageRank centrality to identify the industries with the largest capacity of influence over other (influential) industries through the chain of indirect linkages. PageRank centrality computes the importance of a node based on the structure of the incoming links, and considers a node to be important if it is connected with other important nodes in the network. A weighted PageRank centrality, which takes into account the weight of the links, is defined as:

$$PR(i) = (1-d) + d \sum_{j \in B(i)} \frac{PR(j)}{k_j^{out}} w_{(i,j)} \qquad (15)$$

where $PR(i)$ and $PR(j)$ are rank scores of nodes i and j, respectively, d is a dampening factor usually set to 0.85, k_j^{out} is the number outgoing links of node j, $B(i)$

is the set of in-neighbours of i, and $w_{(i,j)}$ is the weight of the link between nodes i and j. A higher PageRank score indicates higher importance for the node.

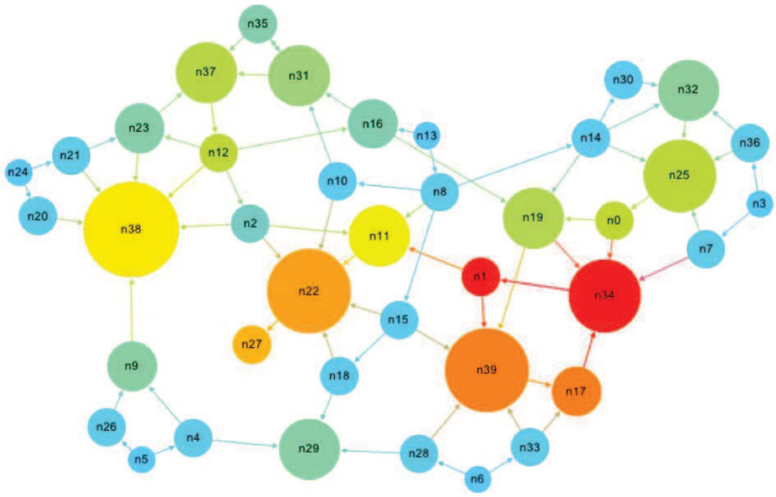


Figure 4: The network is taken from Rieder (2012). Node size represents in-degree, and color represents PageRank score via a heat scale (blue > yellow > red). For instance, although node *n1* has one of the smallest in-degrees, it has one of the highest PageRank scores because it is connected to other influential nodes such as *n39* and *n34*.

The second set of network measures deals with the position of a sector in a neighbourhood of connected sectors. One such metric is the average degree of neighbouring nodes. In the context of the production network, the average degree of a node's neighbours would simply indicate the extent to which a sector deals with other sectors that are themselves well-connected with other sectors in the economy, either as suppliers or as purchasers. Average degree of neighbouring nodes is formally defined as:

$$AvN_i = \frac{1}{|N(i)|} \sum_{j \in N(i)} k_j \qquad (16)$$

where $N(i)$ are the neighbours of node i, and k_j is the degree of node j which belongs to $N(i)$.

Another interesting metric in this category is the "local clustering coefficient" which measures the likelihood of a node being part of a circle of connected nodes. The idea is based on the concept of *transitivity*, in a sense that if node A is connected to node B, and node B to node C, then there is a heightened probability that node A will also be connected to node C. Technically, the three nodes are said to form a *closed triad*.

The local clustering coefficient for a weighted, directed network is defined as (Fagiolo, 2007):

$$CC_i = \frac{(W^{\frac{1}{3}})^3_{ii}}{d_i^{in} d_i^{out} - d_i^{\leftrightarrow}} \tag{17}$$

where $W^{\frac{1}{3}}$ is a weight matrix in which each element is raised by a factor of 1/3, the subscript *ii* notes the *i*-th element of the main diagonal of $(W^{\frac{1}{3}})^3_{ii}$, d_i^{in} and d_i^{out} are respectively the in-degree and out-degree of node *i*, and $d_i^{\leftrightarrow}$ is the number of bilateral links between node *i* and its neighbours.

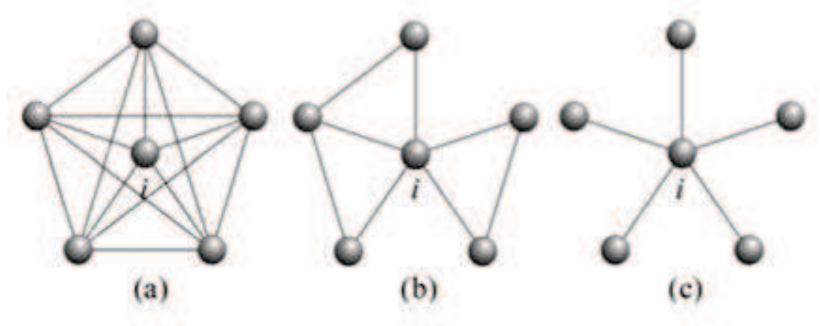


Figure 5: The networks are taken from Costa et al. (2008). In (a), the nodes around *i* are fully connected, and thus the local clustering coefficient for *i* is 1. In (c), node *i* acts like a hub but has a clustering coefficient equal to 0 due to existence of structural holes between its neighbours.

Local clustering is also used as an indicator of so-called "structural holes" in a network – a concept that is highly relevant for our empirical test. Missing links between neighbours in a network are considered as structural holes, which are particularly important if we are interested in studying the efficient spread of information (or shock) throughout the network because they tend to reduce the number of alternative routes of transmission (Newman, 2010, p. 202). Hence, lower values of the local clustering coefficient indicate prevalence of more structural holes around node *i.*

Xu et al. (2011) explain that, in diversified economies, upstream inputs and downstream outputs are well diversified, and alternative suppliers and/or demanders exist depending on substitutability of inputs. The more alternative input-output routes across sectors in the economy, the weaker the propagation of shocks. Thus the local clustering coefficient can be seen as a proxy for the speed or intensity of the propagation of shocks in a neighbourhood or sub-network.

4. Data

We use world input-output tables (WIOTs) developed by Timmer et al. (2015) to build a unique dataset which consists of 35 sectors in 41 countries (1,435 sectors in total). The list of sectors and countries are shown in Appendix II. The descriptive statistics of the variables are presented in Table 1.

Table 1: Descriptive statistics of selected variables

	No. Obs.	Mean	Std. Dev.	Min	Max
Contrib. to volatility *non-i*	1416	5.703	3.629	-0.787	16.514
Shock $_i$	1416	0.358	0.920	-1.052	13.344
Cap. gr. *non-i*	1144	0.049	0.100	-0.980	0.241
Lab. gr. *non-i*	1331	-0.005	0.050	-0.143	0.140
Trade open. $_i$	1416	26.08	29.54	-153.01	118.72
In-degree $_i$	1391	36,388	91,192	0	1,091,579
Out-degree $_i$	1396	36,258	109,864	0	2,207,168
Random walk centrality $_i$	1389	0.745	5.268	0.001	153.090
PageRank $_i$	1435	0.001	0.001	0.000	0.012
Ave. degree of neighb. nodes $_i$	1389	1,596	515	237	2,763
Local clustering coef. $_i$	1389	0.575	0.185	0.086	0.995

World input-output tables are in chain-linked volumes, and are thus comparable across years. The data for gross output and final demand come from the WIOTs, while the data for capital stock and employment come from the Socio-Economic Accounts, also developed by Timmer et al. (2015) for the 2013 release of the WIOTs, expressed in constant prices. We estimate the capital stock changes for a number of missing countries using data from the OECD's STAN Database for Structural Analysis.

The WIOT includes the rest of the world (ROW) as a single consolidated region, which captures all residual transactions with 40 individual countries. While the node-level network measures, defined in Equations 13-17, have been computed over the entire world input-output network (including the ROW), the econometric model only uses the data for 40 countries and excludes the observations for the ROW. The connections with the ROW ought to be included while computing the network measures so as to ensure that they are computed over a full global network and that we capture all existing inter-industry linkages.[13] We produce the network of inter-sectoral flows using the WIOT in 2007, and compute the node-level network measures using MATLAB.

5. Estimation of a sector's indirect contribution to aggregate volatility through network contagion

Results of the fixed effect estimation of equation (11) are reported in Table 2. Country and sector fixed effects are included. Column 1 shows that, unsurprisingly, a shock to sector *i* has no *direct* effect on other sectors' contributions to overall volatility. Likewise, the insignificant coefficients of the shock variable in columns 4 to 5 suggest that the impact of a shock to sector *i* does not automatically translate into volatility induced by other sectors when its indirect impact through complex network linkages is controlled for.

Rather, the propagation of a shock to other sectors – via network contagion – depends on the local structure of the production network, hence the interaction between the shock and network variables. In what concerns the local centrality, measured by the first-order degrees, only out-degree centrality has a significant impact on the transmission of shock during the period investigated (Column 3). The transmission of shocks is therefore relevant only for large input suppliers which is best captured by high levels of out-degree centrality. Expectedly, the coefficient of the interaction term with *random walk centrality* is not significant, confirming that the vulnerability of a sector to shock(s) originating elsewhere in the economy might not affect its propensity for volatility transmission to the rest of the economy.

These results suggest that local centrality, as measured by first-order degrees, only makes sense in the case of input suppliers, as captured by out-degree centrality, in shaping the transmission of sectoral shocks. This does not, however, disqualify any possible impact of more complex notions of centrality, such as *PageRank centrality*. The PageRank centrality assesses the overall influence of a node over the network by measuring the intensity of its connections to other influential nodes. It is therefore a more complex indicator of centrality than the in-degree and out-degree measures, since it includes higher-order degrees in the definition of a sector's centrality, notably by accounting for the degrees featured by other influential nodes to which the sector is tied.

[13] However, the ROW is excluded from the econometric regressions because it is a group of heterogeneous countries and may bias our estimates due to the large weights they carry.

Table 2: Regression of non-*i* sectors' contribution to aggregate volatility (2007-2009): Interaction of shock and network characteristics of sector *i*

Dependent variable: Non-*i* sectors' contributions to aggregate volatility

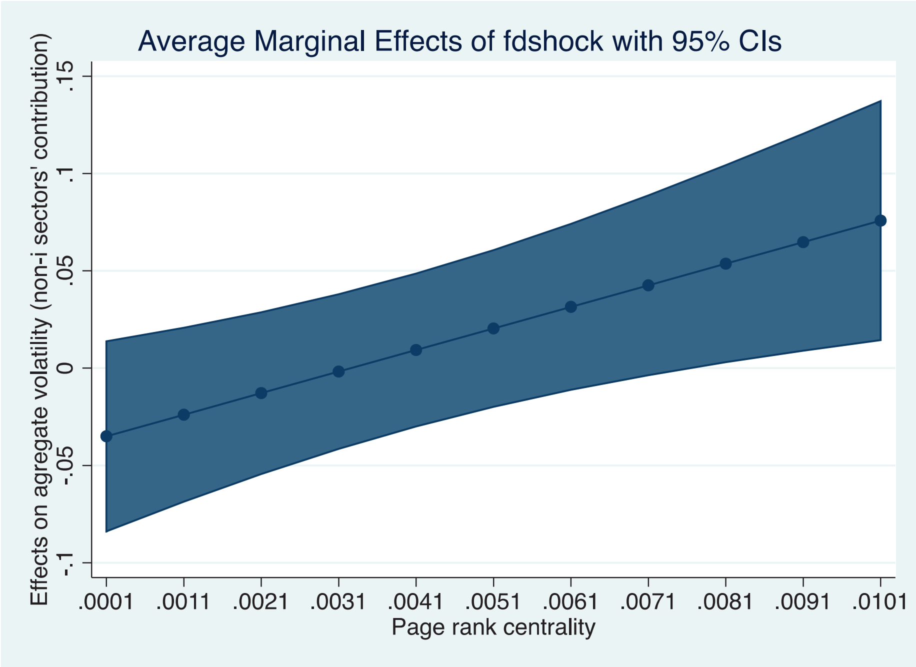
Network characteristics of sector *i*	(1) -	(2) In-degree	(3) Out-degree	(4) Random walk centrality	(5) PageRank centrality	(6) Average degree of a node's neighbours	(7) Local clustering coefficient
Cap. gr. non-*i*	1.236	1.272	1.174	1.205	.955	.238	.238
	(1.36)	(1.36)	(1.36)	(1.36)	(1.34)	(1.32)	(1.32)
Lab. gr. non-*i*	-7.81***	-7.299***	-7.280***	-7.96***	-6.57**	-7.10***	-7.10***
	(2.74)	(2.79)	(2.79)	(2.76)	(2.74)	(2.68)	(2.68)
Shock $_i$	-.024	-.062**	-.051**	-.025	-.036	.045	.045
	(.018)	(.028)	(.022)	(.018)	(.025)	(.029)	(.029)
Network $_i$	-	-2.7e-08	-5.9e-07**	.004**	-95.37***	2.6e-04***	.734***
		(2.9e-07)	(2.9e-07)	(.002)	(20.33)	(3.1e-05)	(.086)
Shock_i*Ntwrk_i	-	7.0e-08	1.4e-07**	.933	11.08***	-5.5e-05**	-.153**
		(5.3e-08)	(6.5e-08)	(1.48)	(3.89)	(2.7e-05)	(.076)
Constant	5.97***	6.00***	6.00***	5.96***	6.05***	5.63***	5.63***
	(.087)	(.089)	(.089)	(.090)	(.088)	(.09)	(.095)
N	1,109	1,101	1,100	1,099	1,109	1,099	1,099
Groups	35	35	35	35	35	35	35
R^2 within	.18	.18	.18	.18	.20	.23	.23

*Values in parentheses are standard errors; *** for p < 0.01, ** for p < 0.05, and * for p < 0.1.* All regressions include country and sector fixed effects. The dependent variable is the contribution of non-*i* sectors to aggregate volatility between 2007 and 2009. The Network variable is specified at the head of columns 2-7. For example, in column 2, the Network coefficient gives the estimated main impact of the number of incoming flows to sector *i* on the aggregate volatility in the absence of any shock, while the coefficient of the interaction Shock*Network gives the average impact of the number of incoming degrees in the case of a sectoral shock.

The positive coefficient of the interaction term Shock*PageRank in column 5 means that a shock to a more influential sector increases all other sectors' contributions to aggregate volatility. As emphasized by Carvahlo (2012), the Acemoglu et al.'s (2012) influence vector is formally close to the definition of PageRank centrality. The impact of an idiosyncratic shock on aggregate volatility is significantly magnified when the affected sector is influential, in a sense that it is more closely linked to other sectors that are themselves influential. High values of *PageRank centrality* denote, at sector level, equally high values of higher-order degrees. Through these cascade effects, aggregate volatility increases once influential sectors are hit by local shocks, although the productive system is otherwise strongly diversified. This finding must therefore be related to Acemoglu et al.'s (2012) analytical argument that higher-order interconnections, subsumed by their 'influence vector', prompt aggregate volatility through 'cascade' effects, whereby sectoral shocks propagate to the rest of the economy through the sequence of links between downstream (for supply shocks) or upstream (for demand shocks) sectors. Sectoral shocks contribute more strongly to aggregate fluctuations if the distribution of inter-sectoral linkages is strongly asymmetrical across the input-output matrix, that is if the productive structure comprises a handful of very large and influential sectors.

Conversely, the negative coefficients of the interaction term in columns 6 and 7 show that the impact of a shock on aggregate volatility is smoothed when the sector hit by the shock is surrounded by sectors that have more diversified links and are themselves connected with each other (*average degree of a node's neighbour* and *local clustering coefficient*). This result suggests that a shock to a denser and better-connected region within the production network may be absorbed throughout the production network by the existence more alternatives routes of shock transmission in the neighbourhood of the affected sector. As formalized by Blöchl et al. (2011), this substitution between diversified alternative links literally breaks down the propagation of idiosyncratic shocks across the different nodes (sectors) of the production network, through input provision. Note that fixed effects estimations with errors clustered by country do not modify these results.

By computing the marginal effects, we can say that, everything else equal, we would expect a 4 to 7 percentage point increase in aggregate volatility after a one unit increase (on a scale of 14) in the intensity of shock for sectors with very high centrality (the top 1% of PageRank centrality distribution), and a 5 to 10 percent point decrease in aggregate volatility after a one unit increase in the intensity of shock for sectors with high local density (the top 40% of the "average degree of neighbours" distribution). The former result is in line with the works by Gabaix (2011) and Acemoglu et al. (2012) which insist on the fat-tailed distribution of firm or sectoral influence within the productive network. These results suggest that while there are only few sectors that may transform idiosyncratic shocks into aggregate volatility due to their influence over the whole productive network, there might be more numerous sectors for which the local density of linkages might absorb idiosyncratic shocks.



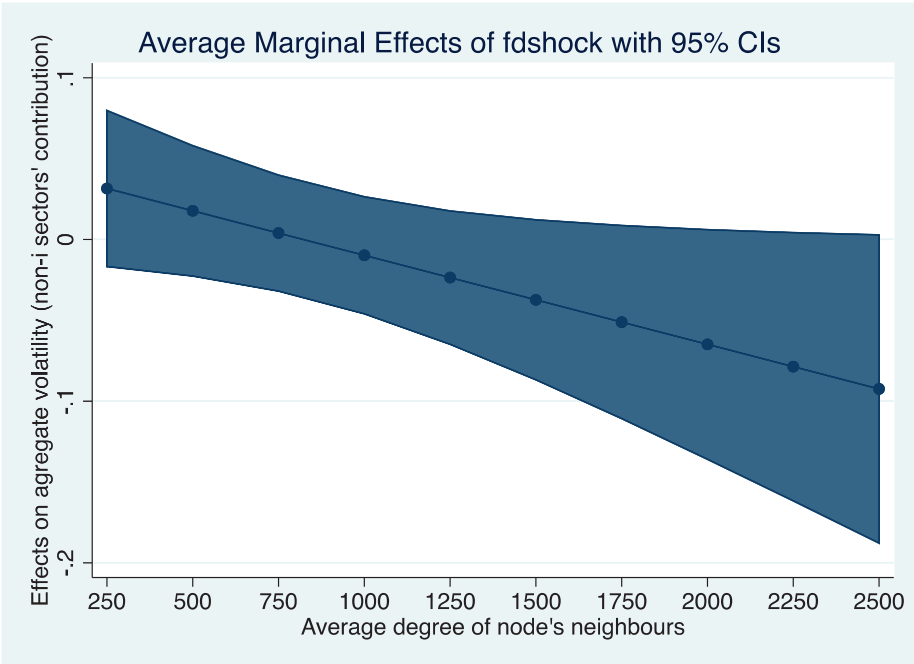


Figure 6: Predicted marginal effects of a one unit increase in the intensity of demand shock on non-*i* sectors' contribution to aggregate volatility for various levels of PageRank centrality and of average degree of neighbouring nodes.

