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Assessing interactions of technologies and markets for technology road mapping

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ABSTRACT

We present a new approach to technology road mapping (TR) which allows one to assess interactions of technologies and markets. Unlike the traditional methodology of TR that mostly relies on qualitative techniques, the proposed approach combines qualitative and quantitative methods. This bottom-up economic model allows the aggregation of estimates on different levels from the product group to industry used to quantify the market development. The KLEMS (capital, labor, energy, materials and services) production factors and multifactor productivity embedded in the model play the role of parameters measuring interactions between market outputs and technology innovation according to market-pull and technology-push effects. The qualitative methods include: STEEPV trend identification, 2 × 2 scenario analysis, and expert procedures. This allows for decreasing the number of parameters, inputs and calculations in the economic model. At the same time, balance between qualitative and quantitative techniques provide more realistic estimates for technological and market parameters. The assessment of interactions between technologies and markets is illustrated using the case of civil aircraft manufacturing in Russia. Technology impact is measured in terms of output growth of the industry.

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1. Introduction

This study provides an approach to TR on the basis of market forecasting allowing for the aggregation of market outlooks of product groups at the industry level and simultaneously taking into account the consideration technology development. To achieve this goal a bottom-up economic model (as in (Meade, 2012)) is utilized to estimate product group parameters and the impact of technology Top-down models (Dedrick et al., 2007) are not suitable for this purpose as it is much less clear how technology influences parameters at the higher level of aggregation.

Technology Road-mapping (TR) has been in wide used by strategic planners for several decades (Vishnevskiy et al., 2015). TR methods have been extensively applied on the: corporate (Phaal et al., 2004), industrial, and national levels (Routley et al., 2013) in many areas of Science Technology Innovation (STI) development. Most of the literature on TR is based on qualitative methods. However, rising uncertainty in new global challenges and changes in the role of technologies require not only an elaboration of a dynamic structure of the technological future, but also a more clear understanding of the parameters of STI. Consequently TR is a complex instrument, that should combine both quantitative and qualitative methods, thereby assisting management in strategic planning by providing different scenarios of technological development.

TR takes a multi-layer approach (Routley et al., 2013) providing perspectives on the interactions between evolving technologies, products, and markets. Technology and market interactions can be very complicated, especially when considered at a macro or industry level. Technology impacts on the market outlook at different levels of aggregation. This should be integrated into TR. The future market outlook can be obtained using a combination of quantitative and qualitative methods. Quantitative methods require many input and parameter estimation for economic modeling making them very vulnerable to model specification errors (Haegeman et al., 2013). However, qualitative estimates based on expert opinions are often controversial and cannot provide an explicit picture of the future parameters. Therefore it is reasonable to implement expert estimates in an economic model to justify values for parameters and avoiding the need for additional modeling.

Technology affects industries, market segments and product groups differently over time. The development of a market outlook procedure in a TR framework is usually tied closely with technologies through specific products and related parameters (Cagnin & Konnola, 2014), this makes it difficult to consider the whole picture as aggregate technology affects long-term industry forecasts. It is often impossible to discover interactions between market forecasts for different innovative products and technologies if forecasts were developed according to different models.

One of the crucial issues for TR is scenario planning. Scenario analysis is applied to market forecasting to develop scenarios for interacting

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technologies. Short-term scenarios are usually more predictable and can be constructed according to the influence of different trends on structural parameters and growth forecasts of product group markets. STEEPV (Society, Technology, Economy, Ecology, Political, and Value) analysis for trend identification is also applied here (Pillkahn, 2008). Expert procedures to estimate the impact of technology in the short-run are also applied. Estimation of long-term effects is more complicated. Consequently, future parameters for each market are forecast using a 2 × 2 framework (Ramirez & Wilkinson, 2014).

Technological impact can be estimated using several approaches to TR; including: market-pull and technology-push (Brem & Voigt, 2009). Both perspectives have advantages and disadvantages. They are also interconnected (Brem & Voigt, 2009). Hence, it is reasonable to combine push and pull (Nemet, 2009). As market growth can be explained by technology development and demand-pull factors including demand for new properties of technology generated products linking the two is logical.

For applying both methods to model output, the multi-factor productivity (MFP) approach (Meade, 2012) is used; as past studies (Cagnin & Konnola, 2014) suggest this as a suitable proxy for value added. Furthermore, intermediate consumption is an important part of demand, absent if value added is the focus. The dynamics of MFP and production factors on the domestic market for each product group and accounting for technology impact is considered.

A bottom-up model based on MFP allows for the estimation of the role of technologies in developing markets. One can better estimate the impact of each technology on the affected markets. With knowledge of the market shares for each product group, an estimate of the influence for a technology on the entire economy can be considered. This offers decision support for prioritization of government sponsored research.

The paper is structured as follows: the literature review describes the different methods used in TR and market forecasts that support methodological choice. Next, the TR approach is introduced and the important parameters are described. The economic model and scenarios for market forecasting are provided. Tools for the assessment of interactions between technologies and markets are considered. The application of this approach to the civil aircraft manufacturing sector in Russia is demonstrated. Finally, conclusions are offered.

