Measuring Industrial Upgrading in Global Value Chains: A Latent Variables Approach

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Abstract: A key question for promoting international competition is how to improve the position of nations and industries in global value chains (GVCs). The first step is to properly measure industrial upgrading in GVCs. This is not a trivial issue because upgrading has not been defined unambiguously. Several authors have used different (and sometimes related) measures, all of which are indicative of certain aspects of upgrading. Rather than trying to find the single, ultimate definition and measurement of upgrading, this paper proposes a different type of framework. We examine the multidimensionality of industrial upgrading, using eight existing indicators for upgrading in an Exploratory Factor Analysis. The indicators all adopt the GVC perspective and include, for example, the growth in market share of value added exports and the growth in the number of high-skilled workers involved in GVCs. We find that industrial upgrading has three dimensions: productivity upgrading, chain upgrading, and skill intensity upgrading. Finally, with these dimensions, we compare and analyze the upgrading of different countries and industries using the World Input-Output Database.

Keywords: industrial upgrading, factor analysis, global value chains, world input-output tables

1.Introduction

Industrial upgrading, which is also often referred to as "economic upgrading" or simply "upgrading", is a topic that frequently returns in mass media, governmental reports and discussions of economic policy, especially for those developing countries which specializing in low-end industries. For instance, with the decline in China's economic growth and gradual disappearance of demographic dividend, Chinese economists and policy makers have always been advocating seeking roads to upgrade low-end industries towards high end in order to improve global competitiveness. Indeed, a key challenge for promoting international competition is how to improve the position of both firms and workers within global production networks. This is particularly important in export-oriented developing countries, where firms and workers are increasingly integrated into regional or global networks. Before considering drastic upgrading reforms, however, we think the first step is to properly measure the level of upgrading. We need quantification to help to find out which industry in a country has experienced relatively more or less upgrading over time and how much upgrading has occurred, and which industry has experienced more upgrading compared to the same industry in other countries.

This article will address these questions and try to answer them with quantitative measures of upgrading. Measurement will help to formulate and assess policies intended to improve industrial upgrading. However, industrial upgrading may be hard to quantify because upgrading has not been defined unambiguously. Upgrading is typically defined as the ability to make better products, to make them more efficiently, or to move into skilled activities (Porter,1990; Pietrobelli and Rabellotti,2006). However, in recent past, the various stages of production, which include design, production, marketing, distribution and support to the final consumer, can take place at different geographic scales(national, regional and global). On this occasion, value chains, which describe the full range of activities that firms and workers perform to bring a product or service from its conception to end-use, are said to be “global” when the activities are carried out in inter-firm networks on a global scale (Gereffi and Fernandez-Stark, 2011).Therefore, in the terminology of global value chains (GVCs), upgrading is defined as the dynamic movement within the value chain from one stage of production to another with higher value activities and increased benefits (Gibbon and Ponte,2005). Humphrey (2004) and Humphrey and Schmitz (2002) promoted to view upgrading in a wider perspective and identified four distinct types of upgrading, namely process, product, functional, and inter-sectoral upgrading.

There have been several empirical attempts to measure upgrading based on these theoretical definitions. Following conventional definitions, Giuliani et al. (2005) define upgrading as innovating to increase value added. In their case studies of 12 clusters in Latin America, in order to quantify the degree of upgrading, they attribute a value ranging from absent (0) to high (3) to each of the following types of upgrading: process, product, functional, and inter-sectoral upgrading. As pointed out by themselves, attributing values personally may cause bias and misinterpretations. Thus, there may be potential problems on the accuracy of the results, and the results will call for caution interpretations. A number of studies have argued for using export unit value to capture upgrading. In a study of Turkish and Bulgarian textiles and apparel, Evgeniev and Gereffi (2008) use export unit value to distinguish between ‘up-market’, ‘middle-market’ and ‘down-market’ exports, and illuminate the possibilities for particular countries to upgrade or climb the industrial ladder of export roles. Li and Song (2011) also use export unit value data in their study of Chinese trade. Kaplinsky and Readman (2005) suggest the use of export market share and export unit value as indicators of upgrading, which gives a more complete and reliable picture about whether a sector experiences upgrading or not. These studies of individual cases of countries or sectors and arguments on the indicators of upgrading imply that upgrading has more dimensions. Using one or several indicators to measure upgrading may ignore some aspects of industrial upgrading.

In this paper, we examine the multidimensionality of industrial upgrading and derive new measures for industrial upgrading, using nine existing indicators based on the framework proposed by Milberg and Winkler (2011). Some conventional indicators are adjusted to reflect the GVC perspective. For example, export growth and growth in export market share are adjusted to be growth in value added exports and market share of value added. To that end, we employ an Exploratory Factor Analysis (EFA) on the set of these indicators. EFA is based on a model which extracts only the information that is common to all indicators. Previewing the factor analysis results, we find that industrial upgrading has three dimensions: productivity upgrading, chain upgrading, and skill intensity upgrading. Finally, with these dimensions, we compare and analyze the upgrading of different countries and industries using the World Input-Output Database.

The remainder of this paper is organized as follows. In Section 2, we describe the indicators and expose the technical calculation based on a multi-sector, multi-region Input-Output model of the world economy. In Section 3, we use a latent variables approach to examine the dimensionality of industrial upgrading. Empirical results are shown in Section 4, and Section 5 concludes.

2. Analytical framework for measuring upgrading

In this section, we introduce our framework for measuring industrial upgrading in global value chains (GVCs). We start with clarifying the indicators and outline our approach in Section 2.1. In Section 2.2, we provide a mathematical exposition of GVC analysis which is rooted in the input-output analysis introduced by Leontief (1936).

2.1. Indicators of industrial upgrading

In this subsection, we introduce our indicators that proxy for industrial upgrading. Selecting indicators is not a trivial issue because industrial upgrading has not been defined unambiguously, and there are no specific variables to measure upgrading. Therefore, rather than trying to find the single, ultimate definition and measurement of upgrading, we extract existing indicators from previous definitions and research done on upgrading and use them to examine the multidimensionality of industrial upgrading. Some conventional indicators based on gross exports are adjusted to be based on domestic (value added) content of exports because increasing fragmentation of production across borders in the GVCs is changing the nature of trade benefits.