We now include various structural and policy variables controlling explicitly for country observable characteristics that might condition the way sector's network characteristics translate an idiosyncratic shock into aggregate volatility. These additional control variables, including trade openness, financial development (proxied by domestic credit in percent to GDP) and distance to technological frontier (measured

Table 3: Regression of non-*i* sectors' contribution to aggregate volatility (2007-2009): Shock and network characteristics interaction and country-level controls

Dependent variable: Non-*i* sectors' contributions to aggregate volatility

Network $_i$:	(1) -	(2) In-degree	(3) Out-degree	(4) Random walk centrality	(5) PageRank centrality	(6) Average degree of a node's neighbours	(7) Local clustering coefficient
Cap. gr. non-*i*	1.082	1.133	1.041	1.098	.833	.163	.163
	(1.25)	(1.25)	(1.25)	(1.26)	(1.24)	(1.22)	(1.22)
Lab. gr. non-*i*	-8.06***	-7.64***	-7.74***	-7.99***	-6.83**	-7.46***	-7.46***
	(2.53)	(2.57)	(2.58)	(2.56)	(2.54)	(2.47)	(2.47)
Shock $_i$	-.029*	-.071***	-.052**	-.028	-.045**	.042	.042
	(.017)	(.026)	(.021)	(.017)	(.023)	(.027)	(.027)
Network $_i$	-	1.01e-07	-4.6e-07*	.003	-86.59***	2.5e-04***	.700***
		(2.7e-07)	(2.8e-07)	(.002)	(18.85)	(2.9e-05)	(.081)
Shock*Ntwrk	-	6.4e-08	1.2e-07*	-.493	11.00***	-5.9e-05**	-.164**
		(4.8e-08)	(5.9e-08)	(1.41)	(3.59)	(2.5e-05)	(.070)
Openness	-.0004	-.0003	-.0003	-.0005	-.0002	-.001	-.001
	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)
Financial dev.	.039***	.039***	.039***	.039***	.039***	.040***	.040***
	(.001)	(.002)	(.002)	(.001)	(.002)	(.001)	(.001)
Dist. to GDP$_{US}$	-.874***	-.902***	-.884***	-.853***	-.914***	-.825***	-.825***
	(.202)	(.204)	(.204)	(.205)	(.201)	(.197)	(.197)
Constant	2.57***	2.56***	2.57***	2.58***	2.55***	2.16***	2.16***
	(.174)	(.176)	(.177)	(.176)	(.173)	(.177)	(.177)
N	1,074	1,067	1,066	1,065	1,074	1,065	1,065
Groups	35	35	35	35	35	35	35
R^2 within	.99	.99	.99	.99	.99	.99	.99

*Values in parentheses are standard errors; *** for p < 0.01, ** for p < 0.05, and * for p < 0.1.* All regressions include country and sector fixed effects. The dependent variable is the contribution of non-*i* sectors to aggregate volatility between 2007 and 2009. The Network variable is specified at the head of columns 2-7. For example, in column 2, the Network coefficient gives the estimated main impact of the number of incoming flows to sector *i* on the aggregate volatility in the absence of any shock, while the coefficient of the interaction Shock*Network gives the average impact of the number of incoming degrees in the case of a sectoral shock.

by distance in income per capita with the U.S.) are constant across sectors within a country, and they are defined for the base year (i.e. 2007). The estimation results, reported in Table 3, remain fully consistent with the baseline estimations reported in

Table 2. The results show that country trade openness does not have any impact on aggregate volatility, while financial development seems to increase aggregate volatility. Meanwhile, technological level matters for the shock transmission. Countries that are closer to the technological frontier experience lower aggregate volatility, while those at lower levels of technology tend to have higher fluctuations.[14] Nevertheless, country characteristics like financial development and trade openness do not condition the impact of network characteristics on aggregate volatility as the interaction terms between these country characteristics and shock*network are not significant (results are not reported). Likewise, distance to the frontier does not condition the transmission of volatility through network characteristics. These results suggest that the transformation of sectoral shocks into aggregate volatility exclusively relies on sector characteristics and not on country characteristics. Hence, the way production networks influence aggregate volatility is neither conditional on trade or financial policies, nor determined by the level of economic development.

Probing into the type of sectors, estimation results reported in Table 4 show that "service" sectors demonstrate a stronger capacity to translate idiosyncratic shocks into aggregate volatility through contagion effects. Allowing for triple interaction between the shock variable, network characteristics, and the dummy variable for service sectors, the statistical significance of the results is much higher. First-order centrality (in-degree and out-degree) now shows a statistically significant effect for the interaction term, while the random walk centrality remains insignificant – consistent with the previous results for the overall sample. The results for PageRank centrality and the two measures of neighbourhood characteristics in the network remain similar to the results for the overall sample estimation.[15] However, the results for the same interaction with manufacturing and primary sectors, respectively, were not statistically significant, suggesting that these sectors do not have a different behavior. This finding points to the fact that service industries play a more active role in transmitting the effects of an idiosyncratic shock to aggregate volatility through their inter-sectoral connections in the network. We also tested whether the degree of *sectoral* trade openness has any impact on transmitting idiosyncratic shocks to aggregate volatility; the estimated coefficient for the triple interactive with sectoral trade openness was not statistically significant.

[14] Note that these results are consistent with the technological diversification model of Koren and Tenreyro (2013) finding that aggregate volatility decreases with economic development.

[15] Clustering errors by country does not modify the results reported in Table 4 (results are not reported).

Table 4: Regression of non-*i* sectors' contribution to aggregate volatility: Interaction between shock, network characteristics, and service dummy variable

Dependent variable: Non-*i* sectors' contributions to aggregate volatility

Network $_i$:	(2) In-degree	(3) Out-degree	(4) Random walk centrality	(5) PageRank centrality	(6) Average degree of a node's neighbours	(7) Local clustering coefficient
Cap. gr. non-*i*	.136	.157	.182	.068	.395	-.395
	(.903)	(.919)	(.923)	(.909)	(.891)	(.892)
Lab. gr. non-*i*	8.351***	8.846***	8.046***	7.979***	6.377**	6.377**
	(2.67)	(2.74)	(2.70)	(2.67)	(2.61)	(2.61)
Shock $_i$	-.187***	-.091***	-.073***	-.119***	.026	.026
	(.039)	(.030)	(.028)	(.039)	(.033)	(.033)
Network $_i$	-1.7e-06***	-8.6e-07***	.018**	-86.55***	2.1e-04***	.591***
	(4.4e-07)	(2.9e-07)	(.008)	(22.56)	(3.3e-05)	(.092)
Shock*Ntwrk*	4.4-07***	1.80e-07***	1.038	19.63***	-6.8e-05**	-.188**
Services	(9.0e-08)	(6.1e-08)	(1.275)	(4.85)	(2.9e-05)	(.081)
	6.324***	6.30***	6.27***	6.33***	5.88***	5.88***
Constant	(.061)	(.062)	(.063)	(.062)	(.088)	(.088)
N	484	484	484	484	484	484
Groups	33	33	33	33	33	33
R^2 within	.27	.24	.24	.26	.30	.30
Clustd err.	No	No	No	No	No	No

*Values in parentheses are standard errors; *** for p < 0.01, ** for p < 0.05, and * for p < 0.1.* All regressions include country and sector fixed effects. The dependent variable is the contribution of non-*i* sectors to aggregate volatility between 2007 and 2009. The Network variable is specified at the head of columns 2-7. For example, in column 2, the Network coefficient gives the estimated main impact of the number of incoming flows to sector *i* on the aggregate volatility in the absence of any shock, while the coefficient of the interaction Shock*Network gives the average impact of the number of incoming degrees in the case of a sectoral shock.

To summarize, our estimations show that: (1) the impact of a sectoral shock on aggregate volatility does exist; (2) it is indirect and integrally transmitted through inter-sectoral linkages across the production network; (3) its sign and direction varies with respect to the type of network characteristics, with shocks to more 'influential' sectors or input suppliers leading to larger aggregate volatility while shocks to sectors that are located in denser sub-networks being absorbed throughout the network; (4) observable country characteristics like trade openness, financial development or technological level – or sector-level characteristic like trade exposure – do not condition the transmission of shocks; and (5) services are more conducive than manufacturing industries in translating idiosyncratic shocks into aggregate volatility through contagion effects.

6. Corroboration tests using alternative outcome variables as dependent variables

In this section, we present two corroboration tests supporting our main finding of section 5 by modifying the nature of the dependent variable. We show that the conditional impact of network characteristics of a sector is consistent across different types of outcome variables: (1) the direct contribution to aggregate volatility of a sector affected by the shock, and (2) the indirect contribution to GDP growth of a sector affected by the shock.

6.1. How do network characteristics condition a sector's direct contribution to aggregate volatility?

The previous sub-section, in which we discussed the *indirect* contribution of a sector to aggregate volatility through the network contagion effects, leaves one question unresolved. One may argue that since part of the shock to influential sectors is transmitted to other sectors through indirect linkages (higher-order degrees), then the own direct contribution of these influential sectors to aggregate volatility should be relatively lower. Symmetrically, the direct impact of sectors located in dense parts of the network should decrease since they are averaged out with more diversified linkages. Therefore, it is important to study the direct contribution of a sector to aggregate volatility given its network characteristics – a task that we undertake in this sub-section – in order to corroborate our main findings. The coefficient of Shock$_i$ measures the impact of a sectoral shock on aggregate volatility through its own direct contribution to volatility, whatever the network characteristics of the sector, while the coefficient of the interaction Shock*network measures how the former impact is modulated by the sector's position or status in the production network.

To do so, we use the direct marginal contribution of a sector to aggregate volatility as our dependent variable. To avoid estimating the exact reciprocal of Equation 11, we choose to separate out the shock-driven volatility from the current volatility contributions, and focus on the contribution to *excess* volatility, i.e. the net additional aggregate volatility prompted by the 2007-2009 shock. To measure excess volatility, we compare the volatility observed over the 2007-2009 period (r_{ic}) against (r_{ic}^{B}) the long-term "benchmark" of the 1997-2007 pre-crisis volatility contribution of each sector i.[16] We simply define y_{ic}, the contribution of sector *i,c* in the aggregate *excess* volatility between 2007 and 2009, as the difference between r_{ic} and r_{ic}^{B}.

To ensure consistency, the shock variable D_{ic} is also expressed in excess to the average 10-year pre-crisis level of the Bartik instrument for the pre-crisis period (1997-2007), or formally as $D_{ic} = \frac{\dot{w}_{ic,2007}\ \Delta D_{i,2007-2009}}{\dot{w}_{ic,1998}\ \Delta D_{i,1998-2007}}$. Since both volatility variables (the sectoral exogenous shock and the sectoral contribution to aggregate volatility) are expressed in 'excess' to pre-crisis average level, we can safely say that a positive sign for the estimated *shock* coefficient would mean that an 'excessive' shock to final demand, irrespective of whether it is a positive or a negative shock, increases the sector's contribution to 'excess' aggregate volatility.

We therefore specify our model as following:

$$y_{ic} = \propto_0 + \propto_1 D_{ic} + \propto_2 M_{ic} + \propto_3 D_{ic} M_{ic} + \grave{Z}_{ic} \propto_4 + \tau_c + \varepsilon_i + u_{ic} \qquad (18)$$

where $y_{i,c}$ is the contribution of sector *i,c* in the aggregate *excess* volatility between 2007 and 2009 as defined above, D_{ic} is the Bartik indicator of final demand shock for sector i in country c between 2007 and 2009, also expressed in *excess* of the long-term pre-crisis level, M_{ic} is a measure of network properties for sector *i,c* in the base year (i.e., 2007), $\grave{Z}_{i,c}$ is a vector of observed characteristics for each sector *i,c*, including changes in capital stock, changes in employment, and trade openness, τ_c and ε_i are country and sector fixed effects, and $u_{i,s}$ is the error term.

The estimation results for Equation 18 are reported in Table 5. Column 1 confirms that, on average, and expectedly, idiosyncratic shocks did increase a sector's direct contribution to aggregate volatility during the period investigated, whatever the sector's position in the production network. Moreover, columns 2 and 3 show that first-order degrees do not matter as the volatility impact of shocks to sectors featuring higher in- and out-degrees is significantly different from that of the whole population (.005 and .006 respectively) albeit with a very low point estimate magnitude of the conditioning impact (-5.7e-08 and -5.2e-08). This is, however, not true for other topological dimensions. Column 4, for instance, shows that for sectors featuring higher *random walk centrality*, i.e., the estimated positive impact of a shock on the sector's contribution to excess volatility (1.92087 = 1.92 + 8.7e-04) is significantly larger than that of the whole population (.00087). This result is fairly consistent since we could logically expect the contribution to excess volatility to be higher for the sectors that are

[16] Our concept of contribution to excess volatility is inspired by methods in portfolio performance management, but our method of calculation remains different from the performance attribution measures used in ex-post portfolio analysis.

Table 5: Estimation of sector *i* direct contribution to excess aggregate volatility: Interaction between shock, network characteristics

Dependent variable: Sector *i*'s contribution to aggregate excess volatility							
Network $_i$	(1) Baseline	(2) In-degree	(3) Out-degree	(4) Random walk centrality	(5) PageRank centrality	(6) Average degree of a node's neighbours	(7) Local clustering coefficient
Cap. gr. *i*	.316***	.313***	.312***	.296***	.306***	.295***	.295***
	(.032)	(.032)	(.032)	(.032)	(.032)	(.032)	(.032)
Lab. gr. *i*	.167***	.161***	.158***	.137***	.155***	.141***	.141***
	(.016)	(.016)	(.016)	(.017)	(.016)	(.017)	(.017)
Trade $_i$	3.3e-04**	3.4e-04**	3.4e-04**	3.4e-04**	3.4e-04**	3.4e-04**	3.4e-04**
	(1.4e-04)	(1.5e-04)	(1.5e-04)	(1.4e-04)	(1.5e-04)	(1.5e-04)	(1.5e-04)
Shock $_i$	.003***	.005***	.006***	8.7e-04	.008***	-.010***	-.010***
	(7.6e-04)	(.001)	(.001)	(8.5e-04)	(.001)	(.002)	(.002)
Network $_i$	-	-8.2e-09	-3.5e-08	-1.3e-04	1.78	2.6e-06	.007
		(4.6e-08)	(3.4e-08)	(8.1e-04)	(3.90)	(7.8e-06)	(.021)
Shock*Ntwrk	-	-5.7e-08***	-5.2e-08***	.0019***	-7.03***	8.5e-06***	.024***
		(1.8e-08)	(1.4e-08)	(2.9e-04)	(1.80)	(1.5e-06)	(.004)
Constant	-.025*	-.025*	-.025*	-.023*	-.026*	-.028	-.028
	(.014)	(.014)	(.014)	(.014)	(.014)	(.019)	(.019)
N	1,104	1,100	1,099	1,099	1,104	1,098	1,098
Groups	35	35	35	35	35	35	35
R^2 within	.26	.26	.27	.27	.27	.28	.28
			Yes	Yes	Yes	Yes	Yes

*Values in parentheses are standard errors; *** for p < 0.01, ** for p < 0.05, and * for p < 0.1.* All regressions include country and sector fixed effects. The dependent variable is a sector's contribution to excess aggregate volatility between 2007 and 2009. The Network variable is specified at the head of columns 2-7. For example, in column 2, the Network coefficient gives the estimated main impact of the number of incoming flows to sector *i* on the aggregate volatility in the absence of any shock, while the coefficient of the interaction Shock*Network gives the average impact of the number of incoming degrees in the case of a sectoral shock.

most frequently visited during the shock propagation to the economy. As for the 'influence' dimension is concerned, as measured by the *PageRank centrality*, column 5 shows that the estimated impact of a shock on the sector's contribution to excess volatility becomes negative (-7.022 = .008 - 7.03) for the influential sectors, while it is positive (.008) for the whole population. Estimations for the average degree of a node's neighbours and local clustering coefficient are rather uneasy to interpret because the shock coefficient takes a negative sign and the sum of the shock and interaction's coefficients is contradictory; negative for the first variable and positive for the second one. Column 7 shows that, for sectors featuring higher values for *local clustering coefficient*, i.e. those located in the densest and connected parts of the IO network which have least structural holes, the estimated positive impact of a shock on the sector's contribution to excess volatility is again significantly larger than that for the whole population. Column 6 shows that the sector's contribution to excess volatility also becomes negative for the sectors featuring higher values of the *average degree of node's neighbours*, that is those connected with neighbours that are themselves well-connected, although the interactive effect is smaller compared to the average population. Estimation results are not modified when errors are clustered by country (see Table A2 in Appendix IV).

Equation 18's estimation results thus suggest that when a shock affects a sector that is more easily accessible to other sectors – those with higher RW centrality – or are located in a dense part of a network – those with higher local clustering coefficient, – it increases that very sector's direct contribution to aggregate excess volatility. However, when the shock hits a more influential sector – that with higher PageRank score, – it reduces that very sector's contribution to excess aggregate volatility to the benefit of the other sectors, because volatility is transferred to these other sectors through the structure of the IO network. Results of this corroboration test therefore confirms the findings of the previous sub-section showing that higher *PageRank centrality* did increase aggregate volatility through *contagion* effects.[17]

6.2. How do network characteristics condition a sector's indirect contribution to GDP growth?

In Equations 11 and 18, output volatility is computed using two data points, namely 2008 and 2009 growth rates, which may raise a number of statistical weakness issues. First, these two years may either underestimate the true volatility because they are too short to really seize the fluctuations, or, on the contrary, they may overestimate them because the two years may record only the downward and then the recovery swings of output linked to the crisis, which may correspond to the paroxystic phase of volatility. Second, an inherent flaw in the definition of standard deviation is that if changes in growth over the course of the period do not vary, for instance if the output growth of a sector is constantly –2 percent in both years, the standard deviation would

[17] Tables A2, A4 and A6 in Appendix II show that these results hold when the standard errors are clustered by country, albeit with slightly lower significance levels, when dominant sectors are excluded and when the model is estimated with alternative estimators. See section 7 for the justification of these robustness tests.

give a value of zero which shows no indication of volatility. In one sense, this may not be a flaw, because a constant –2 percent growth every year is not a fluctuation *per se*. However, for the purpose of our study, we are equally interested in knowing the *output losses* during the Great Recession, even if the negative growth rates were constant.

A priori, we would expect that these weaknesses or flaws should not be relevant in our case and should not pose any credible concern for our analysis. First, in our data, none of the sectors has constant growth rates over 2008 and 2009. For only 6 percent of the sectors, the absolute differences in growth rates between the two years are less than 0.5 percentage point. Second, what we are interested in is the cross-sectoral and cross-country heterogeneity in volatility and not the time heterogeneity. Indeed, all countries' and sectors' output volatilities have been recorded during the same episode of symmetric crisis. Still, in order to ensure that our results are not driven by these measurement issues, we change our dependent variable to non-*i* sectors' contribution to GDP *growth*, averaged over 2008 and 2009. GDP growth contribution should be less sensitive to the measurement issues underlined above, and easily conveys an *indirect* interpretation for output volatility. Empirical data shows that output growth and output volatility are indirectly or inversely related over the long-term, with lower GDP growth rates being correlated with higher output volatility. We observe a similar pattern in our cross-sectoral data, too. Figure 7 plots sectoral growth

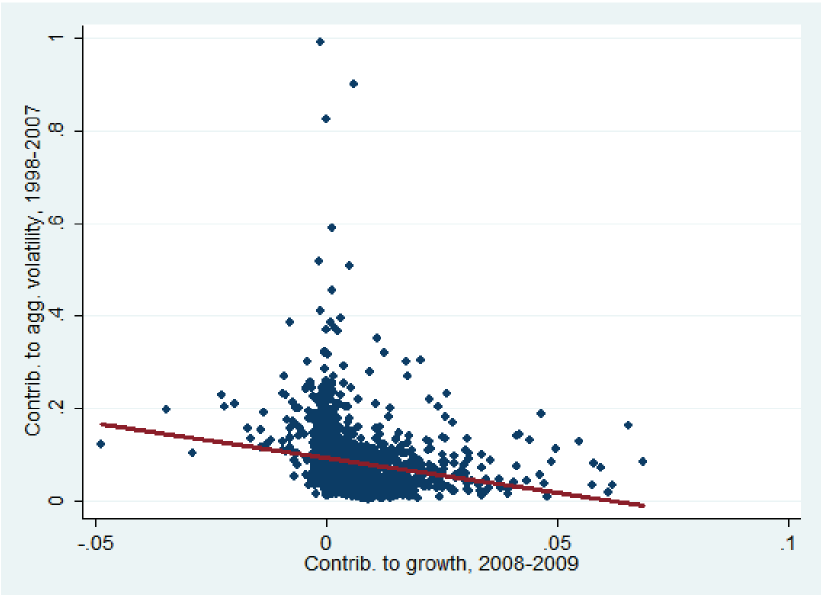


Figure 7: Scatterplot of sectoral contributions to aggregate growth (2008-2009) and to aggregate volatility (1998-2007), for approximately 1435 sectors (35 sectors in 41 countries)

contributions over 2008-2009 against their long-term pre-crisis volatility (i.e., for 1998-2007). As expected, sectors which were inherently more volatile experienced lowest growth rates or largest output loss between 2007 and 2009.