2. Literature review

Quantitative and qualitative methods used in technology road mapping (TR) are now reviewed.

2.1. Qualitative methods — scenario planning

First qualitative approaches used to develop the TR methodology are considered. A very important feature of every Future-oriented Technology Analysis (FTA) — including forecasting, foresight and TR — is scenario planning (Cagnin & Konnola, 2014; Konno et al., 2014). Scenarios help managers in building corporate strategy and authorities in strategic economic planning. Furthermore, scenarios are useful for describing visions of the future (Amer et al., 2013). This paper embeds scenario planning in a quantitative market forecasting model (Malanowski & Zweck, 2007; Chang, 2015). The combination of qualitative scenario planning and quantitative market research is useful for every FTA (Haegeman et al., 2013). By overcoming the drawbacks of the separate approaches, one not only simplifies the quantitative modeling, but also provides an understanding of the uncertainty in expert estimates.

Scenarios allow the investigation of different effects of major trends that impact market and technology development. A traditional STEEPV analysis assists with trend identification (Pillkahn, 2008). However, trends may be unstable or lead to unpredictable undetectable trends in the distant future. Consequently, trends are used mainly in short-term forecasting and scenario planning. Hence, long term forecasts cannot use current trends as their foundation.

Utilizing 2 × 2 scenarios for long term forecasting is a possible solution (Ramirez & Wilkinson, 2014). Two parameters are selected to best describe the future of the market. Next, as estimation of the most possible, but opposite outcomes for these parameters, is made. This allows for the generation of four scenarios based on the different combinations of target outcomes. For example, the two factors could be impact and uncertainty (Konno et al., 2014). Increasing use of 2 × 2 scenario planning is linked to its applicability to other methods. 2 × 2 can be combined with qualitative techniques (Varho & Tapio, 2013) in foresight research. It is also useful for economic modeling (Wang & Lan, 2007) — the application considered here.

Unlike the common approach in the literature, scenarios are divided here into two periods for the purpose of making a short-term forecast and a long-term forecast. This is desired because there are substantial differences in market forecasts for different periods (Bos & Teulings, 2013). Applying trend analysis for the construction of short-term scenarios gives us the opportunity to implement qualitative estimates in economic modeling. The long-term is considered using a 2 × 2 scenario approach allowing for the consideration of possible but unpredictable outcomes of the market's future.

2.2. Quantitative methods — bottom up economic model

Economic modeling is used to construct a market outlook for TR. Despite similar effectiveness of both bottom-up and top-down approaches in aggregate output forecasting (Widiarta et al., 2009), bottom-up economic modeling is preferable for assessing technology impacts on market development (Mercure, 2012). Most of these models, Lotka-Voltera (Mercure, 2012), Bass (Bass, 1969), and Fisher-Pry (Fisher & Pry, 1971) models, concentrate on technology substitution. Such models estimate the rate of the substitution of one technology and corresponding products with another; a crucial contribution to corporate strategy. As this study considers the effect on an entire economy, the goal differs as the output itself may not change while the components and technologies used to make the output change. Hence, technology substitution and the life cycle of the product (Routley et al., 2013) can be overlooked. Focus is placed on technology-push effect on output growth of products, aggregated at the industry and macro levels. Similarly technology may be involved in a market-pull effect, changing the growth of output of the product group.

Many different macroeconomic models exist: Econometric Energy-Environment-Economy Model (E3ME) (Mercure, 2012), Computable General Equilibrium Model (CGE) (Dixon & Jorgenson, 2013), Long-term Inter-industry Forecasting Tool (LIFT) (Meade, 2012) model and others. Applying any of these models to TR is complicated due to the large number of inputs and parameters involved. However, some of the very attractive properties of the models can still be applied. The general economic equilibriums — from CGE — is used for the development of the proposed model/methodology. The LIFT model is a bottom-up model that applies MFP (Meade, 2012). MFP can be an aggregated parameter of technology impact. MFP allows for the consideration of the technology effect on KLEMS production factors (capital, labor, energy, materials and services) (Meade, 2012) and addresses the demand for innovative product properties assuming demand/output equilibrium. Hence, technology-push and market-pull effects can be accounted through MFP growth (the Sallow residual) (Solow, 1957). Under the 2 × 2 scenario framework, changes in production factors and demand growth are used to generate scenario parameters of future markets.

3. Parameters and methodology of forecasting

The common techniques all have certain limitations. Consequently, it is worthwhile proposing a new general methodology for TR that assesses interactions between markets and technologies. The stages of the proposed methodology for forecasting and the associated parameters for the model will now be presented.

An industry is considered in this paper as an economic sector: both service and industrial. While aircraft manufacturing is used as an illustration (and its NAICS code is provided), no specific classification of economic sector should be assumed. However, classification will be necessary for obtaining information on input–output (IO) parameters that are used in the model. Industries consist of segments combining product groups — either goods or services.

To quantitatively estimate future markets with respect to technology impact, we first consider which industries can the technology currently be applied. Next, the structural parameters are estimated and related to macro parameters — taken from external sources. Structural parameters for each industry include: demand parameters, KLEMS factors and MFP. Current trends are based on retrospective growth rates for the last several years and their relation to domestic macro parameters and those of corresponding global industries.