Economic upgrading has been measured mainly through two notions, namely productivity growth and international competitiveness. To track productivity growth, some self-explanatory indicators are always used, such as labor productivity and capital compensation. To track developments in international competitiveness, some indicators based on trade figures are widely used, such as changes in trade volume, shares in world export markets (which is also known as revealed comparative advantage, RCA) and export unit value. For example, Kaplinsky and Readman (2005) state that upgrading hinges on the simultaneous maintenance of world export market share and the attainment of higher export unit values. Similarly, Li and Song (2011) write that product quality can be used directly to reflect whether a country's export has experienced upgrading, and higher export market share and export unit value (the price of a product) reflect global consumers' evaluations and preferences for the quality. Following these previous studies, Milberg and Winkler (2011) derived a list of indicators that have been used to measure economic upgrading. As shown in the second column of table 1, these measures have been used at different levels of analysis: country, sector, and firm.

However, indicators of competitiveness based on the gross value of exports are increasingly doubted in a world with increasing fragmentation of production across borders. Increasing fragmentation means in essence that more parts of the production process are performed in different countries. In the past, a country performed the whole production process and competed with other countries in the global market. The competitiveness of countries was based on the price and quality of their final products. But globalization has entered a new phase, in which today's products and services are made in global supply chains or global value chains, rather than in a specific country. That is to say, a country imports raw materials and intermediate goods, adds one or more layers of value to them, and then sells the product to a foreign producer, who adds the next layer. This corresponds to Baldwin's (2006) "second unbundling", where the location of the production of intermediate inputs differs from that of the final products. In this phase, competitiveness of countries increasingly plays out at the level of activities within the global production process, rather than at the level of final products. To capture this change, new indicators of international competitiveness are needed that are based on the value added embodied in exports, rather than standard trade figures that record the value of exports. In this paper, we propose new indicators which are developed to do just this, and show how these indicators can be derived empirically from world input-output tables.

Actually, concerns about the bias between the gross value of exports and the value added in the production process of exports by a country have been expressed before. Case studies of the iPad and iPhone (Kraemer *et al*., 2011) reveal that China, which exports the final Apple product and is artificially credited with having created all of its value, only captures 1.8% of export value. The global value chain of a product refers to the collection of all activities in the pre-fabrication, fabrication and post-fabrication services (Baldwin and Evenett, 2012). Ali-Yrkko *et al.* (2011) and Dedrick *et al.* (2010) studied the global value chain of the Nokia smartphone and the iPod and laptops and suggest that it is in pre- and post-fabrication activities that most value is added. These activities include research and development, design, branding, logistics and after-sales activities. In the value chain of Apple products, China performs the assembly process on the basis of imported components and parts and captures little value. Koopman *et al*. (2012) and Chen *et al.* (2012) studied the export sectors of China, which has a high share of processing exports which consist of large part of assembly activities based on imported intermediates. They empirically revealed that value added in processing trade is much lower than the export value suggested by standard trade figures. Johnson and Noguera (2012) confirmed the existence of a similar gap and found that bilateral imbalances measured in value added differ from gross trade imbalances. This gap has also attracted the attention of policy makers. For example, Pascal Lamy (the former Director-General of the WTO) proposed, jointly with the OECD , "trade in value added" as a better approach for the measurement of international trade (see OECD-WTO, 2012).

However, none of the studies that are related to economic upgrading has adopted the value-added based indicators. In this paper, we propose to adopt the value-added based indicators to measure economic upgrading. The last column of table 1 presents these indicators. All the indicators based on the value of gross exports have been adjusted. Export growth, growth in export market share and unit value growth of exports have been adjusted to growth of value added in exports, growth in market share of value added in exports, and growth of unit value added in exports, respectively.

As we can see from table 1, increased skill intensity of employment and exports are also used as two indicators for industrial upgrading. We use the growth in the share of high-skilled working hours as proxy for increased skill intensity of employment, and increased skill intensity of exports is measured by the growth in the high-skilled working hours that are directly and indirectly involved in production of final manufacturing exports. High-skilled workers are supposed to have more possibilities than medium- and low-skilled workers of specializing in activities that create more value added, and make better products and make them more efficiently. Thus, the increase in the share of high-skilled workers also indicates whether an industry experiences upgrading or not.

Table 1. Measures of economic upgrading

Level of aggregation	Previous indicators	Indicators in GVCs
Country	Productivity growth Value added growth Profits growth Increased capital intensity Export growth Growth in export market share Unit value growth of exports Unit value growth of output	Labor productivity growth Capital compensation growth Capital intensity growth Growth of value added exports Growth in market share of value added exports Growth of unit value added in exports Increased skill intensity of employment Increased skill intensity of exports
Sector	Productivity growth Value added growth Profits growth Increased capital intensity Export growth Growth in export market share Unit value growth of exports Unit value growth of output Increased skill intensity of functions	Labor productivity growth Capital compensation growth Capital intensity growth Growth of value added exports Growth in market share of value added exports Growth of unit value added in exports Increased skill intensity of employment Increased skill intensity of exports

	Increased skill intensity of employment Increased skill intensity of exports	
Firm	Increased skill intensity of functions Composition of jobs Increased capital intensity Product, process, function, chain upgrading	

2.2. Technical exposition

In this section, we outline our approach to calculate the indicators from the GVC perspective. We follow the approach outlined by Johnson and Noguera (2012), which in turn revived an older literature on a standard input-output accounting with multiple regions introduced by Leontief (1936, 1941). According to Leontief's seminal insight, to produce output one needs intermediate inputs and production factors such as labor and capital. The production of these intermediates involve again production factors and intermediates. Leontief provided a mathematical model which allow us to account for all rounds of intermediate inputs, and then measure the factor inputs needed in all the stages of production a final good. Furthermore, the model can be extended to measure the value added and labor needed in production for satisfying final expenditures. The domestic value added needed in production for satisfying foreign final demand, is called as value added exports (Johnson and Noguera, 2012).