We therefore replace the dependent variable in Eq. 11 as following:

$$g_{non-ic} = \propto_0 + \propto_1 D_{ic} + \propto_2 M_{ic} + \propto_3 D_{ic} M_{ic} + \grave{Z}_{ic} \propto_4 + \tau_c + \varepsilon_i + u_{ic} \quad (19)$$

where g_{non-ic} is the total GDP growth contribution of all non-*ic* sectors, averaged over 2008 and 2009. The estimated results for equations 18 and 19 should be easily comparable, as both dependent variables measure growth and volatility spillovers from sector *ic* to all other sectors. Therefore, given the inverse relation between growth and volatility, we should expect opposite results in Eq. 19. Particularly, the estimated coefficient for our main variable of interest (i.e., *Shock*Ntwrk* interaction) should have opposite sign as compared to in Eq. 18.

The estimation results are reported in Table 6. For first-order degrees, the shock interaction is now statistically significant for *in-degree*, while it was significant for *out-degree* in model 18 which had 'contribution to volatility' as the dependent variable. It seems that idiosyncratic shocks to input *purchasers* have, on average, led to lower growth contributions (or possibly output loss) through inter-industry linkages during the period investigated. As for the second-order degrees, the sign of the estimated shock interactive with respectively PageRank centrality, average degree of neighbouring nodes, and local clustering coefficient are now the opposite of those estimated in model 18. It seems that a shock to more influential sectors (those with higher PageRank scores) has, on average, dampened any positive growth spillover effects through other sectors, while a shock to sectors located in dense sub-networks (i.e., higher average degree of neighbouring nodes or higher local clustering coefficient) has, on average, led to higher growth contributions through inter-sectoral linkages. The latter particularly confirms that growth spillover effects are important in denser and more well-connected industry clusters. The interactive for RW centrality is not statistically significant, similar to in Eq. 18, for the reasons which were previously discussed.

In short, the results for Equation 19, which employs growth contribution of all non-*ic* sectors as the dependent variable, indirectly supports the estimated results for Equation 11 which directly use contribution of other sectors to aggregate volatility as the dependent variable. Thus, it is unlikely that our results in Equation 18 are driven by measurement issues pertaining to the use of the standard deviation.

Table 6: Regression of non-*i* sectors' contribution to GDP growth: Shock and network characteristics

Dependent variable: Non-*i* sectors' contribution to aggregate GDP growth

Network $_i$	(2) In-degree	(3) Out-degree	(4) Random walk centrality	(5) PageRank centrality	(6) Average degree of a node's neighbours	(7) Local clustering coefficient
Cap. gr. *I*	-.232**	-.228**	-.222**	-.232**	-.273**	-.273**
	(.106)	(.106)	(.107)	(.105)	(.106)	(.106)
Lab. gr. *i*	-.147***	-.147***	-.149***	-.145***	-.143***	-.143***
	(.053)	(.053)	(.053)	(.052)	(.052)	(.052)
Shock $_i$	.043*	.021	.009	.040*	-.040	-.040
	(.024)	(.019)	(.016)	(.021)	(.025)	(.025)
Network $_i$	4.3e-07*	3.4e-07	-.0003	41.09**	-9.4e-05***	-.262***
	(2.4e-07)	(2.5e-07)	(.002)	(17.01)	(2.8e-05)	(.074)
Shock*Ntwrk	-9.7-08**	-6.2-08	1.23	-9.05***	5.3-05**	.146**
	(4.3e-08)	(5.4e-08)	(1.23)	(3.23)	(2.3e-05)	(.065)
Constant	-1.86***	-1.85***	-1.85***	-1.86***	-1.71***	-1.71***
	(.050)	(.049)	(.051)	(.050)	(.064)	(.064)
N	1,101	1,100	1,101	1,105	1,099	1,099
Groups	35	35	35	35	35	35
R^2 within	.17	.17	.17	.17	.18	.18
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes
Clustd err.	No	No	No	No	No	No

*Values in parentheses are standard errors; *** for p < 0.01, ** for p < 0.05, and * for p < 0.1.* All regressions include country and sector fixed effects. The dependent variable is a sector's indirect contribution to GDP growth between 2007 and 2009. The Network variable is specified at the head of columns 2-7. For example, in column 2, the Network coefficient gives the estimated main impact of the number of incoming flows to sector *i* on the aggregate output growth in the absence of any shock, while the coefficient of the interaction Shock*Network gives the average impact of the number of incoming degrees in the case of a sectoral shock.

7. Various additional robustness tests

In this section, we run a number of additional robustness tests to further support the validity of our main findings exposed in section 5.

First, a potential concern that may arise with respect to our shock variable is that, in countries where the local sector has a large share in the global production, our specification of the Bartik instrument may not remain entirely exogenous. In cases where the local industry dominates the global output of the industry and could possibly be a price-maker at the global level, the final demand shock as captured by our shift-share instrument could be influenced by the dependent variable. To test if such concern for endogeneity is justified, we exclude the dominant sectors from our sample and assess if we observe any changes in our results. We exclude those local sectors which supply more than 10 percent of the global gross output in that industry. Per our data, many industries in the US, China and Japan dominate the global production, which is not surprising given the size of these economies. Other than those, Germany in machinery, and in transport equipment, and Italy in leather and footwear are producing more than 10 percent of the global output of their respective industries. Note that our sample does not include large resource-rich countries, such as Chile (in which the copper industry might be dominant) or other oil-exporting countries. The estimation results for equation 11 are reported in tables A3 in Appendix IV. Overall, the results remain unchanged compared to the full sample results of Table 2.

As a second robustness test, we use an alternative estimator to ensure that our fixed effect estimator results are not driven by misspecification. We use Generalized Estimating Equations (GEE) estimator to estimate equation 11. GEE, which is an extension of Generalized Linear Model (GLM), generalizes quasi-likelihood estimation to the panel data context and can be used for the analysis of response variables that are continuous. GEE produces estimates for "population-averaged effects" of a change in one or more covariates, rather than "subject-specific effects" which are estimated by the random effects (RE) or fixed effects (FE) models. In comparison to the FE and RE models, as GEE accounts for correlations between records within the same cluster, it produces improved standard errors and more efficient parameter estimators (Liang and Zeger, 1986; Burton et al., 1998). We therefore re-estimated our equation 11 by using GEE estimator, with a Gaussian distribution (as the distributions of our respective dependent variables are closer to normal distribution), an identity link function (i.e. the dependent variable has not been transformed), and an exchangeable (symmetric) or independent working relation for the covariance matrix as indicated in table A4 in Appendix IV. We find that the results by GEE estimator remain broadly unchanged from what estimated by the FE model, except that in the model with non-i sectors' contribution to aggregate volatility as the dependent variable, the estimated coefficient for the symmetric demand shock is now statistically significant for specifications with the RW centrality or PageRank.

Third, we test for the stability of our results against changes in our sample. We estimate our models for two sub-samples, namely developed and developing countries, using GEE estimator, and compare the sub-sample estimates with what reported for the full sample. The results are reported in tables A5 and A6 in Appendix IV. We observe that the sub-sample estimates remain broadly consistent both across themselves and with the full sample, for both specifications with the two dependent variables. One difference, however, strikes as important. It seems that localization in a dense neighbourhood of a production network *in developing countries* is not relevant for shock propagation. The estimated coefficients for both the individual network measures of *average degree of neighbouring nodes* and *local clustering coefficient*, and their respective interactions with the shock variable lose their statistical significance in the sub-sample of *developing countries*. They remain, however, statistically significant in the developed countries sub-sample, and consistent with the full sample results.

Structural differences between developing and developed economies could well prompt differentiated patterns of sensibility to shocks: Developing countries are more vulnerable to output volatility through *contagion* effects since there is no such mechanism of shock absorption through substitution effects like in more developed ones. Developing countries tend to have productive systems that are more asymmetric, with a few influential sectors loosely connected to the others through forward and backward linkages. Koren and Tenreyro (2013) have provided formal and empirical evidence that developing countries exhibit lower levels of technological diversification, that is less diversified set of available inputs. Moreover, in developing countries, influential sectors might be more extraverted, since they are more reliant on foreign direct investment (FDI) and connected to global value chains, than in developed economies. Empirical evidence of the absence of the substitution effects in the sub-sample of developing and emerging economies suggests that these economies are more vulnerable to external shocks because their productive systems feature more structural holes; meaning that they are insufficiently diversified around the sectors that are more vulnerable to external shocks. This may also be the consequence of vertical specialization through global value chains (GVC) which prompts the expansion of a few exporting sectors featuring only limited forward and backward linkages to the rest of the economy (Srholec, 2007; Baldwin, 2011).

Fourth, we check that the impact of a shock to sector i in country c is properly identified and is not driven by a possible co-movement between this shock and the shocks to all other non-i sectors. We therefore control for the intensity of shocks to non-i sectors in Equation 11 by using the average value of the Bartik instrument for all non-i sectors as a control variable. The estimation results, reported in Table A7 of the Appendix IV, remain fully consistent with our core estimation in Table 2, which leads us to conclude that the results are not driven by co-movements in sectoral shocks.

Clustering errors by country (Tables A1 and A2) also enabled concluding that co-movements across sectors within countries do not drive our main findings.

Finally, we exclude the United States from our sample because the US have the extreme shock values. The results are presented in table A8 in the appendix. The test shows that by excluding the US, some of the results change.[18] In particular, the shock-network interactive for local density measures are no more statistically significant and the estimated coefficient for the demand shock turns negative and statistically significant. This deviation from our core results indicates that the US industries exhibit such properties in the network which strongly influence the shock transmission. This is particularly concerning because all other studies on production networks have largely relied on the US data to validate their theoretical results. If the exclusion or inclusion of the US strongly affects the empirical results, then the results of those studies employing uniquely the US data or those that do not include the US in their sample might not be unbiased.

8. Conclusion

By measuring sector-level network indicators from a multi-country production network comprising 40 developing and developed countries, the present paper provides original empirical evidence for the causal effects of different input-output structures on the transmission of idiosyncratic shocks to aggregate volatility. We find that some structural features of the input-output network smoothen the impact of sectoral shocks on aggregate volatility, while others magnify it. We find that: (1) the impact of a sectoral shock on aggregate volatility does exist; (2) it is indirect and integrally transmitted through inter-sectoral linkages across the production network; (3) its sign and direction varies with respect to the type of network characteristics, with shocks to more 'influential' sectors or input suppliers leading to larger aggregate volatility while shocks to sectors that are located in denser sub-networks being absorbed throughout the network; (4) observable country characteristics like trade openness, financial development or technological level do not condition the transmission of shocks; and (5) services are more conducive than manufacturing industries in translating idiosyncratic shocks into aggregate volatility through contagion effects. We checked the robustness of our main findings to alternative

[18] Needless to say that this does not undermine the stability of our results against changes in the sample. The results were consistent when the developed and developing countries samples were separately tested. However, it seems that the US observations have a particular impact on shock transmission in the sample of developed countries.

samples, estimators, definition of the dependent variable, exclusion of potential outliers, and control of unobservable sector and country characteristics.

Our empirical findings provide a nuanced perspective on the relation between diversification and volatility. The structure of the production network and inter-industry linkages plays an important role in how diversification conditions the impact of idiosyncratic shocks on aggregate volatility. The structure of any single production network may convey simultaneously both substitution and contagion effects: shocks to sectors situated in dense sub-networks dissipate across the network of inter-sectoral linkages due to possibility of substitution between alternative input-output routes, whereas shocks to more influential sectors translate into aggregate volatility through contagion effects. Marginal effect computation shows that, everything else equal, we would expect a 4 to 7 percent point increase in aggregate volatility after a one unit increase (on a scale of 14) in the intensity of shock for sectors with very high centrality (top 1% of PageRank centrality distribution), and a 5 to 10 percent point decrease in aggregate volatility after a one unit increase in the intensity of shock for sectors with high local density (top 40% of the "average degree of neighbours" distribution). The former result is in line with the works by Gabaix (2011) and Acemoglu et al. (2012) which insist on the fat-tailed distribution of firm or sectoral influence within the productive network. These results suggest that while there are only few sectors that may transform idiosyncratic shocks into aggregate volatility due to their influence over the whole productive network, there might be more numerous sectors for which the local density of linkages might absorb idiosyncratic shocks.

These findings contribute to the recent economic literature by providing causal empirical evidence supporting the central mechanisms of the technological diversification and the microeconomic determinants of macroeconomic volatility theories. On the one hand, the presence of more diversified links in the neighbourhood of a sector tends to dilute the shock transmission which seems to be absorbed throughout the network. This effect holds even for sectors with large value added shares. This is in conformity with the traditional diversification argument, based on substitution effects, stating that volatility smears out along the different paths of the input-output matrix when upstream and downstream sectors are sufficiently diversified. This finding therefore supports the *technological diversification* argument by Koren and Tenreyro (2013) whereas the substitution between alternative input suppliers or purchasers literally breaks down the propagation of shocks across the network. On the other hand, the aggregate volatility impact of a sectoral shock is significantly magnified when the shock hits more influential sectors, i.e. sectors that are closely linked to other sectors that themselves are influential. We therefore also provide empirical support for the *cascade* effects formally demonstrated by a series of recent papers including Acemoglu et al. (2012). The latter essentially focused on productivity shocks. In order to be consistent with the nature of the 2008-09 crisis which affected national sectors through the demand channel, and not through productivity shocks, we studied the impact of final demand shocks on aggregate volatility through the structure of inter-industry linkages. Our findings can nonetheless be interpreted as providing useful clues to identify the impact of any kind of idiosyncratic shocks on asymmetric production networks on aggregate volatility. We find that contagion effects also hold when the network comprises highly influential sectors in terms of input demand linkages, i.e. sectors that are input buyers to a large number of other sectors. This result may prove particularly relevant as demand shocks tend to be more frequent than productivity shocks.

Diversification should therefore be analysed at a more disaggregated level by looking at the local distribution of linkages around sectors playing strategic roles as input providers to other sectors. Our results suggest that service industries should be more carefully considered by scholars and policy makers since they may be a crucial vector of aggregate volatility. These results can have strong implications for how countries would go about diversifying their economies. The choice of sectors and investment promotion strategies need to be based on a careful understanding of the structure of the economy. Sector strategies must not be developed in isolation to other sectors, and must take into account its linkages with other sectors, its position in the production network, and its importance or influence in terms of how large of a supplier or purchaser it is in the economy.

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Appendix I: Sector contribution to aggregate growth volatility

In section 2, we defined aggregate output growth as the weighted sum of sectoral output growth rates, as following:

$$\tilde{Q}_{c,t} = \sum_{i}^{n} w_{ic,t0}\tilde{x}_{ic,t} \qquad (i)$$

where $w_{ic,t0}$ is the share of sector *i,c* in the aggregate output of country *c* in the base year, t0, and $\tilde{x}_{ic,t}$ is the output growth in sector *i,c* in period *t*. The standard deviation of $\tilde{Q}_c$ will therefore be:

$$\sigma_Q = \left(\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ic}w_{jc}\sigma_{ic}\sigma_{jc}\sigma_{(ic,jc)}\right)^{1/2} \qquad (ii)$$

where σ_Q is the standard deviation of aggregate output growth in country *c*, σ_{ic} or σ_{jc} is the standard deviation of output growth in sector *i* or *j* in country c, and $\sigma_{(ic,jc)}$ is the covariance between sectors *ic* and *jc*. In a vector form, the Eq. (ii) can be written as:

$$\sigma_Q = (W`\Sigma\, W)^{1/2} \qquad (iii)$$

where W is a vector of sectoral output shares and Σ is a covariance matrix.