Forecasting the emergence of a new industry under the influence of a critical technology is challenging. In the long-term, most emergent industries develop across traditional industries and sectors. For example, the Information and Technology (IT) sector is an input to many traditional industries. The consumption of IT output is easily assigned to traditional services; such as: telecommunication, culture, and education. Hence IT's influence can be measured as a change in the output and structural parameters of other industries and sectors.

Identifying the impact of a technology on the parameters at the industry level is difficult. Consequently, consideration at a lower level of aggregation is advisable; that is at the level of industry segments. Alternatively, the next level of detail — product groups — is suggested. Product group contain outdated and current products are gradually replaced by innovative products that incorporate more advanced technology. Having considered the substitution effect on the level of analysis, the consideration of output growth and associated supply and demand parameters are focused on.

While new product groups can emerge under the influence of a technology, these can be assigned to an existing industrial segments or product groups. For example, flying drones are assignable to the either electronic equipment or aircraft manufacturing.

Current and retrospective structural economic parameters for each product group are estimated simultaneously using information at the firms and project level. The bottom-up model is used to aggregate all parameters at the industry and possibly macro level. This approach offer insight into technology impacts at the macro and industry level, while keeping track of the effect of technology within each product group. Retrospective industry characteristic data is used to calibrate and balance estimates.

Consideration of macro level parameters is now offered due to its importance for model calibration. GDP is used as the key macro parameter for estimating a country's future market(s) for a technology. Since our focus is the competitiveness of products in domestic and export markets, the relevant share of the economy in terms of Global GDP is also important for future estimates. However, GDP is not the only important macro parameter. Forecasts for important macroeconomic variables such as export and import values, currency exchange rates, and budget spending can only be used as inputs in the model if the data is available.

The MFP approach is used to relate demand parameters to technological development. The technology impact on KLEMS productivity factors for product groups is estimated with expert opinion or available data sources. For each product group parameters are used to describe the process of technological substitution, changes in the business model, cost structure, labor productivity, efficiency and performance.

MFP growth obtained through the growth of the KLEMS productivity factors is used to estimate demand growth. Demand parameters include consumption of households, and government, intermediate consumption, capital investments, exports and imports. No significant gap between demand and supply is assumed. As market equilibrium is assumed, competitiveness of market players is not a concern. Constant prices for all growth parameters are assumed. Consequently, MFP growth is associated to the rise in product value due to technological improvement that increases the products' attractiveness. Other factors affecting demand include: rising or declining popularity of substitutes and macroeconomic growth. The growth associated with demand for substitutes can be estimated from expert opinions and other data. Alternative macro parameters can model demand growth for consumption. Export and import growth can be estimated by comparing MFP growth for domestic and foreign markets. MFP in the global market offers insight into the competitiveness of domestic development and possible uncertainties in export and import growth. The role of MFP growth on foreign market will be higher for export estimates.

In summary, productivity factors and demand retrospective parameters for each product group is obtained from either experts or estimates and then aggregated at the industry level.

Next short-term forecasting is conducted using unsophisticated methods as the impact magnitude of a technology's market has low uncertainty in the short term. Consequently, basic scenario analysis and economic modeling is applied to current trends. For the short-term outlook, we might rely on available macro scenarios. We start forecasting parameters at the product group level. In order to do so we use both quantitative estimates from retrospective dynamics and qualitative trend analysis. We suggest that the technology's impact could slightly affect the parameters of product groups' trends, which are mostly determined by retrospective dynamics and macro scenarios. By applying the STEEPV approach for trend identification, we can use expert opinion relating the discovered trends to scenarios of productivity factors and demand parameters. It is reasonable to implement gradual changes in the business model for the product group when estimating corresponding changes in productivity factors. After that we are going to calculate MFP and demand growth for each product group using economic modeling. All forecasted parameters could be aggregated up to the industry level, according to scenarios.

After conducting short term forecasting up to the industry level, we then start to develop the procedure for the long-term forecast. Uncertainty is an important factor in the long-term perspective. We cannot rely as much on experts' estimates and retrospective dynamics anymore. It is difficult to predict parameters such as demand growth for substitutes and the international competitiveness. We should carefully build long-term scenarios in order to maintain the ability to track interactions between demand parameters for different product groups.

We can again apply the STEEPV analysis to identify key opportunities and barriers for product group development in the long term. We should identify all possible weak signals including wild cards and jokers that affect the markets for the product groups. For example, an important issue for domestic output growth is the unexpected expansion of a protectionist policy. Those possible events can be integrated into the long-term scenarios for MFP and demand growth. Experts' procedures should be involved in scenario planning.

We apply the well-known 2×2 framework in order to identify and describe long-term scenarios. We identify key factors characterizing the market of the product group. We then choose MFP growth and demand growth as the main parameters for the 2×2 approach. We assume that growth rates will stabilize at a certain annual level in the long-term perspective. Considering that high MFP growth unlikely to be related to low demand, we obtain only three distinct outcomes for the key parameters in 2040. Hence the long-term forecast for each product group should be based on 3 scenarios from the 2×2 analysis. Going all the way back in time from the 2040, we estimate scenario parameters until the end of the short-term forecasting period using MFP and demand growth models as well as scenarios for the macro parameters.