We start by assuming that there are N countries and S sectors in each countries. Each sector in a country produces one good, using domestic production factors and intermediates, which may be sourced domestically or imported from foreign suppliers. On the supply chain, the output may be used as intermediate inputs or be used to satisfy final demand, at home or abroad. Let the value of goods shipped from sector s in country i to country j for final use be $f_{ij}(s)$ and the value of goods shipped from this sector for intermediate use by sector t in country j be $m_{ij}(s,t)$. Then, we can write the product market clearing condition as

$$y_i(s) = \sum_j f_{ij}(s) + \sum_j \sum_t m_{ij}(s,t) \quad (1)$$

where $y_i(s)$ is the value of output in sector s of country i. Note that goods can be used abroad (in case $i \neq j$) and domestically ($i = j$).

Using matrix algebra, we let $\boldsymbol{y}$ be the vector of output, the elements of which indicate the output levels in each country-sector. Define $\boldsymbol{f}$ as the vector of final demand, and its element f_{ij} represents final demand of one specific sector in country j for the products of country i. Final demand consists of household and government consumption and investment. We further define a global intermediate input coefficients matrix $\boldsymbol{A}$ of dimension ($NS \times NS$), the elements of which are defined as the value of intermediate inputs as a share of gross output by the using sector. Its elements can be written as $a_{ij}(s,t) = m_{ij}(s,t) / y_j(t)$.The matrix $\boldsymbol{A}$ describes the input requirements of both domestic and foreign intermediate goods across countries and industries. Using these new we can rewrite the expression from (1) in compact form as $\boldsymbol{y} = \boldsymbol{A}\boldsymbol{y} + \boldsymbol{f}$. Rearranging, we arrive at the fundamental input-output identity:

$$\boldsymbol{y} = (\boldsymbol{I} - \boldsymbol{A})^{-1} \boldsymbol{f} \tag{2}$$

where $\boldsymbol{I}$ is an ($NS \times NS$) identity matrix with ones on the diagonal and zeros elsewhere. $(\boldsymbol{I} - \boldsymbol{A})^{-1}$ is famously known as the Leontief inverse. Its elements represent the gross output values that are generated directly and indirectly in all stages of the production for satisfying one unit of final demand.

Our aim is to measure value added exports, which are the domestic value added generated directly and indirectly by final expenditures abroad. In the standard way, value added is defined as the gross output value minus the cost of intermediate inputs. We define $\boldsymbol{V}$ as the direct value added coefficients vector with dimension $NS \times 1$, the elements of which represent the value added per unit of gross output produced in country-sectors. Importantly, the elements in this vector are sector- and country- specific. For example, the direct value added coefficient in the Japanese transport equipment industry may be different from that in the Japanese chemicals and also different from that in the German transport equipment industry. To take indirect generation into account, we derive the total value added generated by final demand vector $\boldsymbol{f}$ by post-multiplying the direct coefficients vector $\boldsymbol{V}$ with the gross outputs needed for production of this final demand as $\boldsymbol{V}(\boldsymbol{I} - \boldsymbol{A})^{-1} \boldsymbol{f}$. A hat symbol indicates a diagonal matrix with the elements of the vector on the diagonal. To separate the value added generated by foreign expenditures, we decompose the final demand vector into foreign final demand and domestic final demand. Then, the value added by all factors that are involved all stages of production of foreign final expenditures can be derived as follows:

$$VAX = \boldsymbol{V}(\boldsymbol{I} - \boldsymbol{A})^{-1} \boldsymbol{f}^{FOR} \tag{3}$$

where VAX represents value added exports and $\boldsymbol{f}^{FOR}$ indicates foreign final demand. With this equation in hand, we can further calculate the unit value added in exports which is named as "VAX ratio" by Johnson and Noguera (2012). The sector-level bilateral value added to export ratio is calculated by $VAX_{ij}(s)/x_{ij}(s)$, where $x_{ij}(s)$ is the shipment of both intermediate and final goods from country i to country j.

The measurement of the value added embodied in foreign final expenditures outlined above can be generalized to analyze the quantities of labor used in the production of a particular sector. In our following empirical application, we will study the changes in the hours of high-skilled labor involved in the production for foreign final demand. To do so, we define $h_i(s)$ as the hours worked by high-skilled workers in sector s of country i. We further create the column vector $\boldsymbol{L}$ with dimension $NS \times 1$, and its element $l_i(s)$ is defined as the hours of high-skilled labor required in per unit of gross output: $l_i(s) = h_i(s)/y_i(s)$. Similarly, we can derived the direct and indirect high-skilled working hours needed for the production of foreign final demanded goods as follows:

$$HSE = \boldsymbol{L}(\boldsymbol{I} - \boldsymbol{A})^{-1} \boldsymbol{f}^{FOR} \tag{4}$$

where HSE represents the high-skilled working hours involved in final exports and we use it to indicate high-skill intensity of exports in our empirical application.

To implement the accounting method outlined above and calculate the indicators in table 1, we need a database which provides global input-output tables over time. The World Input-Output Database (WIOD, Dietzenbacher et al., 2013) contains time-series of global input-output tables and supplementary labor accounts for 40 countries and the rest of the world (Row). The countries and the WIOD 35-industry classification are given in Appendix 1. Using the database and equation (4), we can measure value added exports and further VAX ratio and market shares of VAX for the listed 40 countries and Row, at both country- and sector-level. The labor accounts provide the hours worked by high-, medium- and low-skilled workers so that we can calculate the high-skill intensity of employment and exports. WIOD socio economic accounts also provide basic data for us to calculate the last three indicators in table 1. Labor productivity is calculated as the value added to labor ratio, and capital intensity is calculated as the capital stock to labor ratio. The labor data in a specific sector has been collected for the number of workers involved in this sector, including self-employed and family workers. The published database contains data from 1995 to 2011. However, it does not provide working hour data by labor skill types for 2010 and 2011. In our following factor analysis, thus, we calculate and use the growth rate of these indicators from 1996 to 2009.