Per Euler's theorem, we can suggest that, as Eq. (iii) is a homogenous function of degree one and continuous and differentiable in *W*, it can be additively decomposed into the following components:

$$\sigma_Q = \sigma(W) = w_1.\frac{\partial\sigma(W)}{\partial w_1} + w_2.\frac{\partial\sigma(W)}{\partial w_2} + \cdots + w_n.\frac{\partial\sigma(W)}{\partial w_n}$$

$$= \sum_{i=1}^{n} w_{ic}\frac{\partial\sigma(W)}{\partial w_{ic}} \qquad (iv)$$

where each $\frac{\partial\sigma(W)}{\partial w_{ic}}$ is the *marginal contribution to volatility* (MCV_{ic}^{σ}) for sector *i,c*, which can also be written as:

$$\sigma_Q = w_1.MCV_{1c}^{\sigma} + w_{2c}.MCV_{2c}^{\sigma} + \cdots + w_{nc}.MCV_{nc}^{\sigma} \qquad (v)$$

Eq. (iv) can also be expressed as the ratio of covariance between output growth of sector *i,c* and the aggregate growth of country c, to the standard deviation of country *c*'s aggregate growth. This can be easily seen if we write the Eq. (iv) in the matrix form:

$$\sigma_Q = W`\frac{\partial(W`\Sigma\, W)^{1/2}}{\partial w} = \frac{1}{2}(W`\Sigma\, W)^{-\frac{1}{2}}\, 2\Sigma W$$

$$\sigma_Q = \frac{\Sigma W}{(W`\Sigma\, W)^{1/2}} = \frac{\Sigma W}{\sigma_Q} \qquad (vi)$$

$$1 = \frac{\Sigma W}{\sigma_Q^2} \qquad (vii)$$

Eq. (vii) which is a ratio of the covariance between $\tilde{x}_{ic}$ and $\tilde{Q}_c$ and the variance of $\tilde{Q}_c$ is principally a *beta* (slope) of sectoral output growth $\tilde{x}_{ic}$ versus aggregate output growth $\tilde{Q}_c$, whose sum would equal 1:

$$\beta_{ic} = \frac{\text{cov}(\tilde{x}_{ic}\,, \tilde{Q}_c)}{\sigma_Q^2} \qquad (viii)$$

By definition, β_{ic} can also be interpreted as the marginal contribution of sector *i,c* to aggregate output volatility (σ_G). We can therefore define MCV_{ic}^{σ} as:

$$MCV_{ic}^{\sigma} = \frac{\partial \sigma(W)}{\partial w_{ic}} = \beta_{ic}\, \sigma_Q \qquad (ix)$$

We also know that the correlation between sectoral output growth $\tilde{x}_{ic}$ and aggregate output growth $\tilde{Q}_c$ is:

$$\rho_{x,Q} = corr\left(\tilde{x}_{ic}\,, \tilde{Q}_c\right) = \frac{\text{cov}(\tilde{x}_{ic}\,, \tilde{Q}_c)}{\sigma_x \sigma_Q}$$

$$\Rightarrow \text{cov}\left(\tilde{x}_{ic}\,, \tilde{Q}_c\right) = \rho_{x,Q}\, \sigma_x\, \sigma_Q \qquad (x)$$

Replacing the value of $\text{cov}\left(\tilde{x}_{ic}\,, \tilde{Q}_c\right)$ in Eq. (viii), and putting equations (viii) and (ix) together, we get:

$$MCV_{ic}^{\sigma} = \sigma_x\, \rho_{x,Q} \qquad (xi)$$

To express this in total contribution to volatility, and not merely in *marginal* contribution of a sector, we can write equation *(xi)* per the additive function expressed in *(v)* as:

$$CV_{ic}^{\sigma} = w_{ic}\, \sigma_x\, \rho_{x,Q} \qquad (xii)$$

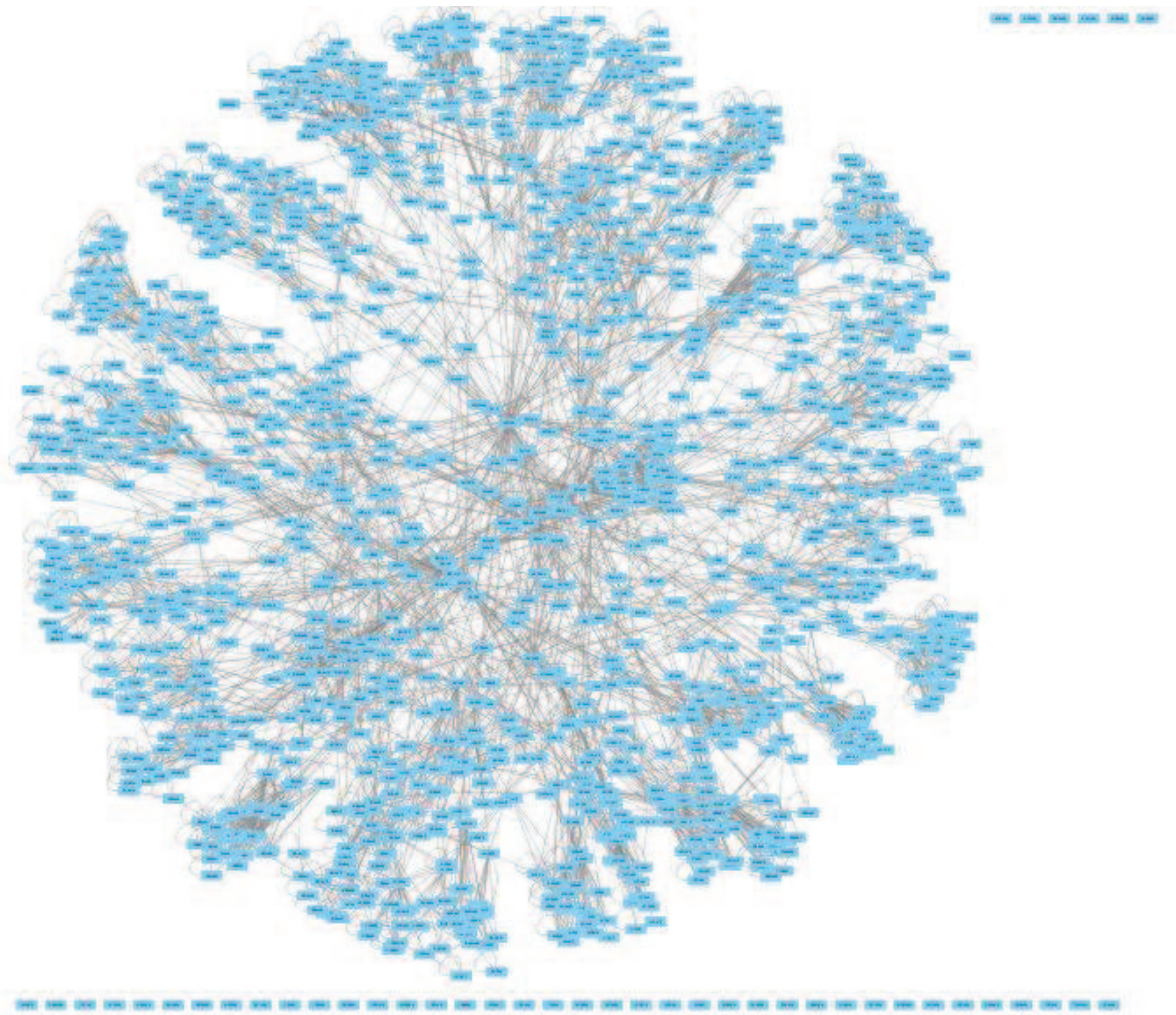
Appendix II: List of sectors and countries

	Sectors
1	AGRICULTURE, HUNTING, FORESTRY AND FISHING
2	MINING AND QUARRYING
3	FOOD , BEVERAGES AND TOBACCO
4	Textiles and textile
5	Leather, leather and footwear
6	WOOD AND OF WOOD AND CORK
7	PULP, PAPER, PAPER , PRINTING AND PUBLISHING
8	Coke, refined petroleum and nuclear fuel
9	Chemicals and chemical
10	Rubber and plastics
11	OTHER NON-METALLIC MINERAL
12	BASIC METALS AND FABRICATED METAL
13	MACHINERY, NEC
14	ELECTRICAL AND OPTICAL EQUIPMENT
15	TRANSPORT EQUIPMENT
16	MANUFACTURING NEC; RECYCLING
17	ELECTRICITY, GAS AND WATER SUPPLY
18	CONSTRUCTION
19	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel
20	Wholesale trade and commission trade, except of motor vehicles and motorcycles
21	Retail trade, except of motor vehicles and motorcycles; repair of household goods
22	HOTELS AND RESTAURANTS
23	Other Inland transport
24	Other Water transport
25	Other Air transport
26	Other Supporting and auxiliary transport activities; activities of travel agencies
27	POST AND TELECOMMUNICATIONS
28	FINANCIAL INTERMEDIATION
29	Real estate activities
30	Renting of machinery & equipment and other business activities
31	PUBLIC ADMIN AND DEFENCE; COMPULSORY SOCIAL SECURITY
32	EDUCATION
33	HEALTH AND SOCIAL WORK
34	OTHER COMMUNITY, SOCIAL AND PERSONAL SERVICES
35	PRIVATE HOUSEHOLDS WITH EMPLOYED PERSONS

	Developed countries*		**Developing countries**
1	Australia	30	Brazil
2	Austria	31	Bulgaria
3	Belgium	32	China
4	Cyprus	33	India
5	Canada	34	Indonesia
6	Czech Republic	35	Latvia
7	Denmark	36	Lithuania
8	Estonia	37	Mexico
9	Finland	38	Romania
10	France	39	Russia
11	Germany	40	Turkey
12	Greece		
13	Hungary		
14	Ireland		
15	Italy		
16	Japan		
17	Korea, Republic of		
18	Luxembourg		
19	Malta		
20	Netherlands		
21	Poland		
22	Portugal		
23	Slovak Republic		
24	Slovenia		
25	Spain		
26	Sweden		
27	Taiwan		
28	United Kingdom		
29	United States		

** countries classified as "high-income" in or before 2007*

Appendix III: The network of global inter-industry flows in 2007



To enhance visualisation of the network, only those links that represent more than 5 percent of input supply to a given sector have been shown, similar to in Carvalho (2010). The network is produced using 'edge-weighted spring-embedded layout' algorithm in Cytoscape.

Appendix IV: Estimation results and robustness tests

Table A1: FE regression of sector non-*i*'s contribution to aggregate volatility (2007-2009): Errors clustered by country

Dependent variable: Non-*i* sectors' contribution to aggregate volatility							
Network $_i$:	(1) Baseline	(2) In-degree	(3) Out-degree	(4) Random walk centrality	(5) PageRank centrality	(6) Average degree of a node's neighbours	(7) Local clustering coefficient
Cap. gr. non-*i*	1.236	1.270	1.174	1.205	.955	.238	.238
	(.960)	(.932)	(.948)	(.973)	(.934)	(1.06)	(1.06)
Lab. gr. non-*i*	-7.81	-7.299	-7.280	-7.96	-6.57	-7.10	-7.10
	(7.06)	(7.85)	(7.89)	(7.74)	(8.03)	(7.54)	(7.54)
Shock $_i$	-.024	-.062	-.051	-.025	-.036	.045**	.045**
	(.030)	(.053)	(.036)	(.031)	(.046)	(.018)	(.018)
Network $_i$	-	-2.7e-08	-5.9e-07	.004*	-95.37***	2.6e-04***	.734***
		(5.0e-07)	(4.7e-07)	(.002)	(33.60)	(4.6e-05)	(.128)
Shock*Ntwrk	-	7.0e-08	1.4e-07	.933	11.08*	-5.5e-05**	-.153**
		(9.2e-08)	(9.4e-08)	(1.87)	(6.25)	(2.4e-05)	(.067)
Constant	5.97***	6.00***	6.00***	5.96***	6.05***	5.63***	5.63***
	(.073)	(.079)	(.073)	(.075)	(.077)	(.104)	(.104)
R^2 within	.18	.18	.18	.18	.20	.23	.23
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Clustd err.	Yes	Yes	Yes	Yes	Yes	Yes	Yes

*Values in parentheses are standard errors; *** for p < 0.01, ** for p < 0.05, and * for p < 0.1.* All regressions include country and sector fixed effects. The dependent variable is the contribution of non-*i* sectors to aggregate volatility between 2007 and 2009. The Network variable is specified at the head of columns 2-7. For example, in column 2, the Network coefficient gives the estimated main impact of the number of incoming flows to sector *i* on the aggregate volatility in the absence of any shock, while the coefficient of the interaction Shock*Network gives the average impact of the number of incoming degrees in the case of a sectoral shock.

Table A2: Regressions of sector *i*'s *direct* contribution to excess aggregate volatility (2007-2009): Errors clustered by country

Dependent variable: Sector *i*'s contribution to aggregate excess volatility

Network $_i$:	(1) Baseline	(2) In-degree	(3) Out-degree	(4) Random walk centrality	(5) PageRank centrality	(6) Average degree of a node's neighbours	(7) Local clustering coefficient
Cap. gr. *i*	.316**	.313**	.312**	.296**	.306**	.295**	.295**
	(.139)	(.139)	(.139)	(.144)	(.140)	(.144)	(.144)
Lab. gr. *i*	.167***	.161***	.158***	.137***	.155***	.141***	.141***
	(.032)	(.030)	(.030)	(.038)	(.031)	(.036)	(.036)
Trade $_i$	3.3e-04	3.4e-04	3.4e-04	3.4e-04	3.4e-04	3.4e-04	3.4e-04**
	(3.1e-04)	(3.2e-04)	(3.1e-04)	(3.0e-04)	(3.1e-04)	(3.2e-04)	(3.2e-04)
Shock $_i$	.003	.006*	.006**	8.7e-04*	.008**	-.010**	-.010**
	(.0026)	(.003)	(.003)	(5.1e-04)	(.004)	(.004)	(.004)
Network $_i$	-	-8.2e-09	-3.5e-08	-1.3e-04	1.78	2.6e-06	.007
		(2.0e-08)	(2.9e-08)	(1.9e-03)	(2.94)	(7.9e-06)	(.022)
Shock*Ntwrk	-	-5.7e-08	-5.2e-08*	.0019***	-7.03*	8.5e-06***	.024***
		(3.8e-08)	(3.1e-08)	(5.4e-04)	(4.06)	(3.0e-06)	(.008)
Constant	-.025	-.025	-.025	-.023	-.026	-.028	-.028
	(.016)	(.016)	(.016)	(.016)	(.016)	(.022)	(.022)
N	1,104	1,100	1,099	1,099	1,104	1,098	1,098
Groups	35	35	35	35	35	35	35
R^2 within	.26	.26	.27	.27	.27	.28	.28
Clustered errors	Yes	Yes	Yes	Yes	Yes	Yes	Yes

*Values in parentheses are standard errors; *** for p < 0.01, ** for p < 0.05, and * for p < 0.1.* All regressions include country and sector fixed effects. The dependent variable is the contribution of sector *i* to aggregate excess volatility between 2007 and 2009. The Network variable is specified at the head of columns 2-7. For example, in column 2, the Network coefficient gives the estimated main impact of the number of incoming flows to sector *i* on the aggregate volatility in the absence of any shock, while the coefficient of the interaction Shock*Network gives the average impact of the number of incoming degrees in the case of a sectoral shock.

Table A3: Estimation of the sectors non-*i*'s contribution to aggregate volatility (2007-2009): Dominant sectors excluded

Dependent variable: Non-*i* sectors' contribution to aggregate volatility						
	(1)	(2)	(3)	(4)	(5)	(6)
Network $_i$:	In-degree	Out-degree	Random walk centrality	PageRank centrality	Average degree of a node's neighbours	Local clustering coefficient
Cap. gr. $_{\text{non-}i}$	1.33	1.26	1.36	.730	.357	.357
	(1.37)	(1.37)	(1.37)	(1.34)	(1.33)	(1.33)
Lab. gr. $_{\text{non-}i}$	-7.78***	-7.99***	-8.39***	-7.23***	-8.39***	-8.39***
	(2.83)	(2.88)	(2.83)	(2.76)	(2.74)	(2.74)
Shock $_i$	-.138***	-.174***	-.129***	-.170***	.023	.023
	(.052)	(.052)	(.039)	(.045)	(.088)	(.088)
Network $_i$	-1.2e-06*	-1.6e-06***	.004**	-256.1***	.0003***	.768***
	(7.1e-07)	(6.0e-07)	(.002)	(40.6)	(3.4e-05)	(.094)
Shock*Ntwrk	7.6e-07	1.3e-06*	2.34	144.9***	-5.1e-05	-.144
	(6.3e-07)	(7.0e-07)	(1.55)	(32.5)	(5.8e-05)	(.162)
Constant	6.21***	6.22***	6.15***	6.33***	5.77***	5.77***
	(.093)	(.092)	(.092)	(.093)	(.101)	(.101)
N	1058	1056	1056	1065	1056	1056
Groups	35	35	35	35	35	35
R2 within	.20	.20	.20	.23	.25	.25
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes
Clustd err.	No	No	No	No	No	No

*Values in parentheses are standard errors; *** for p < 0.01, ** for p < 0.05, and * for p < 0.1.* All regressions include country and sector fixed effects. The dependent variable is the contribution of non-*i* sectors to aggregate volatility between 2007 and 2009. The Network variable is specified at the head of columns 1-6. For example, in column 2, the Network coefficient gives the estimated main impact of the number of incoming flows to sector *i* on the aggregate volatility in the absence of any shock, while the coefficient of the interaction Shock*Network gives the average impact of the number of incoming degrees in the case of a sectoral shock.

Table A4: Regression of non-*i* sectors' contribution to aggregate volatility (2007-2009): Generalized Estimating Equations estimation

Family distribution: Gaussian; Link function: Identity; Working correlation: Independent

Dependent variable: Non-*i* sectors' contribution to aggregate volatility

Network *i* :	(1) In-degree	(2) Out-degree	(3) Random walk centrality	(4) PageRank centrality	(5) Average degree of a node's neighbours	(6) Local clustering coefficient
Cap. gr. $_{\text{non-}i}$	4.40***	4.39***	4.66***	4.51***	4.49***	4.49***
	(.993)	(.991)	(1.01)	(1.00)	(1.00)	(1.00)
Lab. gr. $_{\text{non-}i}$	-27.1***	-27.1***	-26.0***	-26.1***	-26.1***	-26.1***
	(2.06)	(2.05)	(2.08)	(2.06)	(2.07)	(2.07)
Trade *i*	.001	.002	.003	.001	.001	.001
	(.003)	(.003)	(.004)	(.003)	(.003)	(.003)
Shock *i*	-1.32***	-1.28***	-1.21***	-1.47***	-.249	-.249
	(.213)	(.154)	(.131)	(.185)	(.291)	(.291)
Network *i*	-.00001***	-.00001***	.033*	-553.1***	.0005**	1.44**
	(2.1e-06)	(2.1e-06)	(.018)	(158.9)	(.0002)	(.615)
Shock*Ntwk	2.3e-06***	2.8e-06***	1.34	135.9***	-.0009***	-2.49***
	(4.1e-07)	(4.9e-07)	(7.10)	(33.95)	(.0002)	(.712)
Constant	6.43***	6.41***	6.02***	6.47***	5.32	5.32
	(.164)	(.164)	(.163)	(.183)	(.375)	(.375)
N	1,101	1,100	1,099	1,109	1,099	1,099
Groups	35	35	35	35	35	35

*Values in parentheses are standard errors; *** for p < 0.01, ** for p < 0.05, and * for p < 0.1.* The dependent variable is the contribution of non-*i* sectors to aggregate volatility between 2007 and 2009. The Network variable is specified at the head of columns 1-6. For example, in column 2, the Network coefficient gives the estimated main impact of the number of incoming flows to sector *i* on the aggregate volatility in the absence of any shock, while the coefficient of the interaction Shock*Network gives the average impact of the number of incoming degrees in the case of a sectoral shock.

Table A5: Regression of non-*i* sectors' contribution to aggregate volatility (2007-2009) using GEE: Developed countries

Family distribution: Gaussian; Link function: Identity; Working correlation: Independent

Dependent variable: Non-*i* sectors' contribution to aggregate volatility

Network *i*	(1) In-degree	(2) Out-degree	(3) Random walk centrality	(4) PageRank centrality	(5) Average degree of a node's neighbours	(6) Local clustering coefficient
Cap. gr. $_{\text{non-}i}$	-.109	-.091	-.038	-.142	-.167	-.167
	(.922)	(.923)	(.925)	(.925)	(.927)	(.927)
Lab. gr. $_{\text{non-}i}$	-9.34***	-9.20***	-7.96***	-8.46***	-8.47***	-8.47***
	(2.41)	(2.41)	(2.40)	(2.40)	(2.41)	(2.41)
Trade *i*	.003	.003	.003	.004	.003	.003
	(.004)	(.004)	(.004)	(.004)	(.004)	(.004)
Shock *i*	-.733***	-.733***	-.712***	-.867***	-.199	-.199
	(.198)	(.140)	(.117)	(.167)	(.252)	(.252)
Network *i*	-6.4e-06***	-5.9e-06***	.137***	-256.5*	.0004	1.10
	(1.8e-06)	(1.8e-06)	(.047)	(144.9)	(.0002)	(.685)
Shock*Ntwk	9.5e-07***	1.0e-06**	-4.11	62.44**	-.0005**	-1.41**
	(3.6e-07)	(4.4e-07)	(9.82)	(29.8)	(.0002)	(.626)
Constant	5.55***	5.53***	5.35***	5.55***	4.79***	4.79***
	(.178)	(.178)	(.172)	(.195)	(.402)	(.402)
N	661	662	661	666	661	661
Groups	22	22	22	22	22	22

*Values in parentheses are standard errors; *** for p < 0.01, ** for p < 0.05, and * for p < 0.1.* The dependent variable is the contribution of non-*i* sectors to aggregate volatility between 2007 and 2009. The Network variable is specified at the head of columns 1-6. For example, in column 2, the Network coefficient gives the estimated main impact of the number of incoming flows to sector *i* on the aggregate volatility in the absence of any shock, while the coefficient of the interaction Shock*Network gives the average impact of the number of incoming degrees in the case of a sectoral shock.