For example, we assume that in the long run, demand growth for electric vehicles will be high but the industry will experience a lack of domestic technology investment, which results in lower MFP growth then we might suspect that the budget support of electric vehicle production is very low. If at same time we suggest that electric vehicles

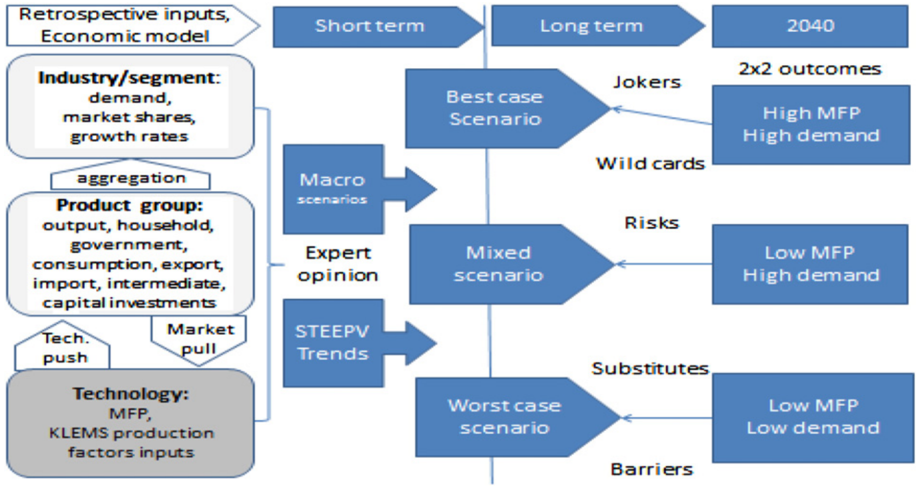

Fig. 1. The procedure of building scenarios and forecasting for TR.

will be very popular among consumers because of their high ecological standards, we might conclude that demand will be met with growing imports. This scenario can be justified if GDP in Russia grows more slowly than in the rest of the world, which fully corresponds to weak budget support of the strategic product group. We should choose a macro scenario with similar parameters that explain described conclusions.

The next step will be implementation of a calibration procedure for the short-term and long-term scenarios to avoid unexpected gaps in forecasting. In order to do this, we go back from the suggested outcomes of the long-term scenarios to the already estimated outputs of short-term outcomes. To maximize the distance between scenarios, we can connect the trajectory of high demand and MFP growth with the trajectory of the best case short-term scenario. Similarly we combine the worst case short-term scenario with low outcomes for demand and MFP growth. Finally we relate the mixed short-term scenario to low MFP but high demand growth.

For example, we assume that demand growth rate in the positive scenario might stabilize at a level higher than the GDP growth rate, which is known from the macro forecast and the higher than historical growth rate for this product group. MFP growth rate could be higher in the short term, but converges with its historically average growth rate at a faster rate. According to the trends associated with the positive scenario, we should choose the parameters that explain the faster demand growth rate for a product group.

Finally knowing demand and MFP growth, we can estimate output growth and other parameters. After modeling all parameters, we obtain a market forecast for a product group according to three different short-term and long-term scenarios. The trajectories that correspond to different scenario outcomes for each parameter of each product group can be drawn. To obtain the complete picture, we aggregate our estimates up to the industry level.

The forecast will provide not only estimates of market outputs at different levels but future production factors and demand parameters allowing one to measure the impact of every considered technology for the purpose of TR. The role of the technology should be considered along the timeline. Experts can make suggestions of how a technology impacts factor productivity parameters in the short term and in the long term according to different scenarios. These estimates will allow for the assessment of the technology-push effect i.e. the impact of a technology on the demand growth of each product group. The market-pull effect can be estimated through MFP growth based on scenarios of outputs for product groups.

The entire procedure is illustrated on Fig. 1.

4. Forecasting model for product group markets

We propose a model that could explain the future market output for every product group. We start with the traditional demand approach. From now on we will use only logarithmic growth rates in our model. For the product group *i* and year *t* we suggest that the following parameters could explain the output's logarithmic growth rate in constant prices $r^Y_{i,t}$:

- Domestic households, government, intermediate and capital consumption growth rate $r^{HGIF}_{i,t}$
- Export growth rate $r^{Exp}_{i,t}$
- Import growth rate $r^{Imp}_{i,t}$

In other words:

$$r^Y_{i,t} = \beta^{HGIF}_{i,t-1} r^{HGIF}_{i,t} + \beta^{Exp}_{i,t-1} r^{Exp}_{i,t} - \beta^{Imp}_{i,t-1} r^{Imp}_{i,t} \tag{1}$$

Coefficients $\beta^{HGIF}_{i,t-1}, \beta^{Exp}_{i,t-1}$ and $\beta^{Imp}_{i,t-1}$ can be estimated using t-1 weights (with respect to output) of each structure variable, namely domestic consumption, exports and imports, i.e. $\beta^{HGIF}_{i,t-1} + \beta^{Exp}_{i,t-1} - \beta^{Imp}_{i,t-1} = 1$. For simplicity we assume that capital investments also include changes in inventories.