3. Latent variables and factor analysis

In this section, we use a latent variables approach to examine the dimensionality of industrial upgrading and evaluate to what extent the upgrading indicators describe the same unobservable concept. The different indicators of upgrading are correlated, as they should, because they are intended to measure the same concept. The pair-wise correlation matrix of the indicators is shown in Table 2. As can be seen from Table 2, however, the correlations between these indicators are not perfect. Therefore, we consider the different indicators as imperfect measures of upgrading, and each of them may capture some aspects of upgrading.

Table 2. Correlation matrix of the upgrading indicators (national level)

	labpr	capcom	capint	vax	vaxs	vaxr	hsemp	hse
labpr	1							
capcom	0.42	1						
capint	0.54	0.16	1					
vax	0.33	0.23	0.14	1				
vaxs	0.34	0.29	0.15	0.75	1			
vaxr	0.06	0.08	-0.07	0.11	0.23	1		
hsemp	0.16	0.11	0.12	0.14	0.17	-0.07	1	
hse	0.15	0.06	-0.09	0.21	0.18	-0.31	0.55	1
labpr	1							
capcom	0.34	1						
capint	0.45	0.12	1					
vax	0.25	0.36	0.05	1				
vaxs	0.23	0.35	0.04	0.72	1			
vaxr	0.09	0.14	-0.01	0.15	0.19	1		
hsemp	0.12	0.01	0.14	0.12	0.02	-0.01	1	
hse	0.19	0.05	-0.18	0.44	0.42	-0.06	0.59	1

Notes: The upper panel shows pairwise correlation coefficients for the national sample and the lower panel shows for the multi-sector and multi-region sample. Both samples are based on the data over the period of 1996-2009, excluding some null values. The acronyms refer to: (labpro) labor productivity growth, (capcom) capital compensation growth, (capint) capital intensity growth, (vax) growth of value added exports, (vaxs) growth in market share of value added exports, (vaxr) growth of unit value added in exports, (hsemp) increased skill intensity of employment, (hse) increased skill intensity of exports.

In order to separate the information that is common to all indicators from the information that is unique to a single indicator, we choose to use Exploratory Factor Analysis. By assuming that the observed indicators are "generated" by a linear combination of unobserved factors and some error terms, EFA is based on a simple model structure which is imposed on the covariance matrix of the indicators. The linear model can be expressed as follows:

$$Z = LF + \varepsilon \ , \tag{5}$$

where Z represents the observed variables and its element z_i is *indicator* i. The element of F is the unobservable concept(the *factor*) that the indicators are supposed to measure. The values of F are called the *factor scores*. When the model is correctly estimated, it is possible to obtain value for the underlying factors which are the separate dimensions of upgrading. The element l_{ij} of matrix L is the parameter(*factor loading*) that captures both the scale of indicator i and the strength of its relation to the factor j. ε_i is random measurement error and called the unique variance, with mean zero and variance ψ_i. Further, the rows of ε are independently identically distributed, and are assumed uncorrelated with the factors F. It is clear that the mean and variance of F can be chosen arbitrarily by changing the corresponding factor loadings or measurement error, without changing the observed variables. Hence, it is customary to assume the elements of F have mean zero and variance one(Bollen, 1989; Wansbeek and Meijer, 2000).

To extract the factors and estimate the factor loadings and scores, we choose to use principal components factoring. This method take equation (5) as starting point and try to find matrix L and F so that the resulting errors ε are as small as possible. This calls for a criterion that can be optimized with respect to L and F. A convenient criterion is the sum of squared errors. Solving the Lagrange function, which is defined on the basis of the sum of squared errors , we can find that the errors are minimized when L is the eigenvector of $Z'Z$ corresponding to its largest eigenvalue. The solution of the eigenvector is closely related to the singular value decomposition (SVD) of the matrix Z. Any matrix Z with rank r can be written as

$$Z = U\Lambda V^{'} \quad (6)$$

where $UU^{'} = V^{'}V = I_r$ and Λ is a positive definite diagonal matrix with the diagonal elements in descending order, $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_r > 0$. With simple transformation, equation (6) can be rewritten as $Z^{'}Z = V\Lambda^2V^{'}$. Then U, Λ and V can be seen as an eigenvalue problem. The columns of V are the eigenvectors of $Z^{'}Z$, and the diagonal matrix Λ^2 contains the eigenvalues of $Z^{'}Z$. Subsequently, the columns of U can be computed as $U = ZV\Lambda^{-1}$, which follows directly from equation (6) by post-multiplication of both sides by $V\Lambda^{-1}$.

Using discrete expression, we can write the SVD as $Z = \sum \lambda_i u_i v_i^{'}$ and the best approximation of rank one is given by $\tilde{Z} = \lambda_1 u_1 v_1^{'}$. Let F_1 be the first principal component of Z and recall that the sample variance of the elements of F_1 is assumed to be one, i.e., $F_1^{'}F_1 / N = 1$, and L_1 is the eigenvector of $Z^{'}Z$ corresponding to its largest eigenvalue. Then the solution is to take $F_1 = \sqrt{N}\mu_1$ and $L_1 = (\lambda_1 / \sqrt{N})v_1$. Because $\mu_1 = Zv_1 / \lambda_1$, F_1 is a liner combination of the columns of Z. Analogously, the discussion of principal components factoring can be extended directly to more dimensions as well. An more detailed introduction of principal component factoring can be found in Wansbeek and Meijer(2000).