Table A6: Regression of non-*i* sectors' contribution to aggregate volatility (2007-2009) using GEE: Developing countries

Family distribution: Gaussian; Link function: Identity; Working correlation: Independent

Dependent: Non-*i* sectors' contribution to aggregate volatility

Network *i*	(1) In-degree	(2) Out-degree	(3) Random walk centrality	(4) PageRank centrality	(5) Average degree of a node's neighbours	(6) Local clustering coefficient
Cap. gr. $_{\text{non-}i}$	10.59**	10.59**	8.77*	8.58*	8.46*	8.46*
	(4.50)	(4.52)	(4.67)	(4.57)	(4.65)	(4.56)
Lab. gr. $_{\text{non-}i}$	-41.8***	-44.0***	-48.78***	-48.1***	-49.3***	-49.3***
	(3.81)	(3.76)	(4.04)	(3.79)	(3.80)	(3.80)
Trade *i*	.010	.013*	.016**	.012	.016**	.016**
	(.007)	(.007)	(.008)	(.008)	(.008)	(.008)
Shock *i*	-4.82***	-3.99***	-1.85***	-3.37***	-1.12	-1.12
	(1.15)	(1.05)	(.623)	(1.04)	(2.25)	(2.25)
Network *i*	-.00009***	-.00006***	.045	-1634.4**	-.00006	-.170
	(.00001)	(.00001)	(.095)	(.719)	(.0005)	(1.41)
Shock*Ntwk	.0001***	.00005***	-2.29	2303.8*	-.0006	-1.72
	(.00002)	(.00001)	(11.36)	(1181.6)	(.001)	(4.42)
Constant	7.93***	7.57***	6.81***	7.70***	6.97***	6.98***
	(.554)	(.542)	(.547)	(.630)	(.975)	(.975)
N	340	340	338	342	338	338
Groups	10	10	10	10	10	10

*Values in parentheses are standard errors; *** for p < 0.01, ** for p < 0.05, and * for p < 0.1.* The dependent variable is the contribution of non-*i* sectors to aggregate volatility between 2007 and 2009. The Network variable is specified at the head of columns 1-6. For example, in column 2, the Network coefficient gives the estimated main impact of the number of incoming flows to sector *i* on the aggregate volatility in the absence of any shock, while the coefficient of the interaction Shock*Network gives the average impact of the number of incoming degrees in the case of a sectoral shock.

Table A7: Fixed effect regression of non-*i* sectors' contribution to aggregate volatility (2007-2009): Controlling for shock to non-*i* sectors

Dependent variable: Non-*i* sectors' contributions to aggregate volatility							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Network $_i$:	-	In-degree	Out-degree	Random walk centrality	PageRank centrality	Average degree of a node's neighbours	Local clustering coefficient
Cap. gr. non-*i*	1.236	1.271	1.174	1.205	.955	.238	.238
	(1.36)	(1.36)	(1.36)	(1.36)	(1.34)	(1.32)	(1.32)
Lab. gr. non-*i*	-7.81***	-7.299***	-7.280***	-7.96***	-6.57**	-7.10***	-7.10***
	(2.74)	(2.79)	(2.79)	(2.76)	(2.74)	(2.68)	(2.68)
Shock $_i$	-.082***	-.119***	-.106***	-.083***	-.091***	-.011	.012
	(.018)	(.028)	(.022)	(.019)	(.025)	(.030)	(.030)
Network $_i$	-	-2.7e-08	-5.9e-07**	.004**	-95.37***	2.6e-04***	.735***
		(2.9e-07)	(2.9e-07)	(.001)	(20.33)	(3.1e-05)	(.086)
Shock*Ntwrk	-	7.0e-08	1.4e-07**	.933	11.08***	-5.5e-05**	-.153**
		(5.3e-08)	(6.5e-08)	(1.48)	(3.89)	(2.7e-05)	(.076)
Shock $_{Non\text{-}i}$	-1.95***	-1.91***	-1.90***	-1.96***	-1.86***	-1.93***	-1.93***
	(.180)	(.185)	(.185)	(.182)	(.181)	(.177)	(.177)
Constant	7.07***	6.99***	7.01***	7.09***	6.99***	6.71***	6.71***
	(.478)	(.483)	(.484)	(.482)	(.477)	(.469)	(.469)
N	1,109	1,101	1,100	1,099	1,109	1,099	1,099
Groups	35	35	35	35	35	35	35
R^2 within	.99	.99	.99	.99	.99	.99	.99
Clustd err.	No	No	No	No	No	No	No

*Values in parentheses are standard errors; *** for p < 0.01, ** for p < 0.05, and * for p < 0.1.* All regressions include country and sector fixed effects. The dependent variable is the contribution of non-*i* sectors to aggregate volatility between 2007 and 2009. The Network variable is specified at the head of columns 2-7. For example, in column 2, the Network coefficient gives the estimated main impact of the number of incoming flows to sector *i* on the aggregate volatility in the absence of any shock, while the coefficient of the interaction Shock*Network gives the average impact of the number of incoming degrees in the case of a sectoral shock.

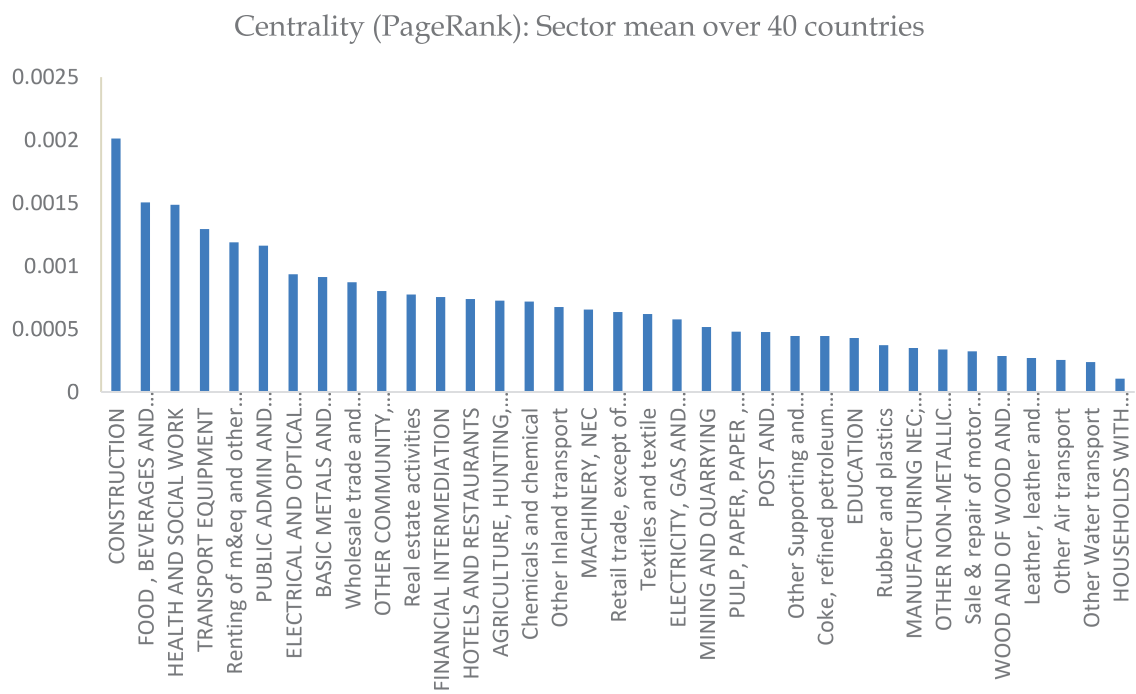
Table A8. Fixed effect regression of non-*i* sectors' contribution to aggregate volatility (2007-2009): Excluding extreme shock values (i.e. USA)

Dependent variable: Non-*i* sectors' contributions to aggregate volatility

Network characteristics of sector *i*	(1) -	(2) In-degree	(3) Out-degree	(4) Random walk centrality	(5) PageRank centrality	(6) Average degree of a node's neighbours	(7) Local clustering coefficient
Cap. gr. non-*i*	1.353	1.326	1.257	1.291	.919	.328	.328
	(1.37)	(1.37)	(1.37)	(1.37)	(1.35)	(1.34)	(1.34)
Lab. gr. non-*i*	-7.26**	-6.997**	-6.836**	-7.50***	-6.25**	-7.11**	-7.11**
	(2.81)	(2.84)	(2.86)	(2.83)	(2.74)	(2.74)	(2.74)
Shock $_i$	-.123***	-.135***	-.159***	-.140***	-.164***	.057	.057
	(.018)	(.051)	(.049)	(.018)	(.045)	(.090)	(.090)
Network $_i$	-	-3.3e-07	-8.3e-07*	.004**	-152.8***	2.7e-04***	.756***
		(4.9e-07)	(4.7e-07)	(.002)	(27.99)	(3.3e-05)	(.093)
Shock$_i$*Ntwrk$_i$	-	1.9e-07	5.9e-07	2.197	72.74***	-9.8e-05	-.272
		(4.7e-07)	(4.9e-07)	(1.56)	(24.6)	(6.7e-05)	(.184)
Constant	6.19***	6.21***	6.22***	6.17***	6.29***	5.81***	5.81***
	(.091)	(.093)	(.093)	(.093)	(.092)	(.100)	(.100)
N	1,075	1,067	1,066	1,065	1,075	1,065	1,065
Groups	34	34	34	34	34	34	34
R^2 within	.19	.19	.19	.20	.22	.24	.24

*Values in parentheses are standard errors; *** for p < 0.01, ** for p < 0.05, and * for p < 0.1.* All regressions include country and sector fixed effects. The dependent variable is the contribution of non-*i* sectors to aggregate volatility between 2007 and 2009. The Network variable is specified at the head of columns 2-7. For example, in column 2, the Network coefficient gives the estimated main impact of the number of incoming flows to sector *i* on the aggregate volatility in the absence of any shock, while the coefficient of the interaction Shock*Network gives the average impact of the number of incoming degrees in the case of a sectoral shock.

Appendix V: Figures



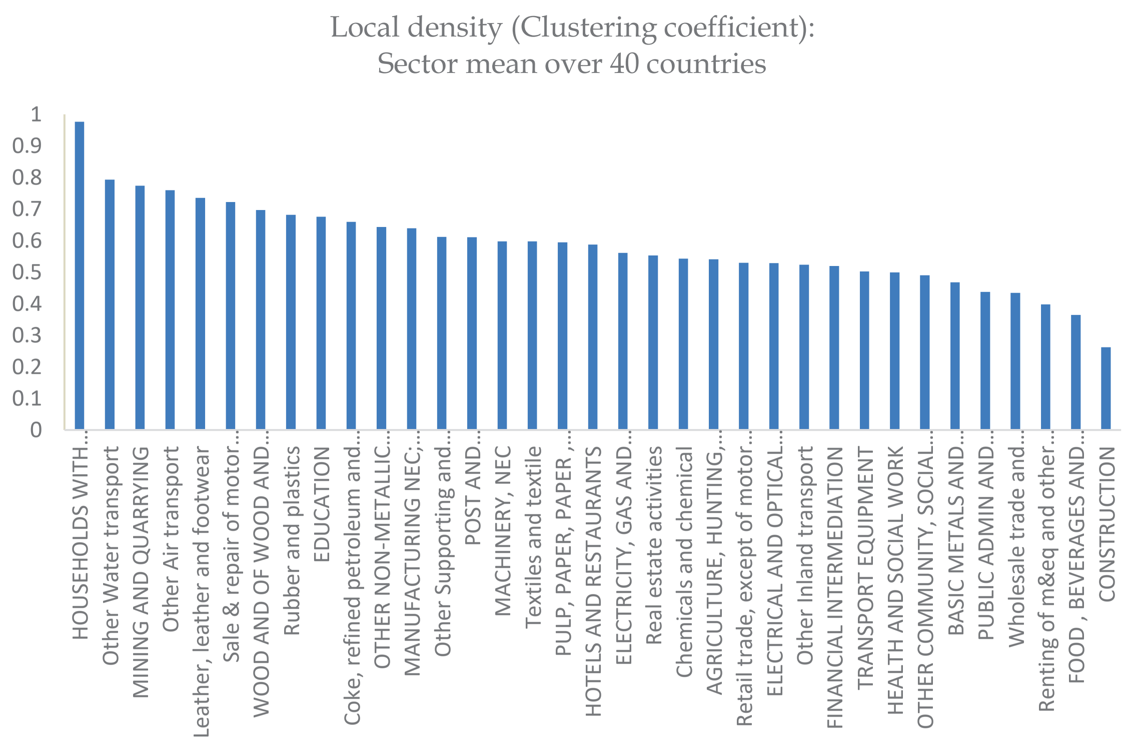


Figure A1. Centrality and local density for 36 sectors. The indicator used to measure centrality is Page rank centrality. The indicator measuring local density is the clustering coefficient. See section 3 for the definition and algebra. Data source: World Input-Output database.

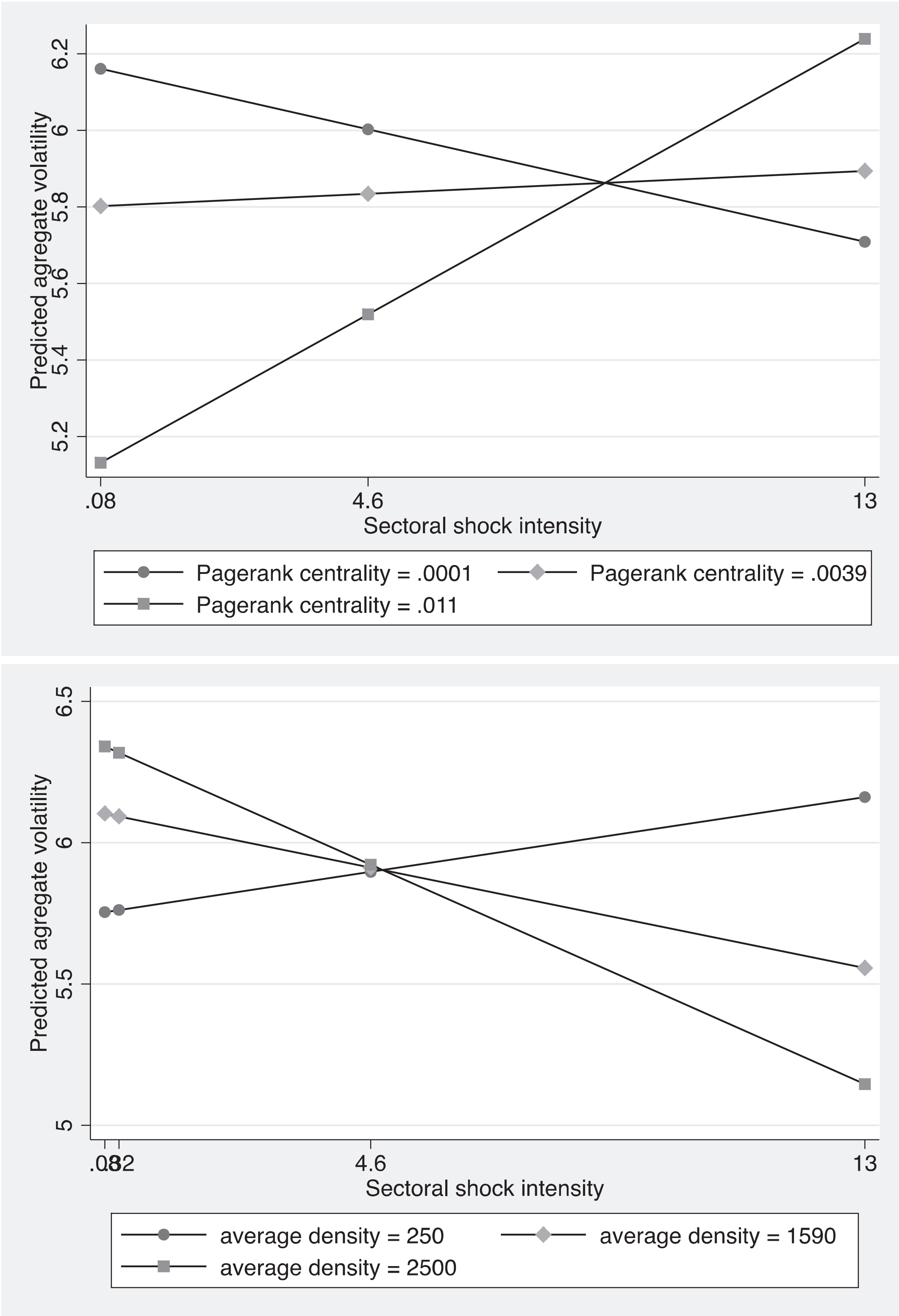


Figure A2. Predicted levels of aggregate volatility with respect to sectoral shock intensity and centrality (PageRank centrality) and local density (Average degree of node neighbours)

Appendix VI: MATLAB Codes and Functions

For *In-degree*, *Out-degree*, and *PageRank*, the built-in functions in MATLAB 9.1 (R2016b) were used:

```
C = centrality (A, type);
type: 'indegree', 'outdegree', 'pagerank'
```

For *RandomWalk Centrality*, the code developed by Blöchl et al. (2011) has been used. The code is published in the website of the Institute of Computational Biology, Helmholtz Zentrum München.[19]

```
function H=mfpt(A)
% computation of the mean first passage time matrix H of a graph with
% adjacency matrix A using Sherman Morrison
% Note that H(i,j) is MFPT from i to j.
n=size(A,1); % number of nodes
H=zeros(n); % preallocate MFHT matrix
A=eye(n)-inv(diag(sum(A')))*A; % compute transition matrix
I=inv(A(2:end,2:end));
for i=1:n % iterate over all nodes
    H([1:(i-1) (i+1):n],i)=I*ones(n-1,1); % compute i-th column of H
    if i<n % compute next inverse by Sherman Morrison
      u=A([1:i (i+2):n],i)-A([1:(i-1) (i+1):n],i+1);
      I=I-((I*u)*I(i,:))./(1+I(i,:)*u);
      v=A(i,[1:i (i+2):n])-A(i+1,[1:(i-1) (i+1):n]);
      I=I-(I(:,i)*(v*I))./(1+v*I(:,i));
      I=inv(A([1:i (i+2):n],[1:i (i+2):n]));
      if any(~isfinite(I)) % Sherman Morrison didn't work
        I=inv(A([1:i (i+2):n],[1:i (i+2):n]));
      end
    end
  end
end
n=size(a,1);
m=mfpt(a);
cen=n./sum(m);
```

[19] https://www.helmholtz-muenchen.de/icb/software/input-output-networks/index.html (accessed January 5, 2017)

For *Average degree of neighbouring nodes* and *Weighted Local Clustering Coefficient,* the codes developed by Bounova and de Weck (2012) and published under "*MATLAB Tools for Network Analysis"* in the MIT Strategic Engineering's website have been used.[20]

```
function ave_n_deg=ave_neighbour_deg(adj)
ave_n_deg=zeros(1,length(adj));   % initialize output vector
[deg,~,~]=degrees(adj);
for i=1:length(adj)  % across all nodes
    neigh=kneighbours(adj,i,1);  % neighbours of i, one link away
    if isempty(neigh); ave_n_deg(i)=0; continue; end
    ave_n_deg(i)=sum(deg(neigh))/deg(i);
end

function wC=weighted_clust_coeff(adj)
[deg,~,~]=degrees(adj);
n=size(adj,1); % number of nodes
wC=zeros(n,1); % initialize weighted clust coeff
for i=1:n % across all nodes
   neigh=kneighbours(adj,i,1);
   if length(neigh)<2; continue; end
      s=0;
   for ii=1:length(neigh)
      for jj=1:length(neigh)
         if adj(neigh(ii),neigh(jj))>0; s=s+(adj(i,neigh(ii))+adj(i,neigh(jj)))/2; end
      end
   end
   wC(i)=s/(deg(i)*(length(neigh)-1));
end
```

[20] http://strategic.mit.edu/downloads.php?page=matlab_networks (accessed January 5, 2017)

Appendix: Case Study: Overcoming the resource curse in Afghanistan: Structural policies, institutions, and political economy approaches

Abstract

Resource-rich countries are not doomed to failure. This paper reviews the set of economic policies and institutional arrangements prescribed in the economic literature to overcome the 'resource curse'; to achieve a productivity-enhancing structural change and to curb the adverse effects of resource abundance. In the second part of the article, I focus on the case of Afghanistan and discuss a number of policies, arrangements and political economy approaches that are relevant and applicable to the context of Afghanistan which is yet to embark on resource exploitation. Specifically, I discuss how resource rents can be used to strengthen political stability in the country and to support the diversification process. I propose a semi-rentier state model, in which financial benefits of natural resources are allocated through cash payments or social transfer systems to those communities that maintain peace and stability, and defend the government vis-à-vis the insurgents; and to those political leaders and former warlords whose interests are aligned with supporting the government and are such to oppose the current insurgent groups. The paper also suggests that economic diversification should be a priority for Afghanistan so that it does not remain dependent on commodity exports for the years to come. I propose a few specific arrangements for how Afghanistan can use the resource rents as a source of financing for its diversification process.

