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METHODS OF DATA PREPROCESSING FOR THE UTILIZATION IN DYNAMIC MODELS OF GENERAL ECONOMIC EQUILIBRIUM

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Motivation

One of the main steps in the process of developing applied economic models is their adaptation to observable statistics, consisting, for instance, in calibration or parameter estimation. The results and quality of this stage strongly depend on input data preparation and preprocessing. Incorrect choice of data preprocessing methods and approaches can have a significant impact on further results, which motivates the need to develop a set of requirements for such procedures in the light of the specific requirements of general equilibrium models. This applies both to the seasonal adjustment phase (it is known that seasonal adjustment techniques may significantly change the properties of the data in terms of unit root tests, shifts of trend breakpoints and other characteristics) and subsequent phases.

Equally serious, especially for economic analysis during crisis periods, may be the problem of delays in data release, which can reach several months (and even a year for some indicators), which is often ignored when proceeding to estimation or calibration of models on real data.

Moreover, in the analysis of multiproduct general equilibrium models it turns out that there is no sufficiently acceptable and universal way of describing the behaviour of agents in models of this kind. Well-studied theoretical multiproduct models often face serious problems when transferred to existing statistical data, whereas applied multiproduct models used a few decades ago stop working under the conditions of substantially more complex modern economy. In this regard, the methods used to describe the interaction between consumers and producers in a multiproduct economy become not only theoretically, but also practically important.

Literature review

Dynamic general equilibrium models are one of the main tools for economic analysis in the current literature, yet data preparation for use in this class of models often remains outside the main focus of researchers’ attention. Two groups of tasks can be distinguished at the preprocessing and data preparation stage: the data processing stage - which includes data preparation in the light of the requirements of the model classes used - and the pre-modelling stage, which is necessary to finally bring the data into the required format.

The first phase of data preparation examines seasonal adjustment issues. There is a large body of research on the problems that seasonal adjustment brings to data. In general, they can be divided into two large groups: one concentrates on the problems with the series as is ([Bessonov, Petronevich, 2013] - false seasonality in seasonally adjusted series containing no seasonality, [Hood, 2002] - instability of adjusted series when adding new data, [Matas-Mir, Osborn, Lombardi, 2008] - seasonal adjustment reduces the magnitude and increases the duration of shocks, [Bruce, Jurke, 1996] demonstrates the instability of X-12-ARIMA to outliers and structural breaks), the other one - on the violation of statistical properties of series after seasonal adjustment. The latter group of papers is of particular interest to us, because it is the study of statistical properties of series (stationarity and cointegration), as a rule, that is the first step when constructing dynamic macroeconomic models. Here we can mention [Ghysels, Perron, 1993], which shows analytically the presence of a shift in the distribution of test statistics in unit root tests when using seasonal adjustment: adjusting a stationary series can lead the tests to take it as non-stationary. This reasoning does not apply to all classes of seasonal adjustment procedures, nor to all unit root tests, but the result has given rise to a body of closely related work: seasonal unit roots are investigated in [Ghysels, Lee, Hoh, 1994], the relationship of seasonal and regular unit roots in [Granger, Syklos, 1995]. In [del Barrio Castro, Osborn, 2014] it is shown that seasonal adjustment of non-stationary series can lead to an uninvertible MA-part in the series, [Franses, Segers, 2010] investigates the preservation of seasonality when revising data in official statistics and points to high instability of year-to-year indicators obtained from such data.

Thus, an inappropriate seasonal adjustment procedure can have a significant negative impact on the properties of the final data, and those, in turn, on the quality of the resulting models, which necessitates the formulation of requirements specific to the estimation of dynamic general equilibrium models and the choice or design of an appropriate seasonal adjustment procedure in terms of these requirements.

Before proceeding to the modelling stage, there is often a problem related to delays in publication of data, primarily GDP and its components statistics, which plays a key role in many macroeconomic models. These delays motivate the use of nowcasting - methods of estimating current levels of not published indicators using more timely data. The main tools in this area are the bridge equations presented in (Ingenito et al., 1996); MIDAS models (Ghysels et al., 2006) and (Ghysels et al., 2007); and mixed frequency vector autoregressions (Kuzin et al., 2011) and (Schorfheide, Song, 2015) applied to nowcasting, which also have Bayesian generalisations, see (McCracken et al. (McCracken et al., 2015).

Finally, a very important issue for a separate class of models - multiproduct models - is the question of accounting for and modelling multiplicity of products within general equilibrium models. The use of multiple products in a single model is necessary to account for differences in the prices of different products, without which the accuracy and quality of the models are naturally limited, for example, by differences in the deflators of GDP components.

In the current economic literature, there are two major areas in which the multiproduct structure of production plays a key role. Conventionally, the first group of works can be associated with the paradigm of dynamic stochastic general equilibrium (DSGE) modeling of the economy, the second - with the paradigm of computable general equilibrium (CGE). One of the key differences between these approaches is that under the DSGE concept models are typically built starting from micro-foundations (in particular, individual firms whose output is then aggregated by non-linear convolution into industry or economy output as a whole), whereas

CGE models are usually based on larger conglomerates interacting with each other in the way of input-output tables.