An important factor for our model is technological development. We try to estimate the impact of a technology on the output of the product group. That is why we will use KLEMS production factors and MFP. We will mostly rely on MFP approach described in Meade (2012). The output $Y_{i,t}$ of the product group *i* will be the function of parameters: capital $K_{i,t}$, labor $L_{i,t}$, energy $E_{i,t}$, materials $M_{i,t}$ and services $S_{i,t}$. In other words output can be presented in the following form:

$$Y_{i,t} = A_{i,t} f(K_{i,t}, L_{i,t}, E_{i,t}, M_{i,t}, S_{i,t}), \tag{2}$$

where $A_{i,t}$ stands for multifactor productivity.

As long as we have access to the necessary data, we may use even more production inputs in our model. Say we consider transport services or electricity consumption as inputs in our model. A greater number of production factors allows us to track technology impact more precisely and will not change the model significantly. But for simplicity we will consider only KLEMS production factors at this point.

As in Meade (2012) we can rewrite (2) in terms of growth rates and get an equation for the Sallow residual or MFP growth:

$$r_{i,t}^{MFP} = r_{i,t}^{Y} - s_{i,t-1}^{K} r_{i,t}^{K} - s_{i,t-1}^{L} r_{i,t}^{L} - s_{i,t-1}^{E} r_{i,t}^{E} - s_{i,t-1}^{M} r_{i,t}^{M} - s_{i,t-1}^{S} r_{i,t.}^{S} \tag{3}$$

Variables $s_{i,t-1}^{j}$ for $j = L, E, M, S$ are the weights in output of corresponding production factors in the previous period. According to Meade (2012) the weight of capital production factor is given by:

$$s_{i,t}^{K} = 1 - s_{i,t}^{L} - s_{i,t}^{E} - s_{i,t}^{M} - s_{i,t}^{S}. \tag{4}$$

All growth rates in (3) are in constant prices, which means that every production factor input should be adjusted according to its deflator.

The estimation of deflators and weights for production factors for every product group is not always easy without access to IO data for each product group. In this case we can use values for industries or its segments as reasonable proxies.

We will now briefly describe parameters of (3). We start with the unit costs of capital. To obtain its value, we will use the OECD methodology (Arnaud et al., 2012). The unit cost of capital growth which corresponds to the growth of capital input will be determined by the following:

$$r_{i,t}^{K} = \left(C_{i,t}^{RR} + C_{i,t}^{Dep} - D_{i,t}^{Cap}\right), \tag{5}$$

where $C_{i,t}^{RR}$ stands for change in required rate of return in the product group i, $C_{i,t}^{Dep}$ refers to changes in the depreciation rate and $D_{i,t}^{Cap}$ is the change in the deflator for capital.

As for labor factor growth we will use the growth in the product of current workforce and deflated average salary. The growth rates of other factors, i.e. energy, material and services, will be obtained from the corresponding inputs adjusted for inflation.

Now we will return to the estimate of demand growth rates. Domestic consumption growth rate $r_{i,t}^{HGIF}$ depends on several factors. First of all, as we discussed earlier, the demand growth in constant prices is closely tied to the MPF growth. Again, we recall here that we assume for simplicity that the economy is always in equilibrium, that is, output is equal to demand and every price change will be immediately reflected in the changes of output.

Hence the growth of consumption due to technological advantages resulted in changes of the business model and new consumer properties of product groups can be measured with MFP growth $r_{i,t}^{MFP}$. Technological advantages might include new properties or significant improvement of the current properties of products. We assume that technological advantages equally affect all consumers: households, public organizations, intermediate consumers and fixed capital consumers from other product groups.

Consumption growth is also affected by macro-driven parameters such as disposable income of households, population growth, interest rates, budget spending and others. We suggest that domestic GDP growth M_{t}^{GDP} is suitable proxy for macro variables affecting domestic demand. We consider GDP growth as an input parameter for the model which comes from macro scenarios. In terms of the production function, the macroeconomic fraction of consumption growth can mainly be explained by changes in inputs of production factors.

Another important parameter, which is outside of the product group demand model, is rising or declining demand for substitutes from other product groups or even industries. The assessment of this parameter is rather difficult. Instead of developing a very complicated model accounting for interrelations between the outputs of product groups and industries, we will rely on expert opinion for estimation of the fraction of demand growth associated with rising demand for substitutes $r_{i,t}^{sub}$.

In summary, we obtain the following formula for domestic demand growth:

$$r_{i,t}^{HGIF} = r_{i,t}^{MFP} + M_{t}^{GDP} - r_{i,t}^{sub} \tag{6}$$

Another parameter of the demand for the product group is the export growth rate $r_{i,t}^{Exp}$. This parameter again depends on the growth of MFP. But on the foreign market, domestic goods and services compete with foreign products. That is why it is reasonable to include the MFP growth of the product group on the world market $r_{i,t}^{WMFP}$in the model. Actually we can suggest that the difference between domestic MFP growth and global MFP growth will explain the relationship between export growth and the technological advantages of domestic products over their substitutes on the world market. Global MFP growth can be estimated based on retrospective dynamics and expert estimates according to developed scenarios.