1. Introduction

The resource curse phenomenon is usually advocated to caution the resource-rich countries from solely relying on their natural resources as they forget the sound and good economic policies they need to adopt as they move on their development path.

Rather than discouraging the low-income, resource-rich countries from moving towards resource development – because they eventually do, – the focus of the international policy dialogue should be to guide these countries on how best, in practice, they can overcome the resource curse phenomenon. Effective economic and structural policies, and efficient institutional arrangements are key to escape the resource curse.

Afghanistan is rich in natural resources, which have largely remained unexploited. Currently the resource sector represents only less than 1 percent of GDP, but the potential for resource development in the country is huge, with the value of mineral deposits estimated between US$1 and $3 trillion.

The importance for resource development in Afghanistan arises from the country's despair need for resource rents given its current development challenges. First, the fiscal deficit, excluding donor grants, is as large as 16 percent of GDP, with the domestic revenues covering only around 40 percent of public expenditure. The budget deficit is entirely met by donor grants. In addition, off-budget expenditures – as large as the government's budget – are directly funded by the donors. Thus, the overall financing gap reaches to around 45 percent of GDP. The long-term outlook for the fiscal sustainability is also discouraging. According to the World Bank, the overall financing gap would only reduce to around 18 percent of GDP by 2030.[23] Further, the potential for increasing domestic revenues – which are currently at 10 percent of GDP – are limited. The estimates for revenue potential in Afghanistan are around 14.5 percent of GDP. Thus, Afghanistan desperately needs revenues from natural resource exploitation to improve its fiscal sustainability.

Secondly, foreign aid is not going to be everlasting for Afghanistan. Any reduction in foreign aid will exacerbate macroeconomic risks. The current trade deficit of nearly 40 percent of GDP is mostly financed by foreign aid inflows. Any unpredicted fall in foreign aid inflows may lead to serious macroeconomic imbalances and balance of payments crisis, unless alternative sources of foreign exchange are made available. Natural resources can alternatively be a potential source for foreign exchange earnings.

Finally, prospects for long-term growth in Afghanistan without a resource-based growth are significantly weak. Long-term projections point towards an average yearly growth of nearly 4 percent, which given the strong population growth of around 2.5 percent is not sufficient to help reduce poverty, strengthen revenue

[23] The World Bank. "*Navigating Risk and Uncertainty in Afghanistan*." October 2016

mobilisation, and generate sufficient employment opportunities. Analysis by the World Bank shows that a resource-based growth strategy (supported by agriculture and mining development) can help achieve higher growth rates of up to 6.5 percent. Therefore, a successful development scenario cannot be envisaged for Afghanistan if it does not include the development of natural resources sector.

Afghanistan possesses vast amounts of fuel and non-fuel minerals. Geological surveys by the US and the UK have shown that Afghanistan holds huge deposits of iron ore, copper, cobalt, gold, lithium, niobium, uranium, chromite, granite, marble and other metallic and non-metallic minerals. The deposits of copper and iron ore are some of the largest in the world, consisting of 60 and 2,200 million tonnes, respectively. The amount of lithium is also significant, which has led the experts to state that Afghanistan could become the "Saudi Arabia of lithium." Surveys have also shown that there are huge blocks of oil and natural gas in northern Afghanistan. It is estimated that there are 3.4 billion barrels of crude oil, 444 billion cubic meters of natural gas, and 562 million barrels of natural gas liquids in the country. Moreover, precious and semi-precious stones such as high-quality emerald, lapis lazuli – of which Afghanistan holds the largest and the unique-quality reserves in the world – and ruby are found in huge volumes in Afghanistan.

Almost all these minerals and fuel resources are untapped. So far, only three large deposits were granted to private firms, but the extraction has still not started due to political and security reasons. In 2007, the Aynak copper mine was awarded to a Chinese firm under a $4.4 billion deal; the operations are yet to start. In 2011, the Amu Darya oil basin was awarded to a joint venture of a Chinese and a local firm. The production started in 2012, but suspended after a year of operations. Finally, the Afghan government awarded in 2012 the Hajigak Iron ore deposit to a consortium of 7 Indian firms and a Canadian firm for a total investment worth nearly $15 billion. The investment is yet to start.

Natural resources are, of course, not a solution to all problems. The resource curse is a potential risk. Natural resource abundance leads to poor economic growth performance through the Dutch Disease effect, encourages rent-seeking in the economy, weakens the institutions, damages democracy, increases the probability of civil war, and leads to poor development outcomes. Nonetheless, this paper argues that natural resources can be an advantage for growth and development if efficient institutional arrangements are put in place to constrain corruption and rent-seeking in the economy, limit expropriation of resources, build political consensus, and strengthen government capacity to effectively implement economic and structural policies and to regulate the economy. Further, optimal structural policies to improve human capital, economic diversification and sound macroeconomic management are prerequisites for achieving good economic performance and strong development. If these conditions are not met, natural resource endowment will not only fail to generate growth and induce development but will also impede these. Hence, in this paper I explain the possible ways to overcome the "resource curse" and discuss an optimal strategy for Afghanistan to make its abundance in natural resources a success story.

In the next section, I give an overview of various policies and arrangements discussed in the literature which can help in curbing the adverse effects of resource exploitation. These are based both on empirical results in other countries, and on theoretical discussions. In section 3, I turn to the case of Afghanistan and recollect a number of these policies and arrangements that are relevant and applicable to the case of Afghanistan. An important element is the contextualisation of these policies. I also put forward a number of political economy propositions which may help turn natural resources into a stabilising factor in the country. I conclude this paper in section 4.

2. How to escape the resource curse?

Economists have proposed a wide range of policies that enable a country to successfully exploit its natural resources and to make its resource endowment an advantage for its growth and development. These policies can be of different nature – ranging from macroeconomic policies to politico-institutional arrangements. This paper, however, discusses the most deliberated suggestions made by economists.

2.1 Structural Policies

i. Education and Technological Progress

Growth theory and empirical studies document a significant role for human capital in the long-run growth. Human capital increases economic growth by enhancing labour productivity and encouraging technological progress and innovation. Focusing on resource-rich countries, economists have found a significant role for human capital in these economies. Studies have found that resource endowment may lead to a decline in economic growth only in countries with *low levels of human capital*, whereas in countries with human capital *above a certain threshold*, resource abundance propels economic growth (Gylfason, 2001; Bravo-Ortega and de Gregorio, 2007). In fact, a high level of human capital may more than offset any negative effects of natural resources on growth. Bravo-Ortega and de Gregorio (2007) argue that "it is difficult to explain the faster growth of Scandinavia compared with Latin America without highlighting the *educational gap that emerged between the two groups of countries over the period 1870-*

1910, and which remained large throughout the 20th century" (emphasis by authors). The authors emphasize that if natural resources are coupled with the accumulation of human capital, they could be transformed into an engine of economic growth.

Therefore, a national effort in education is necessary so that resource-rich countries reap the benefits of their natural resources. National policies to improve the level of education in a resource-rich country should not only focus on standard education, but also on vocational & technical trainings that respond to the needs of the mining industry. In Sweden, for example, technical colleges were established in almost all cities of the country since the 19th century. This was one of the main factors for the successful resource-based development of Sweden. Additional examples include those of Australia, Chile, Mexico and the United States where mining institutes were established.

Furthermore, national "learning" capacity for technological adoption and tinkering is an important factor for a successful exploitation of natural resources. Technological progress increases productivity growth and creates dynamic industries in the country. Maloney (2007) explained that one of the reasons that Latin America missed the opportunities for resource-based growth, while other countries and regions such as Australia, Canada and Scandinavia enjoyed it, was their deficient national "learning" or "innovative" capacity, arising from low investment in human capital and scientific infrastructure. Therefore, it is not the inherent character of natural resources that matters for resource-based development, but "the nature of the learning process through which their economic potential is achieved" (Wright and Czelusta, 2007). In reality, natural resources require extensive investments before they become productive assets, and the required investments not only include physical capital and infrastructure, but also the acquisition of knowledge and adoption of technologies that make natural resources valuable.

ii. Diversification / Resource-based industrialisation

Empirical studies have found that export concentration is negatively correlated with economic growth (Lederman and Maloney, 2007b; Murshed and Serino, 2011). The argument is that export concentration exposes the country to terms-of-trade shocks (Koren and Tenreyro, 2007; Malik and Temple, 2009) which, in their turn, negatively affect the growth rate. Resource-abundant countries are usually commodity exporters with a concentrated basked of exported goods. Murshed and Serino (2011) argue that "it is only specialization in unprocessed natural resource products that slows down economic growth, as it impedes the emergence of more dynamic patterns of trade specialization."

Economists have therefore suggested that diversification into natural resource processing (resource-based industrialisation) can be seen as a way out of the resource curse (Hesse, 2008; Gelb and Grasmann, 2010; Murshed and Serino, 2011; Massol and Banal-Estañol, 2012). Diversification is found to have a positive impact on economic growth in developing countries. It minimizes the risks that countries are faced with, lowers the negative impact of external shocks on the economy, prevents the Dutch Disease (i.e. appreciation of the real exchange rate) from affecting the manufacturing or other traded sectors, and – above all – allows for a gradual allocation of resources to their most productive uses in the economy. Chile, Indonesia, Malaysia, Mexico and Sweden represent best examples of resource-rich countries that were able to diversify their economies.

Gelb and Grasmann (2010) explain that diversification requires a combination of three policies: (i) a reasonable level of macroeconomic stability; (ii) a reasonably open trade policy; and (iii) the active use of resource rents to increase the productivity of other traded sectors, whether by increased spending on infrastructure, offering temporary subsidies or other methods.

2.2 Citizen dividends or social transfers

An interesting proposition made by some economists is to distribute the resource revenues to citizens. The objective is to transform a resource-abundant country into "non-resource abundant" one in which there will be no windfall revenue that would encourage rent-seeking behaviour and corruption. However, economists have different opinions on how the transfer of rents should take place. Below various methods of rent transfers are discussed.

i. *Lump-sum distribution*

A first type of rent transfer is the direct distribution of resource revenues to the citizens. The theoretical argument is that individuals at micro-level know better how to make optimal choices for consumption, saving and investment. This also gives them a good reason to feel that they are the real stakeholders in the ownership of natural resources in their country (Frankel, 2010), which may contribute to achieving social cohesion for resource exploitation and increase political stability in the country. One good example of such a policy is the Alaska Permanent Fund that redistributes part of the state's oil revenue to the citizens. Iran and Mongolia, too, use across-the-board transfer system to households to distribute their oil and mineral revenues (Gelb and Grasmann, 2010). Sala-i-Martin and Subramanian (2003) suggested that Nigeria should distribute its oil revenues to the population on an equal per capita basis, and

Birdsall and Subramanian (2004) made similar suggestion for Iraq. In fact, even if all revenue is distributed, the government can still receive a significant share of it through its effect on tax revenues.

However, some economists are sceptical of the feasibility of this proposition. Collier et al. (2009) highlighted that "this argument, though correct, is of doubtful relevance, since the countries with the worst governance are unlikely to implement such a scheme, and those most likely to implement have least need of it."

ii. Social protection schemes/ Conditional transfers

This is a variant model of direct transfer programmes. Conditional cash transfer schemes are based on household's performance on specific indicators, such as children attending school or receiving essential health services, including vaccinations. Such model has been implemented in at least 14 developing countries, including Mexico, Brazil, and South Africa and has proven quite effective. A more comprehensive model is social protection schemes that not only depend on the accumulation of human capital by households (education or health) but also on that of physical capital, for example if farmers maintain their assets during drought or economic downturn.

iii. Loan to private sector

Another option is that the government uses the resource revenue for lending to private firms on concessional terms. In developing countries, financial sector is usually underdeveloped and credit constraints impede private investment. Concessional lending to private sector thus removes credit constraints and may boost investment in the country. Such a lending could be done through public credit schemes or a development bank. Though the historical record of development banks has been extremely poor, on a modest scale "it may be worthwhile for resource rich countries to revisit and rethink this option" (Collier et al., 2009).

iv. Subsidies

Rent distribution can also be done through the channel of subsidies. The government can subsidise prices of fuel or agricultural crops, private investment, or even employment. Price subsidies consist of setting the domestic prices of certain products well below the world prices for specific welfare objectives, while investment subsidies include a wide-range of policies such as subsidising factors of production (e.g. land and other inputs), extension of credit, financing R&D activities, and provision of public goods. Investment subsidies are believed to be much effective, while fuel subsidies may be distortionary and fiscally and environmentally unsustainable (Collier et al., 2009; Gelb and Grasmann, 2010). Employment subsidy – also called an "income subsidy" – consists of setting/increasing the national minimum wage (Collier et al., 2009) whilst the government pays for the wage deficit of private sector employees. Another model is that payments from the government increases with the income of workers to encourage skills upgrading in the country (Gelb and Grasmann, 2010).

Examples of public subsidies in developed resource-rich countries include the Common Agricultural Policy in Europe, coal mining in Germany, and cheap leases of federal lands to oil companies in the United States (Frankel, 2010). Moreover, Chile, Indonesia and Australia also allocated extensive investment subsidies to the agriculture sector throughout the second half of the 20th century. Chile actively used its resource rents to create new export industries for fruit and vegetables, and was able to diversify away from the mining sector.

v. Tax reduction

Reducing non-oil taxes can also be a good option for the government. A lower tax burden may reduce the deadweight costs of taxation and could be a useful strategy for enhancing business environment and attracting investments to diversify the non-oil economy (Gelb and Grasmann, 2010).

2.3 Fiscal rules & policy

i. Increased public spending

One of the channels through which resource rents can be allocated in the economy is through increased public spending on infrastructure, education and health (Collier et al., 2009; Gelb and Grasmann, 2010). Increasing public expenditures can have both short- and long-term effects on the economy. The short-term impact of an expansionary fiscal policy is an increase in demand in the economy and thus higher economic growth. However, it may also have some unfavourable consequences; such as an inflationary impact, crowding out of private investment, and a widening trade deficit (if public spending uses imported goods). Nonetheless, with sound macroeconomic management, these unfavourable short-term consequences can well be managed and an expansionary fiscal policy may lead to higher economic growth. The long-term effect of such a policy comes through decreased transaction and transportation costs due to improved infrastructure, and enhanced productivity outcomes of education and health, which significantly impacts the long-term growth in the economy.

The argument in favour of increased public spending to offset the adverse growth effects of the resource curse is, thus, based on the long-term effects of improved physical and human capital. A prerequisite for a successful fiscal policy is the presence of strong fiscal institutions and higher administrative capacity because the government will control both the macro-level policy design and the micro-level project implementation. Nonetheless, economists strongly emphasize that public spending in resource-rich countries must be confined to fiscal rules to avoid pro-cyclical policies and enlarging fiscal deficit – a lack of which may create serious macroeconomic instability as boom-bust cycles happen repetitively in commodity markets.

ii. Rules on public spending: Countercyclical fiscal policy

Boom-bust cycles in world commodity prices pose great challenges to commodity exporting countries. In the absence of fiscal discipline, governments in developing countries have the tendency to run procyclical fiscal policy. During commodity price hikes, governments cannot resist the temptation or political pressure to increase spending proportionately – in fact, some of the increased spending is financed by borrowing from abroad (Frankel, 2010). However, in downturns when prices crash, governments are inclined to both decrease public spending – which is often difficult to do due to social and political constraints and due to micro-constraints at project implementation – and pay off some of the excessive debt that they accumulated during the upturn. Therefore, such instances create serious macroeconomic instability and significantly affect fiscal sustainability in the country.

One suggestion that is usually made to resource-dependent countries is to run *countercyclical fiscal policy.* However, such policy will be hard to implement in the absence of (legally-binding) "fiscal rules". Hence, governments in resource-rich countries are asked to impose targets on specific fiscal indicators, such as on fiscal deficit, expenditures, or structural surplus. The objective of fiscal rules in resource-rich countries should include: i) achieving macroeconomic stability; ii) moving towards fiscal sustainability; ii) scaling up growth-enhancing expenditures; and iv) adequate accumulation of precautionary savings (Baunsgaard et al., 2012).

Among the resource-rich developing countries, Chile is applauded for its successful countercyclical fiscal policy (Rodríguez et al., 2007; Frankel, 2010). Chile, under its fiscal rules, has fixed a target for *structural surplus* – originally set at 1% of GDP, then lowered to 0.5% of GDP, and subsequently to 0 in 2009. Structural balance nets out cyclical components from the actual budget balance, and thus reflects the balance that is independent of cyclical resource revenues. Since Chile largely depends on its copper revenues, its structural balance isolates the prices of copper and estimates the fiscal performance as if copper prices had been running at their long-term level.