To extract the appropriate number of factors to be included in the analysis, we use various statistical tests. First, we consider the Kaiser criterion, which states that factors with eigenvalues greater than one should be included in the model. In principal components factoring, each component explains a variance equal to the corresponding eigenvalue of the correlation matrix, and hence relevant components correspond to eigenvalues larger than 1. According to this rule, three eigenvalues exceed one in our analysis, and hence three factors are appropriate. The other eigenvalue-based rule is Catell's scree plot (Catell, 1966). The scree plot also shows three factors have a larger eigenvalue relative to the other factors and explain a relatively larger part of the variance contained in all indicators.

Next, we apply a Likelihood Ratio (LR) text. It tests whether the three-factor model fits significantly worse than a saturated model. The test rejects the null-hypothesis, which suggest that the estimates are in favor of the three-factor model. Finally, we also consider the value of Akaike's information criterion and the Schwarz criterion, which both lead us to make the conclusion that three factors is most appropriate.

The estimated results of the rotated factor loadings are shown in table 3. The method of rotation is Direct Oblimin. The idea behind Oblimin is that it minimizes the correlation between columns of the factor loadings matrix. Hence, every indicator tends to have a high loading on one factor, while it has low loadings on the other factors. The indicators with high loadings can be used to interpret the factors. In table 3, it is clear that the same indicators have high loadings on the specific factor in both the national and the sectoral sample.

Table 3. Rotated factor loadings matrix and unique variance estimates

Indicators	chain	productivity	skill	Unique variance	chain	productivity	skill	Unique variance
labpr	0.12	0.85	-0.03	0.21	0.26	0.81	0.01	0.24
capcom	0.19	0.52	0.09	0.62	0.25	0.59	-0.14	0.55
capint	-0.11	0.84	-0.13	0.34	-0.19	0.87	0.10	0.26
vax	0.88	0.02	0.11	0.18	0.89	-0.01	0.07	0.17
vaxs	0.92	0.03	0.01	0.13	0.90	-0.02	0.05	0.16
vaxr	0.32	-0.11	-0.31	0.60	0.39	0.05	-0.20	0.72
hsemp	0.01	0.12	0.75	0.40	-0.09	0.21	0.91	0.13
hse	0.18	-0.20	0.86	0.18	0.23	-0.26	0.74	0.11

Notes: Factor loadings are estimated using principal components factoring. The method of rotation is oblique promax. The left panel shows the estimates for the national sample and the right panel shows the estimates for the multi-sector and multi-region sample. For illustrative purpose, the factor loadings with absolute terms larger than 0.3 are in grey.

In both samples, the first factor has high loadings for growth of value added exports, growth in market share of value added exports and growth of unit value added in exports. These three indicators are all related to the trade benefit in the global value chains. Therefore, we label this factor as “chain upgrading”. Indicators that are associated with “labor productivity” and “capital productivity” clearly have high loadings on the second factor and, therefore, we accordingly label the second factor as “productivity upgrading”. Finally, the third factor has high loadings for indicators that relate to the increase of skill intensity. This factor, in turn, is labelled as “skill upgrading”.

Apart from the factor loadings, table 3 also reports the estimated measurement errors of the individual indicators. The variance of an indicator contains two parts, the common variance and the unique variance. The former is accounted by the factor and the latter refers to the variance contained in the individual indicators which cannot be attributed to any of the factors. In other words, the indicators with high unique variance contain relatively much variance that cannot be attributed to one of the upgrading dimensions. Whereas, the growth in the share of value added exports seems to be a good proxy for chain upgrading, and growth in labor productivity captures productivity upgrading.

After the model is appropriately estimated and interpreted, it is possible to obtain values for the underlying factors, i.e., the factor scores for the three dimensions of upgrading. The factor scores we obtained reflect different dimensions of upgrading. Table 4 shows the correlation matrices of the predicted factor scores. It can be seen that the factors moderately correlate, which implies that they indeed reflect different dimensions of upgrading.

Table 4. Correlation matrices of the identified dimensions of upgrading

	chain	productivity	skill	chain	productivity	skill
chain	1.00			1.00		
productivity	0.21	1.00		0.36	1.00	
skill	0.13	0.08	1.00	0.22	0.12	1.00

Notes: The left panel shows the correlation coefficients between the three factors of upgrading for the national sample. The right panel shows the correlation coefficients for the multi-sector and multi-region sample.

4. Empirical results

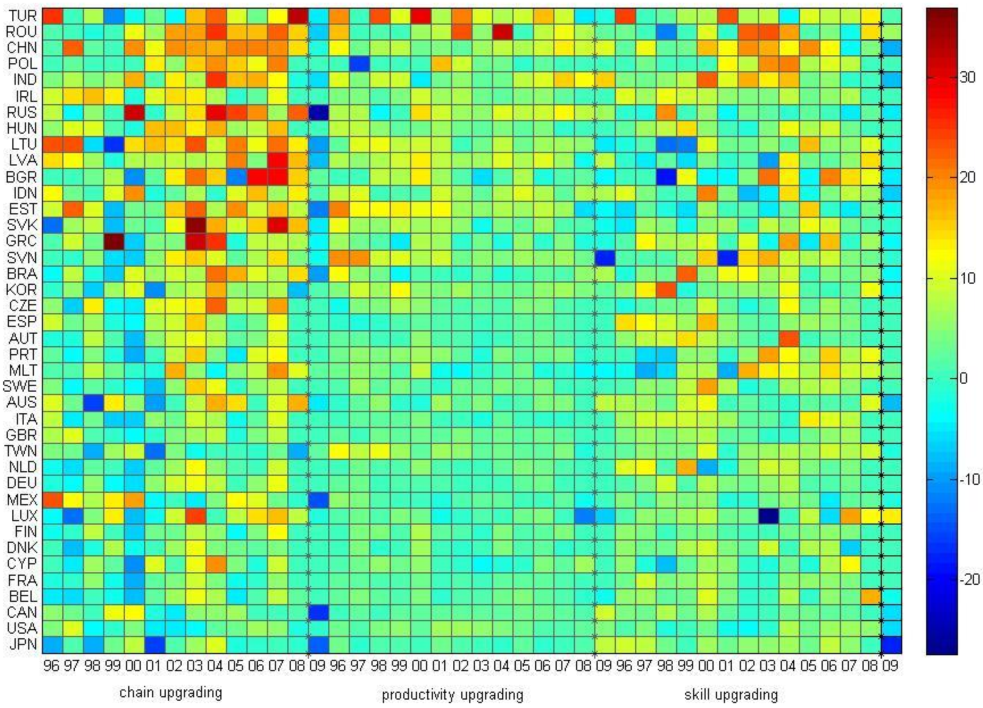
Since individual countries and sectors could be quite heterogeneous with respect to their production structures, the upgrading scores of the dimensions are country- and sector- specific. For example, the upgrading level of Chinese transport equipment industry may be different from that of Chinese chemicals and also different from that of German transport equipment industry. Whereas, we firstly present the country-specific results which are based on the national sample. Then we zoom in further and consider sector-specific upgrading level in subsection 4.2.