The export growth rate will be also affected by global macro parameters. Similar to domestic case we suggest that those parameters can be expressed in terms of gross world product (GWP) growth M_{t}^{GWP}. We assume that we have access to external sources with data on scenarios of the global economy's development.

Export growth may also depend on demand for the substitutes of a product group. This parameter is extremely difficult to estimate. We can use a domestic parameter instead, but we adjust it for the export share on the world market for the previous period $S_{i,t-1}^{\exp}$. The reasoning behind this adjustment is that if the exports are relatively small compared to the size of the total market for the product, then growth of exports will be mainly due to the advantages of domestic over foreign products. But if the export share is very large on the global market, then substitutes may significantly impact its growth.

Finally the export growth can be expressed thus:

$$r_{i,t}^{Exp} = \left(r_{i,t}^{MFP} - r_{i,t}^{WMFP}\right) + M_{t}^{GWP} - r_{i,t}^{sub} S_{i,t-1}^{exp} \tag{7}$$

The import growth rate $r_{i,t}^{im}$ depends on technological advantages of domestic products over imported products, which can be measured as the difference in MFP growth, i.e. $r_{i,t}^{WMFP}$-$r_{i,t}^{MFP}$ Similar to domestic consumption, import growth is affected by demand for substitutes and macro parameters. Hence we can express the import growth as:

$$r_{i,t}^{Im} = \left(r_{i,t}^{WMFP} - r_{i,t}^{MFP}\right) + M_{t}^{GDP} - r_{i,t}^{sub} \tag{8}$$

Now we combine (6), (7) and ((8) and plug them into formula ((1) for output growth:

$$\begin{aligned} r_{i,t}^{Y} = {} & \left(\beta_{i,t-1}^{HGIF} + \beta_{i,t-1}^{Exp} + \beta_{i,t-1}^{Imp}\right) r_{i,t}^{MFP} - \left(\beta_{i,t-1}^{HGIF} + \beta_{i,t-1}^{Exp} S_{i,t-1}^{exp} + \beta_{i,t-1}^{Imp}\right) r_{i,t}^{sub} + \\ & + \left(\beta_{i,t-1}^{HGIF} - \beta_{i,t-1}^{Imp}\right) M_{t}^{GDP} + \beta_{i,t-1}^{Exp} M_{t}^{GWP} - \left(\beta_{i,t-1}^{Exp} + \beta_{i,t-1}^{Imp}\right) r_{i,t}^{WMFP}. \end{aligned} \tag{9}$$

Substituting (3) into (9) and recalling that

$$\beta_{i,t-1}^{HGIF} + \beta_{i,t-1}^{Exp} + \beta_{i,t-1}^{Imp} = 1 + 2\beta_{i,t-1}^{Imp}$$

we express output growth in terms of production input growth:

$$\begin{aligned} r_{i,t}^{Y} = {} & \frac{1}{2\beta_{i,t-1}^{Imp}} \{1 + 2\beta_{i,t-1}^{Imp}) \sum\nolimits_{j=K,L,E,M,S} \left(s_{i,t-1}^{j} r_{i,t}^{j}\right) - \beta_{i,t-1}^{Exp} M_{t}^{GWP} - \left(\beta_{i,t-1}^{HGIF} - \beta_{i,t-1}^{Imp}\right) M_{t}^{GDP} \\ & + \left(\beta_{i,t-1}^{Exp} + \beta_{i,t-1}^{Imp}\right) r_{i,t}^{WMFP} + \left(\beta_{i,t-1}^{HGIF} + \beta_{i,t-1}^{Exp} S_{i,t-1}^{exp} + \beta_{i,t-1}^{Imp}\right) r_{i,t}^{sub} \}. \end{aligned} \tag{10}$$

Formulas (9) and (10) provide us with the parameters that explain the output growth. The technology impact will be associated either with MFP growth or growth of KLEMS production inputs. Other parameters include macro variables, namely domestic GDP and GWP growth.

The parameters of competitiveness on domestic and foreign markets presented in the model by growth of the MFP on the world market and the fall of consumption associated with demand for substitutes.

For the purpose of forecasting and scenario planning, all of those parameters should be estimated. As we mentioned before, the macro parameters are assumed to be given from externally obtained macro scenarios. In constructing short-term scenarios we can rely on macro scenarios, uncovered trends and the extrapolation of retrospective dynamics for estimation of: MFP growth in the domestic and global economy; production factor parameters and the demand for substitutes. Expert estimates may also help in calibrating the obtained estimates.

In long-term scenario planning we use the 2×2 framework. We start with the identification of wild cards that may cause a sudden drop or sharp rise in growth parameters. We assume that the scenario of high demand and MFP growth corresponds to the macro scenario where high domestic GDP growth exceeds GWP growth. We also suggest that there is slightly negative growth in demand for substitutes and the difference between MFP growth in the domestic and global economy is equal to the difference in the growth of domestic GDP and GWP. At the same time, output growth of the product group is equal either to the historically high average output over a five-year period or for example to double digit growth justified by identified wild cards. These assumptions completely determine the parameters of the model.