There are several main approaches to the treatment of multiproductivity in DSGE models. In [Pytlarczyk, 2005] and [Cuche-Curti et al., 2009] authors introduce firms producing an "intermediate" product whose output is then converted into a "final" product by the firms producing the "final" product. Sometimes, exporting and importing firms are also introduced separately, with importers usually considered as part of the industry producing the "intermediate" products (final products being usually aggregated from domestic and imported intermediate products, as in [Born et al., 2013]) and exporters as part of "final" products industry. In most models, the government does not produce any product (see, among others, [Forni et al., 2009], [Cavallo, 2005]), but sometimes models also contain a separate industry producing a monopoly government product, which is explicitly accounted for in the utility of all households in the economy, as in [Papageorgiou, 2014] and [Leeper et al., 2017]. An example of work that contains all of the above mechanisms is [Mucka, Horvath, 2016].

Another big trend is the introduction of several branches having the same nature and differing only in certain parameters, as for example in [Lee, 2010; Carvalho, Lee, 2011; Ivashchenko, 2016]. In [Chatterjee, Cooper, 2014], consumer and investment markets are considered separately, while [Minniti, Turino, 2013] considers multi-product firms: in contrast to the more standard approach, where each firm produces one product (products are different), here each firm produces a set of products at once, which works as a mechanism to amplify shocks in the economy.

A common feature of models of this kind is the introduction of additional restrictions on the nature and structure of model products - they tend to turn out to be tied to some observable statistical indicator. Because of this, there may be situations, especially in crisis periods, where the processes observed in the data conflict with the assumptions introduced in the models (for example, the breakdown into imported and domestic products implicitly introduces the assumption that the import deflator at all times is the minimum or maximum of all GDP components' deflators), which motivates exploration of ways to account for multiproduct structure of the economy without being bound to observable indicators.

Objectives of the research

An object of the thesis is general economic equilibrium models, which contain detailed description of real sector of economy.

The subject of research is methods of analysis and preparation of statistical data for use in general equilibrium models, and related specifics of description of interaction of economic agents.

The objective of the study is to develop methods of statistical data preprocessing for their use in dynamic general equilibrium models containing description of multiproduct structure and to test these methods on the model of Russian economy.

The objectives of the study are:

1. To develop procedures for data preparation for use in general equilibrium models, including unification of long data series and exclusion of the seasonal component.
2. To explore the possibility of using nowcasting methods to form a statistical base of general equilibrium models.
3. Exploring the possibility of using a system of model product traders in general equilibrium models based on the decomposition of GDP components by expenditure.
4. Formulation of a multi-product model of Russian economy which includes descriptions of consumers, producers and traders and uses the methods proposed in the thesis.

Methodology

It is analytically proved that the proposed seasonal adjustment procedure meets the introduced requirements motivated by the specificity of dynamic general equilibrium models. The properties of the proposed procedure are tested by Monte Carlo method and a standard set of tests is used to estimate the bias in unit root tests: augmented Dickey-Fuller test, Phillips-Perron test and KPSS-test.

The paper considers a set of econometric models for nowcasting. MIDAS models are estimated by OLS, models using LASSO and adaptive LASSO are estimated by numerical optimization algorithms, posterior coefficient estimates of Bayesian vector autoregressions with mixed frequency data are estimated using MCMC. The accuracy of the models is estimated by out-of-sample forecasting for the last 10 and 20 quarters, whereby the value of GDP in the current quarter is excluded from the training sample, but not the values of the explanatory variables in order to replicate correctly the actual nowcasting procedure.

The main equations used in estimating multiproduct decomposition are derived analytically. At the estimation stage, the parameters, including the series of unobserved model products' prices, are estimated numerically by a modification of stochastic gradient descent optimization algorithm over successive blocks of data (to preserve the time dependence structure). To speed up convergence of the procedure, a penalty for non-smoothness of the model product prices is added to the objective function at the first stage of optimization and then removed.

The solution of the agents' problems in the proposed multiproduct model is found analytically, and the obtained equations are estimated from the data numerically.

Main findings

Seasonal adjustment and data preparation

The paper identifies a number of requirements for seasonal adjustment procedure, which are specific to general equilibrium models - first of all, to preserve multiplicative relationships between indicators (series in constant and current prices and their deflators, for instance), and proposes a seasonal adjustment procedure designed to meet these requirements. The proposed procedure is based on the use of a set of dummy variables describing the seasonal component. The procedure has an outlier detector to obtain more robust results and uses dummy variables in multiplicative form.

The paper tests the proposed procedure for a number of standard problems for seasonal adjustment algorithms:

1. Stability on series with outliers, including testing the accuracy of reproduction of the original (seasonally unseasoned) series on simulated data
2. Bias in unit root tests
3. Bias in cointegration tests

The procedure is successfully tested, the robustness to the identified problems is demonstrated to be at the level of standard methods.