4.1. Country-specific results

Figure 1 presents the colormap of the country-specific upgrading scores over the period of 1996-2009, where countries are ordered according to their average level of chain, productivity and skill upgrading scores. On the basis of this figure, the following observations can be made. Firstly, the figure shows that the dimensions of industrial upgrading vary both within and across countries. Secondly, there are more red grids in the area of chain upgrading than productivity and skill upgrading, which implies that most countries performed better in chain upgrading than productivity and skill upgrading. Thirdly, the upgrading scores largely decreased in 2009 since the color grids tend to be deeper dark blue. The global financial crisis turns out to have a dramatic effect on the upgrading scores.

If we say a country has experienced upgrading (downgrading) when the factor score for this country is greater (less) than 0, we can find most of the countries in the sample have experienced more or less upgrading over the period. The number of countries which have experienced upgrading or downgrading is given in Appendix 2. In most years, the number of upgrading countries is significantly larger than that of downgrading countries. It is the opposite case for the year 2008 and 2009 when the global financial crisis broke up. Since 2002, most countries have been performing better and better on the chain upgrading. This global upgrading suggests the growing demand in the global market until 2008. China was a typical beneficiary of the prosperous global economy. Its chain upgrading scores kept above 40% from 2002 to 2007. This growth was due to China's entrance to World Trade Organization (WTO) and its greater participation in global value chains.

Figure 1: The colormap of the country-specific upgrading scores



According to the overall average scores of the dimensions over the entire period, developing countries such as Turkey, China and India have experienced more upgrading than developed countries such as USA and Japan. Figure 1 shows that Turkey, Romania, China, Poland and India are ranked the top 5 of most upgraded countries. However, the rankings in

Appendix 3 reflect that countries ending up in the top 5 of most upgraded countries on one dimension do not necessarily end up in the top 5 of any other dimension. For example, countries that have the highest factor scores on the “chain upgrading” dimension are China, Romania, Poland, Lithuania and Russia, while countries that have the highest factor scores on the “productivity upgrading” dimension are Turkey, Romania, Estonia, Russia and China. Again, this reinforces the view that these three dimensions moderately correlate, but they indeed reflect different dimensions of industrial upgrading.

Recalling the interpretation of chain upgrading, countries like China, Romania, Poland, Lithuania and Russia with the highest scores should have relatively larger growth rate of value added exports, market share of value added exports and value added to export ratio. On the contrary, countries like Japan, Belgium, France and USA with the lowest scores have relatively lower value of these indicators. For instance, we observe that the market share of value added in exports of China increased from 3.18% in 1995 to 9.53% in 2008 (pre-crisis year), while that of USA and Japan decreased from 15.49% and 10.21% to 10.90% and 5.53%, separately. Similarly, countries with higher growth rate of labor productivity, capital compensation and intensity perform better in productivity upgrading. And countries with larger growth rate of skill intensity of employment and exports have higher scores in skill upgrading.

4.2. Sector-specific results

Since individual sectors in different countries could be quite heterogeneous with respect to their production structures, we now zoom in further and consider sector-specific upgrading level in this section. Figure 2 presents the colormap of the arithmetic mean of the factor scores for each sector over the period. The sector-specific average scores in a given year are derived as the arithmetic mean of the scores for the 40 countries in that year. Industries are ordered according to the ranking of their average level of upgrading scores over the whole period. We find that in the global value chains the most upgraded sector is Post and telecommunications (WIOD code: c27) which has an average score of 6.50%. Renting (c30) and Electrical and optical equipment (c14) consistently show, respectively, the second and third highest upgrading scores. On the contrary, Textiles and textile products (c4) and Leather, leather and footwear (c5) have the lowest level of upgrading.

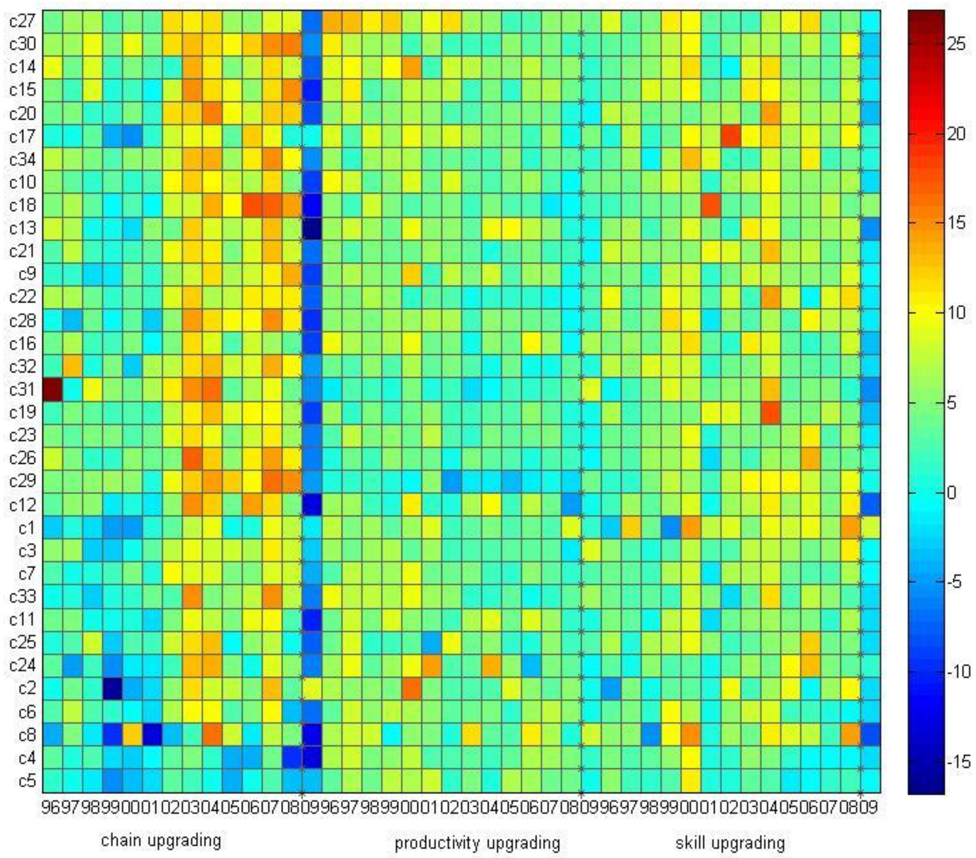
To be more specific, we have the following findings.