Frankel (2010) emphasized that "any country, but especially commodity-producers, could usefully apply variants of the Chilean fiscal device." Under the

Chilean rules, the government can run a deficit larger than the target to the extent that: i) output falls short of potential, in a recession, or; ii) the price of copper is below its 10-year average level; "with the key institutional innovation that there are two panels of experts whose job it is each mid-year to make the judgements, respectively, what is the output gap and what is the medium term equilibrium price of copper… The principle of separation of decision-making powers should be retained: the rules as interpreted by the panels determine the total amount of spending or budget deficits, while the elected political leaders determine how that total is allocated" (Frankel, 2010). The Chilean model worked very well; as during the years of high copper prices, Chile was able to save $20 billion, equal to 12% of GDP, in a stabilisation fund by the end of 2008. During the 2008 global recession, it was able to pay for a large fiscal stimulus of about 3% of GDP which helped the economy to maintain its growth (The Economist, 2010b).

iii. Transparency and accountability

An important arrangement that must be put in place in resource-rich countries is a transparent system of revenue and fiscal transfers. In addition to introducing explicit fiscal rules, disclosure of the terms of contract and of payments and revenues helps increase transparency in natural resource management. The Extractive Industries Transparency Initiative (EITI), launched in 2002, includes the criteria of full publication and verification of company payments and government revenues from oil, gas and mining projects. Resource-rich developing countries adhering to the principles of transparency and checks & balances can join this global initiative and become an EITI Compliant country.

Further suggestions for a transparent financial regime in resource-rich countries include depositing resource revenues in a special foreign bank account (Iimi, 2007) and giving extra powers to the foreign bank or a global clearing house such as freezing the account in the event of a coup (Humphreys and Sandhu, 2007; Frankel, 2010). An example of such a system is the Kuwait's Natural Resource Fund; during Iraq's invasion of Kuwait, access to Kuwait's bank accounts in London remained to the Kuwaitis.

Such type of arrangements promoting transparency in resource-rich countries can well avoid the expropriation of funds by political elites, and reduce the incentives for corruption and civil war.

2.4 Sovereign Wealth Funds

It is often discussed that it may be desirable for resource-rich countries to have Natural Resource Funds (NRF). These funds can be in two forms: i) Stabilisation Fund or Sovereign Liquidity Fund (SLF); or ii) Sovereign Wealth Fund (SWF). The primary distinction between the two types is their temporal function; SLF aims at smoothing the short-run volatility effects of commodity boom-bust cycles on government revenues/spending (explained in the next section), whilst SWF aims at saving resource rents for future generations over the long-run. The strategy of building an SWF requires that the government saves part of the resource rents during commodity booms and uses it to invest in a fund that is composed of financial assets (such as bonds, stocks and other financial instruments), precious metals such as gold, and other nonfinancial assets. The oldest and biggest SWFs belong to oil-rich countries in the Persian Gulf such as Kuwait, Saudi Arabia and the United Arab Emirates.

Economists have argued that in the absence of rules on spending out of the fund, an SWF – in itself – does not constrain politicians from misappropriating the money. However, if funds are transparently and professionally run, and if they are given clear instructions that politics should not interfere with their objective of maximizing the financial wellbeing of the country, SWF can be well effective (Frankel, 2010). The Norwegian State Petroleum Fund (now called Norwegian Pension Fund) is cited as a good example. Humphreys and Sandhu (2007) recommend that spending out of the fund should go through the regular budget, so that politicians will not be able to spend the money through out-of-budget methods. It has also been suggested that spending out of SWFs should be directed to education, health or retirement support for future generations, and this should be imposed by rules so that funds are not used for military or other corroding purposes.

2.5 Institutions for macroeconomic stability

i. *Stabilisation funds*

Stabilisation funds, also called Sovereign Liquidity Funds (SLFs), provide a good strategy to smooth out the volatility effects of natural resources and reduce their adverse effects on the economy. As explained in the earlier section, SLFs differ from Sovereign Wealth Funds (explained in earlier section) in that they have short-term objectives and are composed of easily liquidable assets.

Stabilisation funds enable governments to make saving during commodity booms, and use it for the periods of downturn. In fact, savings in SLFs will be invested in international capital markets and then the fund will be run down when commodity prices fall. The size of the SLF depends on the degree of prudence of policy makers, the level of volatility of resource revenues, and the difference between marginal cost of borrowing and marginal return to lending (Collier et al., 2009). Since volatility in commodity prices is highly uncertain and unpredictable, determining the size of an SLF is not a clear task. The main problem with building an SLF is that if it is too large enough to offer a reasonable chance of successfully smoothing, it implies that domestic investment of revenue is extremely low (Collier et al., 2009). Thus, there is high opportunity cost associated with an SLF and if it becomes too large it runs into the same problem of an offshore SWF; funds are not made available for domestic investment, and benefits are pushed too far into the future (Collier et al., 2009).

ii. Price setting in contracts

Price setting in oil and mining contracts is often subject to a problem known as "dynamic inconsistency": the price in the contract is set *ex ante,* but later when the world prices go up the government intervenes *ex post* and sets a new price. Such uncertain behaviour makes foreign companies extremely reluctant to invest in the country and the process of negotiation can have large transactions costs, to an extent which may involve interruptions in the export flow (Frankel, 2010).

Humphreys, Sachs and Stiglitz (2007) and Frankel (2010) have recommended that the terms of contract should be explicitly made dependent on future market. The best option would be *indexed contracts*, in which the share of gains & losses between the government and the company is indexed on market prices. For example, if the world price goes up 10 percent, then the gains are split between the company and the government in some particular proportion. "Indexation shares the risks of gains and losses, without the costs of renegotiation or the damage to a country's reputation from reneging on a contract (Frankel, 2010).

iii. Denomination of debt in terms of commodity prices

The Latin American debt crisis in 1982 proved the fact that while borrowing may be easy for commodity exporters during boom periods, they may face serious repayment problems during downturns when the cost of servicing their debt soars. One way to avoid such an undesirable phenomenon is to index the debt to the price of the commodity (Frankel, 2010). This way, debt service obligations automatically rise and fall with the commodity prices. Frankel (2010) emphasizes that the reluctance of commodity producers to index their debt to the price of their export commodity is primarily due to the fact that foreign banks may not be lending in the currencies of emerging markets. Yet in recent years, more and more developing countries are able to borrow in local currency.

iv. Maintaining high levels of investment

Theoretical and empirical studies have found that the cost of volatility in macroeconomic aggregates such as consumption, government expenditure or trade – in terms of economic welfare – may be larger than the cost of volatility in investment. Investment is the most volatile component of national accounts, even in best functioning economies. Collier et al. (2009) argue that the volatility of investment is likely to be less problematic than might initially appear, and thus coping with this volatility may not be a fundamental problem. The authors present structural and cyclical analyses and suggest that it should be primarily domestic investment to adjust to fluctuations, "so that during boom periods resource revenues are translated into domestic capital."

The main question that arises is that how the domestic investment process should be managed. Collier et al. (2009) explain that the policy implication is that the government should focus on running a high long-term rate of investment. High rates of investment (as percentage of GDP) will exhibit proportionately smaller degrees of volatility, and thus they are easier to manage. The authors highlight that the typical investment rate for low-income Africa is currently 19 percent of GDP. However, an efficient use of resource revenues on the above principles might roughly double this level.

2.6 Privatisation

Most economists maintain that countries that have privatised their energy and mining sectors will most likely to avoid the resource curse, because privatisation may prevent the problem of rent-seizing (Weinthal and Luong, 2001; Ross, 2001a; Moreen, 2007). Weinthal and Luong (2001) argue that privatisation offers a potential path out of the resource curse "when it involves a transfer of ownership to domestic actors." The authors explain that foreign companies have a bargaining advantage vis-à-vis the state only in the short-run because the government needs capital to develop its resources. But once foreign investors had their capital sunk in the country, the bargaining power shifts to the government. However, domestic investors are present in the country over a long-term, and thus they help develop a viable tax system in the country because both the government and the domestic companies need one another to survive. Therefore, although privatisation may offer a way out of the resource curse, it has a "more positive impact on the development of tax regimes when the transfer of ownership is to domestic investors" (Weinthal and Luong, 2001).

2.7 Monetary Policy

i. Exchange rate and monetary policy regimes

The choice of an exchange rate regime may have important implications for a resource-rich country, given the fact that the country is an exporter of commodities whose prices experience strong fluctuations in the world market. The advantages/disadvantages of fixed and floating exchange rates are mixed. A *fixed exchange rate* (conventional peg arrangements) provides a "nominal anchor" to prices, has often been instrumental in reducing inflation, and may help promote fiscal discipline. However, a pegged exchange rate increases the vulnerability of the economy to adverse external shocks in such that, by eliminating foreign currency risk, it encourages overborrowing by domestic firms at lower interest rates in world capital markets. Increased exposure to external shocks will induce monetary aggregates to fluctuate. As a result, changes in liquidity may translate into sharp movements in interest rates (Agénor, 2004). On the other hand, a *flexible exchange rate* gives the central bank greater independence in choosing its inflation objective and it allows the balance of payments to automatically adjust to the terms-of-trade shocks. However, arguments against choosing a flexible exchange rate are that it may not prevent a real exchange rate appreciation (hence a loss of export competitiveness) and may be characterised by excessive volatility (Agénor, 2004).

Some have suggested that an appropriate exchange rate regime for middle-size developing economies is probably an intermediate exchange rate regime, namely a *managed floating exchange rate,* in which monetary authorities control the movements of the exchange rate through active intervention in the foreign exchange market without specifying or committing to a preannounced path or margin for the exchange rate. Many resource-rich countries have also adopted the intermediate regime since the early decade of 2000, in between a few commodity exporters with a flexible regime (such as Chile and Mexico) and a few with a fixed exchange rate (such Gulf oil producers, and Ecuador) (Frankel, 2010).

In countries with flexible or managed floating regimes, the exchange rate is not usually a nominal target. Therefore, alternative "nominal anchors" such as Consumer Prices Index (for Inflation Targeting) or monetary aggregates (e.g. money supply or monetary base) have been chosen. Though inflation targeting is practiced in Sweden, Canada, Australia, Chile, Brazil and Norway, Frankel (2005, 2010) argues that it has a particular disadvantage for commodity producing countries: it is not robust with respect to changes in the terms of trade. He explains:

> "Consider a fall in world market conditions for the export commodity, a decrease in the dollar price. It has a negative impact on both the balance of payments and the level of economic activity. It would be desirable for monetary policy to loosen and the currency to depreciate, to boost net foreign demand and thereby restore external balance and internal balance. But CPI targeting tells the central bank to keep monetary policy sufficiently tight that the currency does not depreciate, because otherwise import prices will rise and push the CPI above its target. Conversely if the world price for the export commodity goes up, a CPI target prevents a needed appreciation of the currency because it would lower import prices and push the CPI below its target." (Frankel, 2010, page 28)

Frankel (2005, 2010) proposes an alternative monetary policy regime for resource-rich and commodity exporting countries: Peg the Export Price Index (PEPI). In a PEPI, the central bank targets a price index of a basket of export commodities. The argument in favour of the export price targeting proposal is that it combines the advantage of both pegged and floating exchange rate regimes: it automatically accommodates terms of trade changes, as floating is supposed to do, while simultaneously abiding by a pre-announced nominal anchor, as a pegged exchange rate promises. Under PEPI, when the dollar price of exports rises, the currency appreciates in terms of dollars. On the contrary, when the dollar price of exports falls, the currency depreciates in terms of dollars.

A more moderate version of export targeting proposal is to target an even more comprehensive index of domestic production prices, including nontraded goods, such as the Producer Price Index or GDP deflator (Frankel, 2005, 2010). In practice, it is often difficult to separate production into nontraded and exported goods. The key point is to include export commodities in the index and to exclude import prices, whereas the Inflation/CPI Targeting does it the other way around.

ii. Foreign exchange accumulation by central banks

In countries where Natural Resource Funds are politically influenced while the Central Bank preserves its independence, it is desirable to accumulate foreign exchange reserves for the objectives of stabilizing the exchange rate during external imbalances and/or smoothing spending over time. However, economists consider accumulating international reserves for the objective of smoothing government expenditures (through lending to the fiscal authorities during commodity downturns) as a sub-optimal mechanism (Frankel, 2010).

2.8 Acquiring high-quality institutions

Last but not least, strengthening the institutions is a vital step in order to overcome the resource curse. Resource-rich countries with strong institutions have experienced rapid growth and development, while those that had weak institutions were trapped into the resource curse. Acemoglu et al. (2002) give the example of Botswana as a successful case story. The authors explain that "good policies were chosen in Botswana because good institutions… were put in place." The existence of inclusive pre-colonial institutions which put constraint on political elites, and maintaining and strengthening of institutions of private property in post-independence were keys to Botswana's success.

Institutions such as good governance, rule of law, effective judiciary system, increased transparency and accountability, appropriate property rights, contract enforcement, increased government efficiency, existence of egalitarian and democratic rights, free elections, presence of social safety nets, and institutionalised representation of minority groups are necessary for not only resource-rich countries, but also for developing countries as a whole, to achieve strong economic growth and development. These institutional reinforcements, however, need to be supported by measures to build "social capacity and political consensus" in resource abundant countries (Woolcock et al., 2001).

New Institutional Economics maintain that markets need to be supported by non-market institutions because markets are not self-creating, self-regulating, self-stabilizing, or self-legitimizing. Dani Rodrik (2007) explains that, in order for markets to function well, there needs to be five types of market institutions alongside the market: property rights, regulatory institutions, institutions for macroeconomic stabilisation, institutions for social insurance, and institutions of conflict management. In fact, property rights are necessary to guarantee an adequate control over the return to the assets (e.g. an innovation) that are produced by entrepreneurs; regulatory institutions curb fraud, anticompetitive behaviour, and moral hazard; institutions for macroeconomic stabilisation – that were discussed partly in section 2.5 – help smooth out the real, financial, monetary and external shocks in the economy; institutions for social insurance help achieve social cohesion in the country; and institutions of conflict management prevent detrimental struggles between social factions by reducing the payoff to socially uncooperative strategies.

Rodrik (2007) explains that there is no unique type of institutions for all countries. There is a large variety of regulatory, stabilizing, and legitimizing institutions that can support a well-functioning market economy. The acquisition of institutions depends on local knowledge, experiences and capabilities. Institutions need to be developed locally; they cannot be independent of a country's history, culture and social norms. Nonetheless, a country can always learn from the institutional arrangements prevailing in other countries – best practices, and international codes and standards can always help.

3. What strategy for Afghanistan?

"Imagine that a valuable natural resource is suddenly discovered both in Afghanistan and Switzerland. What would the economic consequences in each of the two countries be? Would the new wealth turn out to be a curse or a blessing?" This question was hypothetically posed by Mehlum et al. (2006). After discussing the implications of the institutional quality for growth and development, the authors conclude that "the economic consequences of discovering a new valuable resource are therefore likely to be quite different in warlord-dominated Afghanistan and law-obedient Switzerland."

Mehlum et al.'s (2006) argument is precisely true. The objective of this paper is, therefore, to discuss such policies, arrangements and measures applicable to Afghanistan so that, by adopting those, it is not left deprived of the same gains that Switzerland would have enjoyed from the discovery of a new natural resource. Policy recommendations range from political economy approaches to economic policies, discussed so forth.

3.1 Resource rents as a source of political stability

Numerous works have discussed that natural resource abundance negatively impacts political stability. Natural resources encourage rent-seeking behaviour in the economy and may create rapacious redistributive struggle between political and social factions in the country. They also have an impact on the type of political regime and on the quality of democratic institutions. Above all, natural resources tend to increase the probability of civil war, especially in ethnically fractionalized countries.

Further, political instability itself determines how successfully and effectively natural resources are exploited in the country. Political instability not only discourages private companies from engaging in the extraction and exploration of natural resources, but also pushes the governments into "rapacious resource depletion" (van der Ploeg and Rohner, 2012). Private investment in mining projects usually span over 25 to 30 years, and such long-term investments depend, above all, on political certainty and stability. Increased uncertainty about future political environment will prevent the country from attracting noteworthy investments by international companies.

Uncertainty about the future also encourages the governments to engage in over-extraction of natural resources in order to reduce the future rents which incentivise the rebel groups (van der Ploeg and Rohner, 2012).

Conventional policies prescribed to resource-rich, conflict-prone countries are:

(i) to increase political stability through strengthening the *institutions of conflict management* (i.e. democratic institutions, participatory political regimes, free elections, egalitarian rights to minority groups, civil liberties, and social insurance mechanisms)[24] and supporting these with "social consensus" to minimize the risk of coups and authoritarian regimes in the future;

(ii) to restrict rent-seeking behaviour in the economy through acquiring high-quality institutions (e.g. effective judiciary system, rule of law, property rights, contract enforcement, etc.) that constrain political elites from expropriating resource rents and limit corruption in the country; and

(iii) to develop *meta-institutions that reduce the political feasibility of capturing the rents* and thus to reduce the incentives for rebellion groups. Such meta-institutions include both political and social measures. Political arrangements may consist of building strong national military forces, enacting agreements for the military presence of foreign countries or international military organisations (such as NATO, UN security missions, etc.), and strengthening the constitutional bodies (such as parliament). Social measures, on the other hand, include strengthening the civil society and promoting social awareness for political rights and freedom.

Another stream of thinking in the political economy literature is based on the "rentier state thesis". The rentier state theory suggests that as governments in resources-rich countries receive large amounts of "unearned" income, they should develop greater redistributive capacity of rents through various social transfer programmes or political channels. However, the problem with the rentier state is that they tend to be autocratic and authoritarian regimes, and use the resource rents for patronage politics (i.e. to reward individuals for their electoral support).

With a rentier state approach, resource rents can be used to buy off anti-government groups, which helps bring about political stability in the country (Smith,

[24] For a discussion of "conflict-management institutions", see Rodrik (1999).

2004; Bjorvatn and Naghavi, 2011; Connelly, 2011; van der Ploeg and Rohner, 2012). To put simply, social transfer policies bribe the rebel groups to work rather than to fight. The proponents of the rentier state thesis argue that in politically unstable environments the democratisation process does not work very well. Priorities in such countries should be to create incentives for rebel groups to engage in cooperative action, and to increase the cost of conflict so that the transfer program serves as a disciplining force.

With reference to Afghanistan, the typical rentier state suggestions may not be suitable because capture of resource rents do not constitute the fundamental objective of the insurgent groups in Afghanistan. When resource rents are an element of the objectives of the insurgent groups, then transferring part of the rents to insurgents make sense as it reduces their incentive to engage in secessionist conflicts.[25] However, the insurgent groups in Afghanistan (such as the Taliban and the ISIS) allegedly hold a non-pecuniary and ideological objective and struggle for capturing the whole state (i.e. a centrist conflict) rather than engaging in a secessionist conflict to form a state of their own to capture the resource rents. Further, natural resource exploitation in Afghanistan has not yet generated large amounts of revenue for the government, and the insurgent groups also know that most of the natural resources in Afghanistan are *not lootable* resources that they could have quickly exploited. Hence, it is less likely that *direct* transfer of rents would discourage the insurgents from pursuing the conflict.

Nonetheless, an alternative version of a rentier state policy may well be effective in Afghanistan. Cash payments or social transfers should not be made directly to the insurgent groups, but to those political leaders and ex-warlords who oppose the Taliban and the ISIS and have, in principle, supported the government, or to those communities who maintain peace and stability and fight the insurgents in support of the government. The following variants of a rentier state policy can be applicable in Afghanistan:

(i) Resource rents should be used to generate employment opportunities and to provide public goods for the population living in areas that are prone to insurgency influence. The purpose is to buy off local communities to cooperate with the central government and to discourage them from joining the insurgency groups. This can be done through launching large infrastructure projects, undertaking public works, establishing hospitals

[25] Secessionist conflict refers to which a political entity secedes from the state to form an independent state of its own.

and health care facilities, extending access to electricity, and providing other public goods and services in those areas.