Similarly we can describe the remaining two scenarios with high or low MFP growth and correspondingly high or low demand. After that we can linearly extrapolate growth rates from the end of short-term scenarios to the target parameters of the long-term scenarios. The estimated values can be then adjusted according to the expert opinion.

Knowing the current output parameters for each product group and projected growth rates according to the scenarios, we can then aggregate the parameters to the segment and industry level.

5. Assessing the interaction of technologies and markets

In the previous section, we proposed a forecasting model that allows us to assess the interactions of technologies and markets under a TR framework. Hence, the next step will be to estimate the effect of the technology or group of technologies on the market parameters. The impact of the technology on the parameters of the product group can be measured through a change of weights $s^j_{i,t}$ for KLEMS production factors and the effects on the growth of MFP.

We can even estimate market-pull and technology-push effects using the developed model. Assume that the formula (9) may reflect the market-pull effect. Indeed if we rewrite (9) in the following form:

$$r^{MFP}_{i,t} = \frac{1}{1+2\beta^{Imp}_{i,t-1}}\{r^{Y}_{i,t} + \left(\beta^{HGIF}_{i,t-1} + \beta^{Exp}_{i,t-1}S^{exp}_{i,t-1} + \beta^{Imp}_{i,t-1}\right)r^{sub}_{i,t} - -\left(\beta^{HGIF}_{i,t-1} - \beta^{Imp}_{i,t-1}\right)M^{GDP}_{t} - \beta^{Exp}_{i,t-1}M^{GWP}_{t} + \left(\beta^{Exp}_{i,t-1} + \beta^{Imp}_{i,t-1}\right)r^{WMFP}_{i,t}\} \quad (11)$$

we then can notice that the demand growth can induce technological advantages that result in MFP growth of the product group.

On the contrary, (10) may demonstrate the technology-push effect. The technology affects production inputs, which has an influence on output growth. For example, the technology impacts the electricity production factor by decreasing electricity costs by 10%. For simplicity's sake, the technology impacts only the cost of electricity and no other production factor. Assume that according to estimated parameters in (10) the output growth rate depends on the reduction of electricity costs with a coefficient of 0.1. Then we might conclude that the increase in output growth attributed to technology will be 1%. Knowing now the share of the studied product group in the industry, say 5%, we conclude that the impact of technology on the industry output growth through this product group will be 0.05%.

In order to balance and justify the obtained results, we may elaborate on expert procedures to estimate the role of technology for the industry or the whole economy.

6. The case of civil aircraft manufacturing sector in Russia

We decided to illustrate the proposed approach for the case study of one of Russia's strategic industries, aircraft manufacturing. The choice was made for several reasons. The structure of the industry is relatively easy to analyze and there is plenty of available information on the subject. Besides that, there is a relatively active STI in this industry, which is widely supported by Russian government. A whole range of nanotechnologies is widely applied in aircraft manufacturing.

At the same time we may witness a large number of internal and external risks that can seriously damage the industry's development. For example, several years ago, Russian manufacturers completely stopped the production of civil airplanes and resumed it only a couple of years later. Competition with global leaders such as Boeing and Airbus provide strong barriers for different market niches. Wide body civil aircraft are only in the research and development phase and will enter the market several years later when the competition will probably be even higher due to growing industries in emerging markets.

However, it is not only the competition on the domestic and foreign markets that may hurt the aircraft industry in the long run. Some disruptive technologies such as drones and flying automobiles may become substitutes for the role of airplanes in the transportation system. The growing speed of railroad transportation may also affect the capital intensive aircraft manufacturing sector, especially if we keep in mind the huge investments required for aircraft infrastructure. All the mentioned factors may significantly impact the development of the industry.

We do not intend to provide a careful STEEPV analysis of aircraft manufacturing industry here because our main goal is to illustrate the capabilities of technology's impact estimation.

We divided the industry in three segments of civil airplanes, civil helicopters and aircraft parts. The main product groups include wide body transport airplanes, single aisle transport airplanes, regional jets, general and special airplanes, civil helicopters, aircraft engines, construction components and equipment.

Due to strong global competition, imports in most of product groups excluding helicopters and parts approached almost 80% of domestically purchased civil aircrafts in 2013. We assume that in the best case scenario, the import share will significantly decrease after launching sales of several types of aircraft, which are currently under development. We applied the forecasting model from Section 4 for the development of scenarios for the civil aircraft manufacturing sector. After an analysis of all available information, including macro scenarios and trends, we obtained the following scenarios for output growth in the airplane segment (Fig. 2).

As an example of a promising technology, we can mention the nanotechnologies used in construction materials for aircraft. Nanotechnology materials are actively being developed for aircraft. The widespread use of these in aircraft is an issue for the near future and in the long run we expect that the technology may affect many characteristics of airplanes including ecological parameters, flight characteristics and possibly fuel economy. We will try to assess the nanotechnologies' effect on the airplane manufacturing segment.