1. Similar to the country-specific results, the rankings based on the “chain upgrading” dimension differ from that based on “productivity upgrading” and “skill upgrading”. However, all the three dimensions reveal that service sectors generally perform better than other sectors.

2. In the industrial sectors, technology-intensive industries like Electrical and optical equipment (c14) and Transport equipment (c15) have the higher level of upgrading. They rank in the front end no matter the ranking is based on the "chain upgrading" dimension or any other dimensions. Resource- and labor-intensive industries have the lower level of upgrading. These industries are (in descending order of their rankings) : Mining and quarrying (c2); Wood and products of wood and cork (c6); Coke, refined petroleum and nuclear fuel (c8); Textiles and textile products (c4) and Leather, leather and footwear (c5).

3. Due to the global financial crisis, the extent of international trade in intermediates and final goods largely decreased in 2009. The crisis turns out to have a dramatic effect on industrial upgrading, as the upgrading scores, especially the chain upgrading scores, largely decreased in 2009.

Figure 2: The colormap of the sector-specific upgrading scores



As illustrated above, electrical and optical equipment (c14) is the most upgraded industrial sector. Therefore, in the following comparative analysis, we select this typical globalized sector to compare whether it has experienced more or less upgrading compared to the same industry in other countries.

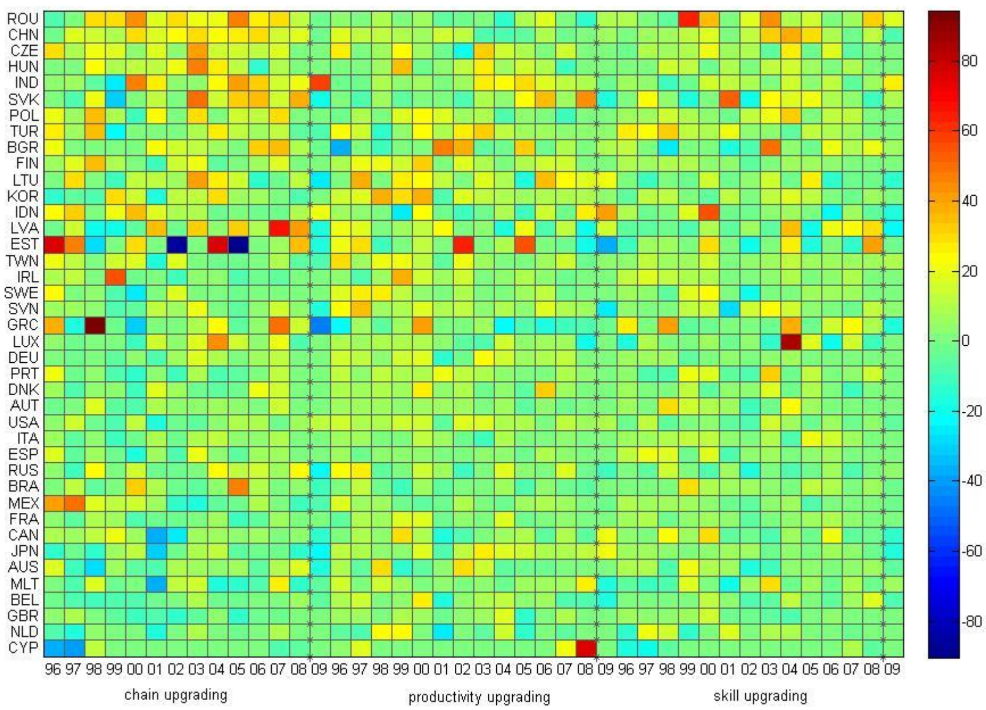
If we rank the 40 countries according to the arithmetic mean of the three dimensional upgrading scores, visualized in figure 3, over the 14 considered years, the findings are as follows.

1. The upgrading scores of electrical and optical equipment (c14) have a much wider range than country- and sector-specific results because of a few outstanding scores. The scores of a particular sector for a specific country may fluctuate more strongly. For example, Estonia's chain upgrading score in 2004 was 74.43% and it sharply declined to -90.30% in 2005.

2. The average scores for all the 40 countries are positive, which implies that all the listed countries have experienced upgrading over the period. However, their upgrading levels are different. According to average scores, Romania and China are ranked as the top two upgraded countries in electrical and optical equipment (c14).

3. If we rank the countries according to the average level of chain, productivity and skill dimension, separately, we can find China and Romania do not perform well in productivity upgrading. On the contrary, countries like South Korea, Finland, Japan, USA and Turkey perform the best.