(ii) Conditional social transfer to a community (instead of individuals or households) may also be a good approach. Specific forms of "social protection schemes" such as conditional cash transfers and agricultural subsidies to *communities* that exhibit stability and peace and that do not provide help or show favouritism to the insurgents can be an effective policy. This will provide incentives at community levels to cooperate with the government and to exclude those individuals, from within the communities, who join the insurgency.

(iii) Provision of rewards, cash payments, and financial benefits to anti-insurgency political elites at community, district, provincial, regional and national levels who cooperate with the government. These political figures can be effective means of gaining the public support through their influence on people of related ethnic, political and religious groups.

(iv) The "reconciliation process" put forward by the Afghan government to encourage Taliban members to withdraw from insurgency and join the government in exchange for cash and non-cash (e.g. providing job) benefits is also a good instrument but has, so far, not been properly implemented or utilized. The Government has so far focused on the "carrot" mechanism for the reconciliation process, and has entirely forgotten to also put in place a "stick" mechanism. If there are incentives for groups to join the central government, then there should also be a mechanism to penalise those who rejoin the insurgency. Many incidences have been reported where reconciled groups have again left to rejoin the insurgency and have not cooperated with the government. To make the reconciliation process successful, a comprehensive carrot-and-stick mechanism will be necessary. Future resource revenues could be used to support the incentive packages allocated through the reconciliation process, but only if it is coupled with a mechanism that penalises re-joining the insurgency.

The above propositions can transform the "conflict-triggering effects" of natural resources into "regime stabilizing effects." However, these policies should not impede and harm the democratic institutions developed in the country over the past 15 years. An effective mechanism for implementing the social transfer programmes may well be aligned with democratic norms and not necessarily induce excessive patronage practices.

Nevertheless, the destabilizing effects of natural resources in Afghanistan are expected to be minimal compared to other resource-rich countries that have faced extensive conflict (Ross, 2010). Ethnic divisions are not likely to generate conflict-triggering effects if natural resources and political power are evenly dispersed throughout the country. However, when the geographical distribution of natural resources is concentrated in a region that coincides with the presence of a minority group, conflict is harder to avoid (Morelli and Rohner, 2010). In Afghanistan, natural resources are luckily spread throughout the country and are not concentrated into a single region where a single ethnic group would claim the rights for mineral resources.

To conclude, natural resource abundance, if well managed, can be a source of political stability in Afghanistan, instead of a destabilizing and conflict-triggering factor. Policies based on traditional rentier state thesis that involve direct rent transfer to rebellion groups may not be stabilizing in Afghanistan because the insurgents here are not after a secessionist conflict to capture the resources rents. However, alternative variants of a rentier state approach can be effective – and politically and socially feasible – if the social transfers are not directed to the insurgent groups but instead to local communities that show better peace performance and to political elites and ex-warlords strongly opposing the insurgent groups.

3.2 Diversification

Diversifying the economy should be a necessary policy of the Afghan government so that the country does not remain dependent on commodity exports for the years to come. As explained in section 2, resource-dependent and commodity exporting countries experience strong macroeconomic volatility subsequent to boom-bust cycles in global commodity markets. Macroeconomic volatility entails significant costs in terms of decline in economic growth, welfare loss and increase in inequality and poverty.

The Afghan economy is already least diversified. The exports basket is concentrated around few agriculture commodities and agriculture-based products. Manufacturing is highly concentrated, with food processing and carpet industry representing around 95 percent of total manufacturing output. As a result, growth volatility has been excessively high in Afghanistan; the standard deviation of the real GDP growth between 2003 and 2016 has been 5.8 percent. With mining development and subsequent commodity exports in the future, growth volatility is likely to exacerbate. It would be fundamentally important for the country not to become a commodity exporter and to diversify into other (new) industries.

The country may either diversify into resource-based industries – a strategy known as *resource-based industrialisation* – or into other new industries and activities, be them in agriculture, manufacturing or services. Given the narrow industrial base, limited technological know-how and low capital in Afghanistan, it will be difficult for the country to develop resource-based industries without foreign direct investments. Resource-based industries, particularly down-stream processing sectors, are highly capital-intensive and often require sophisticated industrial technology. The costs for resource-based industries will therefore be substantial.

Nonetheless, another approach to diversification would be to diversify into new activities and sectors – not necessarily dependent of the resources sector – where Afghanistan may well have a comparative advantage. Activities which require relatively less capital, lower technology and less sophisticated skills might be most feasible for Afghanistan, given the local endowments and intermediate inputs. However, it is not possible to identify *ex-ante* these potential activities and sectors. Identification of new activities requires "discovery" of an economy's cost structure – that is, discovery of which new activities can be produced at low enough cost to be profitable. Ricardo Hausmann and Dari Rodrik (2003) have called this process "self-discovery" – learning what a country is good at producing.

In fact, investment in new activities and sectors has a large social value, but their private return is too low because the first entrepreneur who invests in a new activity will have to share the value of his discovery with other entrepreneurs who will quickly emulate. Conversely, if his investment in the new activity fails to be profitable, he will bear the full cost of his failure. Thus, returns to investments in new activities are not fully appropriated. This basically arises from an information externality. Free entry by competitors (i.e. imitators or copycats) makes the nonappropriability problem worse and undercuts the incentive to invest in new activities (Hasumann and Rodrik, 2003). Further, new investments by local entrepreneurs require experimentation with new product lines and "technological tinkering" to adapt established technologies of foreign producers to local conditions. Nonetheless, transferring a certain technology to a new economic and institutional environment has always an uncertain probability of success (Rodrik, 2007).

Further, discovering new activities and sectors require simultaneous, large-scale investments to be made in order to become profitable and to attract private investors. "Profitable new industries can fail to develop unless upstream and downstream investments are coaxed simultaneously" (Rodrik, 2007). Such a problem is known as "coordination failure". In the presence of coordination externalities, the government will be required to coordinate the investment and production decisions of entrepreneurs.

Information externalities and coordination failures both are reasons to believe that diversification is unlikely to be successful without direct intervention of the government or other public action. Investment in underdeveloped countries may have been constrained by inadequate incentives to bear the possible costs of investments in new activities and thus "laissez-faire cannot be the optimal solution under these circumstances" (Hasumann and Rodrik, 2003). The first-best policy response in the presence of information externalities is to subsidise investments in new activities. This can be done through providing public credit or guarantees, public R&D, temporary monopolies, tax incentives, import tariff exemptions of input materials, or even trade protection of key sectors (Rodrik, 2007).

The aforementioned policy instruments constitute basically an "industrial policy" – which is an interventionist and sectoral policy, as opposed to "laissez-faire" approach. Though industrial policy has often been blamed for 'picking winners' in the market which may be subject to misjudgement by the government and to political influence, some mainstream economists have emphasised the importance of "rethinking industrial policy" in today's era of post-crisis realism and on a more active role of the government in coordinating investments and facilitating industrial upgrading (Rodrik, 2007; Aghion et al., 2011; Lin, 2011; Stiglitz, 2011). Countries such as Japan, China, Malaysia, Indonesia, South Korea, Thailand, and Chile used growth-enhancing sectoral policies throughout the 20th century which favoured their development. The question is not whether industrial policy is justified at all, which is being implemented in one form or another by many countries in the world today[26], but how industrial policy should be designed as part of a growth strategy to favour economic development in a country (Spence, 2008; Aghion et al., 2011). Export promotion policies, development of export processing zones (EPZ) and incentives for foreign direct investment (FDI), which are being extensively practiced today around the world, all qualify as industrial policies (Rodrik, 2007; Spence, 2008).

Therefore, Afghanistan should use the resource rents as a source of financing for its diversification strategy. Following are some specific suggestions for the Afghan government on how to pursue such a policy:

[26] See *The Economist (2010a)* on recent examples of industrial policy practices by countries such as Japan, France, China, United States and Britain.

(i) Resource rents should be used to finance both "hard" and "soft" infrastructure projects in order to minimize transaction costs for investment and to increase returns to capital. Hard infrastructure refers to roads, highways, railway, telecommunication systems, electricity grids and other public utilities. Soft infrastructure includes institutions, regulations, social capital[27], and other economic arrangements (Lin, 2011). Increased access to public goods and services, decreased transaction costs, and higher marginal return to investment are some of the most important incentives for local and foreign entrepreneurs to invest in a country.

(ii) Resource rents should be allocated for "horizontal" and "vertical" policies of the government to support private investment. Horizontal measures refer to financing R&D activities across industries and economy-wide skills/technological upgrading measures. Meanwhile, vertical policies consist of promoting specific sectors and supporting specific businesses by provision of subsidies, public credit, tax holidays, or temporary tariff protections. However, these vertical interventions must be carefully designed and well calculated because any system of incentives is subject to moral hazard and political capture. Therefore, the policy should be embedded in an appropriate institutional context so that misuse and rent-seeking are fully prevented.

(iii) Resource rents should be used for providing "investment guarantees" to foreign investors. In fact, Afghanistan exhibits high political uncertainty which makes foreign investors reluctant to invest in the country. Investment guarantees and incentives for FDI are some of the best instruments to attract noteworthy investments in various resource-based industries and to offer an insurance mechanism of political uncertainty to foreign and local entrepreneurs. Several resource-rich countries relied on foreign investment and technology to develop their industries and to diversify away from natural resources. One good example is Mexico whose industrialisation was almost entirely undertaken by foreign entrepreneurs and immigrants (Maloney, 2007). Hence, due to limited technical know-how and lack of access to technology by local entrepreneurs in Afghanistan, encouraging foreign investments in

[27] Social capital refers to social interactions, relations and norms between individuals in the society that have economic value and benefits. Economic theory has recently suggested that social capital contributes to economic growth.

resource-based industries should be an important strategy of the government.

Nevertheless, Afghanistan should not abandon agriculture production in favour of specialising in manufacturing and resource processing industries. Plantation crops do constitute the resource base of a country. Some of these crops such as coffee/cocoa in African countries generate high rents just like other point-source natural resources. Resource-rich countries such as Chile, Brazil, Indonesia and Australia have actively used resource rents to develop their comparative advantage in agriculture-related industries and have diversified their production structure. For Afghanistan, agriculture sector not only offers huge potential for reducing unemployment, but also for poverty reduction. Around 80 percent of Afghan households depend somehow on income received from agriculture-related activities. Therefore, public support to agriculture production may constitute an effective way to reduce poverty – which is currently at 39 percent – and to strengthen macroeconomic stability. The government can use the resource rents to subsidize seeds and fertilizers, provide concessional credit to farmers, rehabilitate and expand irrigation infrastructure, and, last but not least, pursue an agriculture intensification policy through introduction of modern machinery and more drought-tolerant and flood-resistant seeds.

Further, opium production generates huge rents to farmers, which is a strong incentive to cultivate opium poppy instead of other cereals. The problem with opium rents is that they escape the government revenues, finance terrorism and insurgency, damages human capital and increases social instability, and makes macroeconomic management difficult for the government. Unfortunately, efforts by the Afghan government and international community over the past 15 years to eradicate opium production in the country have not been much effective. One good strategy is to provide farmers with *economic incentives* to switch from poppy cultivation to other cereals and crops. The best incentive would be to subsidise the prices of other crops, for example wheat. Though agriculture price subsidies are criticised for distorting the market prices, they are actively used in countries around the world, including the European Union, for the reason that they may be welfare-enhancing. In Afghanistan, agriculture subsidies would be even more effective due to its poverty-alleviation momentum and its capacity to reduce opium production. Wheat can qualify as the best alternative crop to be subsidised because it constitutes the primary nutritional item of Afghan households, especially the poor. Hence, resource rents can be used to subsidise the price of wheat. This, itself, can be an industrial policy instrument to encourage diversification in the economy.

3.3 Security and political tensions

Security is the most important condition for attracting foreign direct investments. Regrettably, security is worsening in key mining sites over the past few years, such as in the Aynak copper mine in Logar province and in the Hajigak iron ore deposit in Bamyan and Wardak provinces. Bamyan which was one of the most stable and secure provinces in Afghanistan has recently experienced insurgency activities. Former minister of mines, Waheedullah Shahrani, once accused "regional intelligence units" for strategically destabilizing the mining sites in Afghanistan.[28] In late 2012, the Chinese consortium of MCC and Jiangxi Copper companies halted their operations at the Aynak copper mine and repatriated their employees due to security threats they received from the insurgency groups.[29]

The Afghan government needs to restore security in areas where mining sites have been awarded for extraction or have been put for tender. Though a special police force have been created to provide protection for mining activities, it seems that more effort needs to be put in place. The government needs to find proper solutions to the security challenges through political channels. One possible way would be to make local communities feel responsible for the security of mining sites whose operations directly impact their lives. Local communities must be given the awareness that insecurity may result in halting the mining operations and, as a result, they may lose the benefits that they would have received from mining operations. Local communities must be made involved in the process of security enhancement in exchange for financial benefits, because the economic incentives offered by mining projects increase the cost of engaging in non-cooperative behaviour or supporting the insurgents.

Recent incidences have proven that Afghan communities have the push back on the insurgents and prevent them from infiltrating their regions. For instance, more than 50 villages rose against the Taliban forces in south-eastern Afghanistan in 2012, which involved armed uprisings.[30] Thus, a solution to the security threats posed to mining activities is that the mining companies enter into formal or informal agreements with local communities in which the main conditionality to offer further economic benefits to communities would be to establish better security around the area. In some African countries, mining companies regularly bribe local rebel groups

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[28] Minister Shahrani's exclusive interview at ToloNews, with Mujahed Kakar. September xx, 2012

[29] "China halt at flagship mine imperils Afghan future" by Jessica Donati and Mirwais Harooni. September 27, 2012. Reuters. http://af.reuters.com/article/worldNews/idAFBRE88Q0XL20120927 (accessed 16/10/2012)

[30] "Armed uprising against Taliban forces insurgents from 50 Afghan villages" by Ben Farmer. August 14, 2012. The Telegraph. http://www.telegraph.co.uk/news/worldnews/asia/afghanistan/9475141/Armed-uprising-against-Taliban-forces-insurgents-from-50-Afghan-villages.html (accessed 16/10/2012)

not to jeopardize their operations. As argued in section 3.1, an optimal approach in Afghanistan would be to transfer the financial benefits to local communities. Such social transfers can well be conditional on specific performances of local communities.

A concern may rise that empowering local communities to get involved in security enhancement of their districts may result in an arming process of communities. However, the Afghan government already has past experience in creating local armed groups through the Afghanistan National Auxiliary Police (ANAP) and the Local Defence Initiative (LDI) programmes. Though the programmes were not very effective (Lefèvre, 2010), they invalidated the initial concerns of formalizing local militias. Hence, the Afghan government can well have the ability to control, manage and discipline the process of community involvement in the security process of mining sites.

3.4 Policy, regulations and institutions

In addition to the above recommendations which involved political economy approaches, a number of conventional policies, regulatory set-ups and institutional arrangements discussed in section 2 will also be important for Afghanistan:

- Afghanistan lacks skilled workers for mining industry. It is imperative that the government establishes vocational schools and technical mining institutes to train the workers for future employment in mining. The two large mining projects of Aynak and Hajigak will require thousands of skilled workers. Local recruitment can only take place if the required skilled workforce is available locally. If local labour is not employed, it will incite social discontentment for the fact that the companies would be bringing foreign workers. Furthermore, establishment of technical training centres will enhance human capital in the long run and will increase the growth impact of mining development in the country.
- The government should lay the foundations for an effective fiscal discipline in the future. A successful system of fiscal rules cannot be created spontaneously. It requires years of institutional practice, amendments and revisions until a newly-created system is adopted into the contextual needs. Therefore, the work needs to start now so that the government could establish effective fiscal rules in the future. This needs planning on a medium-term fiscal sustainability programme, and avoiding pro-cyclical fiscal policies at present and until mining operations effectively generate huge income to the government.

- Once mining revenues become the principal source of revenue for the government, the creation of a stabilisation fund in the foreseeable future will be a useful initiative. It will greatly help the Afghan government to minimize macroeconomic volatility in the economy.
- The current nominal anchor for the managed floating exchange rate in Afghanistan is the *monetary base,* called "reserve money targeting". Monetary policy authorities should envisage moving towards targeting a *price index* that would include commodity prices. This should be planned for the medium-run, when the share of mining sector in GDP becomes significant – at least more than 10 percent of GDP – and commodity exports represent more than half of total exports. In such circumstances, a price-index-targeting regime for monetary policy may effectively maintain price stability in the country.
- Last but not least, developing high-quality institutions is imperative. Minimizing corruption and limiting political elites from capturing resource rents can only be feasible if strong and efficient institutions are developed. The government should work on strengthening the rule of law, improving the judiciary system, maintaining transparency and accountability in mining contracts, enforcing checks & balances, establishing contract enforcement mechanisms, introducing property rights system, increasing government effectiveness, strengthening the regulatory capacity of the government, and promoting good governance as a whole.

4. Conclusion

Resource-rich countries are not doomed to failure. While 'resource curse' is an actual and potential risk, countries can well avoid this phenomenon by adopting effective economic policies and efficient institutional arrangements, which on the one had enables the country to achieve a productivity-enhancing structural change and, on the other hand, curb the adverse effects of resource abundance. In this case, natural resources become an advantage for growth and development rather than a detrimental factor.

This paper reviewed the set of policies, regulations and arrangements prescribed in the economic literature to overcome the resource curse, including structural policies to enhance human capital and diversify the economy; establishing social transfer systems to distribute the resource rents to citizens; establishing effective fiscal rules to enforce a countercyclical fiscal policy; establishing natural resource funds to save the resource rents for future generations; developing institutions for macroeconomic stability; undertaking privatisation to avoid the problem of rent-seizing; effective monetary policy; and acquiring high-quality institutions.

In the second part of this article, I focused on the case of Afghanistan and discussed a number of economic policies, institutional arrangements and political economy approaches that are relevant and applicable to the context of Afghanistan which is yet to embark on resource exploitation. Specifically, I discussed how resource rents could be used to strengthen political stability in the country. I propose a semi-rentier state model, in which financial benefits from natural resources are allocated through cash payments or social transfer systems to those communities who maintain peace and stability, and fight the insurgents in support of the government; and to those political leaders and former warlords who oppose the current insurgent groups and are, in principle, supportive of the government.

The paper also suggested that economic diversification should be a priority for Afghanistan so that it does not remain dependent on commodity exports for the years to come. Specific arrangements were proposed for how the country can use the resource rents as a source of financing for its diversification strategy. The government can play an important role in the diversification process by actively coordinating the investment decisions, providing incentives for investment in new activities and sectors, and allocating the resource rents to develop and improve both "hard" and "soft" infrastructures. Rents from fuel and non-fuel minerals can also be used as an instrument to fight opium cultivation by providing incentives for farmers to switch to the cultivation of alternative agricultural crops; for example by subsidizing wheat prices.

Meanwhile, technical and vocational institutes must be established in the country to train skilled workers for the mining industry, and this does not only have short-run employment benefits but also leads to long-run human capital enhancements. Furthermore, the government should work on a medium-term fiscal sustainability approach, and lay the foundations for an effective system of fiscal rules in the future. Finally, the paper recommended that Afghanistan should acquire high-quality institutions in order to minimize corruption and limit political elites from capturing the resources rents.

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