We assume that all forecasting procedures were conducted but nanotechnologies' effect was not yet considered. Our estimate of sector's MFP growth averaged 3.1% annually compared to 4.7% of output growth in the five-year period starting from 2035 to 2040 in the best case scenario. The share of construction material costs averaged almost 16% for different types of aircraft in 2013. We expect that this share will increase by 2035 and will be around 20% on average among all civil airplanes. Using expert opinion we assume that nanotechnology accounts for 2% of the further annual increase in material costs from 2035 to

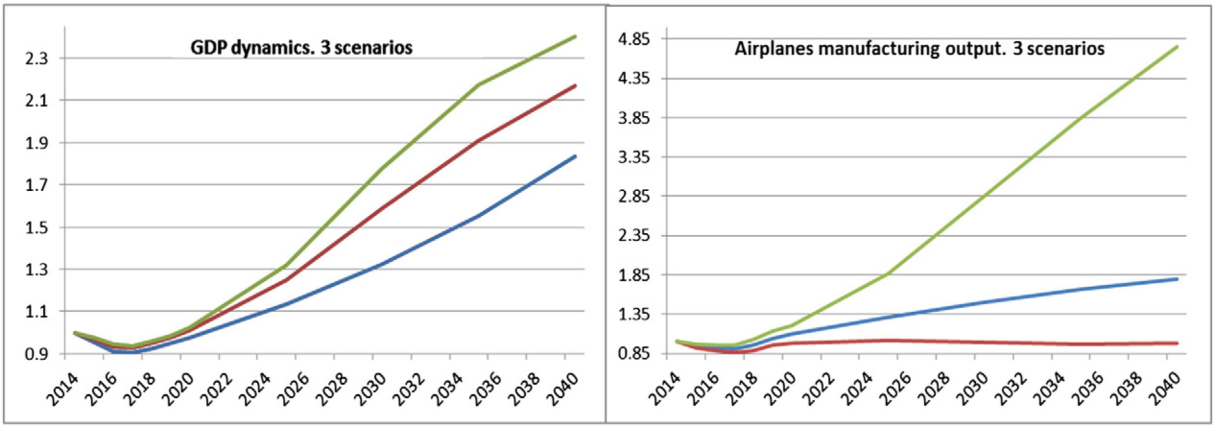

Fig. 2. Output growth in airplane segment compared to GDP growth in Russia (%).

2040. The increase in the material production factor may be associated with the better properties of aircraft, which will be reflected in higher added value. That is why we assume here that material factor growth will not affect the MFP growth, which remains at 3.1% level in the best-case scenario despite the growing costs. Then nanotechnologies' implementation will cause an increase in output growth assuming everything else is constant. At the same time, we discovered that the ratio of import and output will significantly drop by 2035 and reach 0.28 compared to almost 5 in 2013 and the export share of output will increase to 17% from the current single digit values.

It is reasonable to assume that nanotechnologies impact aircraft material costs globally. That is why the growth of the material factor for the aircraft manufacturing industry in the world will also increase by 2%, partly offsetting the effect on output in the domestic market. In other words, we should subtract the coefficient beside global MFP in (9) from the coefficient beside domestic MFP. Now according to (10) we can rewrite the part of output growth related to nanotechnology development as.

$$r_{i,t}^{YNANO} = \frac{1}{2\beta_{i,t-1}^{Imp}} \left(1 - \beta_{i,t-1}^{Exp} + \beta_{i,t-1}^{Imp}\right) s_{i,t-1}^{M} r_{i,t}^{MNANO} \quad (12)$$

where $r_{i,t-1}^{MNANO}$ is the growth of the material factor related to nanotechnologies.

Now plugging into ((12) all obtained values, we calculate that nanotechnology will contribute 0.79% to the annual output growth of the airplane manufacturing segment in Russia during the period 2035 to 2040.

The above simple exercise demonstrates that we can track the effect of technologies on output through a set of parameters estimated by the economic model. Further research could consider the effect of technology on the parameters of other product groups. We also did not estimate the demand for substitutes, which can change with the growth of output due to material costs.

This example illustrated the assessment of technology-push effect. The market-pull effect arises from an increase in MFP growth, which could be explained by innovation such as computer modeling of airplane parts, for example. Again we leave this outside of boundaries of this research.

7. Conclusion

We proposed an approach to TR which allows one to quantify the STI impact on markets and which can assess interactions between the market and a technology's development. The approach is based on qualitative methods such as trend analysis and quantitative methods such as the bottom-up economic model which allows one to control for technology innovation through KLEMS production factors and MFP growth. The important part of the TR methodology includes scenario analysis, which accounts for great uncertainties in market development.

This approach has certain limitations. First of all, it is based on many inputs for different product groups. Retrospective parameters are not always available. The same problem may arise when we are looking for scenarios for macro parameters.

The simplification of the model also poses some risks. Using macro parameters as proxies for the parameters in product groups is not always adequate. The expert procedures involved in the estimation of the parameters sometimes are not suitable. For example, the estimation of demand for substitutes is a difficult task for an expert and some modeling here could be very helpful. The demand formulas (6), (7) and ((8) may depend on determinants with non-unit coefficients, which require additional econometric estimates.

However, the considered approach to TR demonstrates some potential in the combination of qualitative and quantitative methods which allows one to assess the market and technology interactions.

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