Figure 3: The colormap of upgrading scores for electrical and optical equipment



Even though our results present that developing countries have generally upgraded more than developed countries in technology-intensive industries like electrical and optical equipment and transport equipment, we stress that higher upgrading level means growing faster. It never implies that developing countries have already had absolutely stronger competitiveness than developed countries in GVCs. For example, China performed significantly better than USA, Japan and European countries in upgrading, but its absolute values of labor productivity, high-skilled workers intensity and VAX ratio were much lower than that of these countries. This is in line with findings of, e.g., Timmer et al. (2015), who state that the EU captured the largest part of GVC income and it has consolidated its position in global markets of transport equipment. The steadily fast upgrading of developing countries like China and India was largely due to the greater participation of these countries in the GVCs. However, they participate in the GVCs through production and delivery of relatively standardized parts and components. They have no core technology or competitiveness in the global chains of the technology-intensive industries.

5. Conclusion

In this paper, we aim to measure the industrial upgrading level of different countries and industries in global value chains. This is not a trivial issue because upgrading has not been defined unambiguously, and there is no standard analytical framework for measuring upgrading empirically. Several researchers have measured upgrading mainly through two notions, namely productivity growth and international competitiveness. This paper points out that traditional indicators of international competitiveness such as changes in trade volume and shares in world exports markets are increasingly misleading in a world with increasing fragmentation of production along the global value chains. Therefore, the indicators used in this paper are adjusted to adopt the GVC perspective. Using eight adjusted indicators for upgrading in an Exploratory Factor Analysis, we examine the multidimensionality of industrial upgrading rather than trying to find the single, ultimate definition and measurement of upgrading.

Using the 1996-2009 time series of the world input-output tables and socio economic accounts available from the WIOD database that covers 35 industries for 40 countries and the rest of the world, we find that industrial upgrading has three dimensions: productivity upgrading, chain upgrading, and skill intensity upgrading. With these dimensions, we compare and analyze the upgrading levels at both national and industrial level. Some of our results are as follows.

Chain, productivity and skill upgrading moderately correlate, but they indeed reflect different dimensions of industrial upgrading. Importantly, the upgrading scores of the dimensions are sector- and country- specific. That is to say, for example, the upgrading level of Chinese transport equipment industry may be different from that of Chinese chemicals and also different from that of German transport equipment industry.

In terms of countries, most of countries have experienced more or less upgrading over the period 1995-2008. Almost all the countries experienced downgrading in 2009 because of the global financial crisis. To be more specific, developing countries such as Turkey, China and India have experienced more upgrading than developed countries such as USA and Japan.

In terms of sectors, service sectors and technology-intensive industries such as electrical and optical equipment and transport equipment have experienced higher level of upgrading than resource- and labor- intensive industries. The upgrading levels of technology-intensive industries in developing countries are generally higher than that in developed countries. However, we stress that higher upgrading level means growing faster. It never implies that developing countries have already had absolutely stronger position than developed countries in GVCs.

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Appendix 1: WIOD country acronyms and industry classification

Acronym	country	Code	Industry description
AUS	Australia	c1	Agriculture, hunting, forestry and fishing
AUT	Austria	c2	Mining and quarrying
BEL	Belgium	c3	Food, beverages and tobacco
BRA	Brazil	c4	Textiles and textile products
BGR	Bulgaria	c5	Leather, leather and footwear
CAN	Canada	c6	Wood and products of wood and cork
CHN	China	c7	Pulp, paper, printing and publishing
CYP	Cyprus	c8	Coke, refined petroleum and nuclear fuel
CZE	Czech Republic	c9	Chemicals and chemical products
DNK	Denmark	c10	Rubber and plastics
EST	Estonia	c11	Other non-metallic mineral
FIN	Finland	c12	Basic metals and fabricated metal
FRA	France	c13	Machinery, nec
DEU	Germany	c14	Electrical and optical equipment
GRC	Greece	c15	Transport equipment
HUN	Hungary	c16	Manufacturing, nec; recycling
IND	India	c17	Electricity, gas and water supply
IDN	Indonesia	c18	Construction
IRL	Ireland	c19	Sale, maintenance and repair of motor vehicles and motorcycles; Retail sale of fuel
ITA	Italy	c20	Wholesale trade and commission trade, except of motor vehicles and motorcycles
JPN	Japan	c21	Retail trade, except of motor vehicles and motorcycles; Repair of household goods
KOR	Korea	c22	Hotels and restaurants
LVA	Latvia	c23	Inland transport
LTU	Lithuania	c24	Water transport
LUX	Luxembourg	c25	Air transport
MLT	Malta	c26	Other supporting and auxiliary transport activities; Activities of travel agencies
MEX	Mexico	c27	Post and telecommunications
NLD	Netherlands	c28	Financial intermediation
POL	Poland	c29	Real estate activities
PRT	Portugal	c30	Renting of machinery &equipment and other business activities
ROU	Romania	c31	Public admin and defence; Compulsory social security
RUS	Russia	c32	Education
SVK	Slovak Republic	c33	Health and social work
SVN	Slovenia	c34	Other community, social and personal services
ESP	Spain	c35	Private households with employed persons
SWE	Sweden		
TWN	Taiwan		
TUR	Turkey		
GBR	United Kingdom		
USA	United States		

Appendix 2: The number of upgrading and downgrading countries

	chain		productivity		skill	
	upgrading	downgrading	upgrading	downgrading	upgrading	downgrading
1996	28	12	37	3	31	9
1997	25	15	37	3	35	5
1998	31	9	37	3	32	8
1999	21	19	36	4	34	6
2000	18	22	37	3	38	2
2001	27	13	33	7	29	11
2002	37	3	33	7	30	10
2003	37	3	30	10	30	10
2004	37	3	36	4	35	5
2005	29	11	36	4	35	5
2006	36	4	35	5	37	3
2007	40	0	36	4	33	7
2008	20	6	16	10	25	1
2009	6	18	13	11	4	20

Appendix 3: Ranking most upgraded and downgraded countries

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

Appendix 4: Ranking most upgraded and downgraded countries for electrical and optical equipment

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