The data preparation also considers the issue of standardisation of GDP statistics over different periods. Currently, GDP at current annual and quarterly prices is available separately for two different time periods: from 1995 to 2011 and from 2011 to 2017. GDP in base year prices in annual and quarterly breakdowns is available for four different time periods, with different years as base years. The paper describes a procedure that produces long series of GDP, household and NCO consumption, government consumption, gross fixed capital formation, exports and imports. After reconstructing them as the difference between GDP and the sum of its components, the sum of the change in inventories and the statistical discrepancy is calculated.

Nowcasting of model indicators

In this thesis a number of nowcasting procedures on quarterly data for Russian GDP is studied. The following models are considered:

1. MIDAS (both restricted and unrestricted)
2. Mixed frequency Bayesian vector autoregressions (MFBVAR)

3. Linear models with adaptive LASSO regularisation

Production indices for different economic activities are used as explanatory variables.

It has been established that the highest accuracy of the scientist is obtained using MFBVAR-models and the highest accuracy among MIDAS-models and their modifications is obtained using linear models similar to U-MIDAS with several variables and regularisation by adaptive LASSO.

Model decomposition of GDP components

The thesis considers a procedure of GDP and its components decomposition into several unobservable (in the general case) products, which we call GDP decomposition.

The paper introduces a number of requirements for the decomposition procedure. We will require it to satisfy the following properties:

1. Be able to correctly reproduce the calculations when the base year changes, i.e. to take into account the difference between normal prices and deflators,
2. Not to assume linear relationships linking observed indicators in base year prices to their non-observable components described by the model. Instead, CES-functions describing a sufficiently broad class of relationships will be used.
3. Be scalable to an arbitrary number of model products, as the question of their required number should be decided already at the stage of working with statistical data.

Let us consider a decomposition scheme on the example of two model products. It is assumed that for each element of GDP by expenditure $X \in \{C, G, J, E, I\}$ at each point in time, the following representation is valid:

$$X_t = X_0 \left[\alpha \left(\frac{X_t^A}{X_0^A} \right)^{\rho} + (1-\alpha) \left(\frac{X_t^B}{X_0^B} \right)^{\rho} \right]^{\frac{1}{\rho}},$$

Where α, ρ - CES-function coefficients, X_t^A, X_t^B - model components (we will call them product A and product B), combination of which gives the analysed GDP component, X_0^A, X_0^B, X_0 - the values of the relevant variables at the point in time that is considered the baseline. It should be noted that the last three coefficients are rather rarely used in functions of this kind. Nevertheless, their presence is fundamental. First, they will allow to further correctly solve the problem of base year change, which is reduced in our case to simply recalculating these coefficients, but will not affect, for example, the coefficients α, ρ and model variables. Secondly, the presence in the model X_0^A, X_0^B, X_0 solves the dimensionality problem: not the money indicators are calculated in power ρ, but the dimentionless values. Moreover, we do not sum model variables X_t^A, X_t^B directly.

Let us assume that the relevant to the indicator $X \in \{C, G, J, E, I\}$ macroeconomic agent (respectively consumer, state, producer, exporter, importer) solves the problem of optimal utilisation of the model products available to it by maximising the right-hand side of the above equation by X_t^A, X_t^B within a given constraint

$$p_t^X X_t = p_t^A X_t^A + p_t^B X_t^B,$$

Since the problem is in fact static (it is solved at any time period independently of others), its solution is relatively easy to find using Lagrange's principle. The solution of the problem gives expressions for the volumes of unobservable model products:

$$X_t^A = X_0^A \frac{p_t^X X_t}{p_t^A X_0^A + p_t^B X_0^B \Omega_t^X},$$

$$X_t^B = X_0^B \frac{p_t^X X_t \Omega_t^X}{p_t^A X_0^A + p_t^B X_0^B \Omega_t^X}.$$

Where $\Omega_t^X = \left[\frac{1-\alpha}{\alpha} \frac{p_t^A X_0^A}{p_t^B X_0^B} \right]^{\frac{1}{\rho-1}}$

A description of the theoretical model used in the following has been given above, in a rather general form, indicating that it is scalable to any number of products. The experiments conducted show that when two products are used for decomposition, the accuracy of the fit of the observed variables is rather poor. This is due, among other things, to the minimum and maximum deflator problems already mentioned above. When using three (and even more four) products the instability problems begin to appear: with the addition of new points the coefficient estimates can change quite dramatically. In addition, problems with the interpretation of the model products begin to emerge.

In a situation where two products are few and three are many, it is proposed to consider a three-product decomposition, but to assume that one of the GDP by expenditure elements consists of only one of the products, while this product itself can also be used in other GDP by expenditure components. As a result of the analysis, government consumption turned out to be the highlighted GDP component.

Multi-product model of Russian economy

In chapter three, we study a model of economy consisting of producer and consumer operating in an economy with several products, and traders of products collecting observed variables from unobserved product flows and reverse decomposition. The consumer and the producer interact directly with a single product, with the multiproduct economy enabled by the operation of a system of traders who aggregate and disaggregate intermediate products into final products. This approach maintains the simplicity of single-product economy descriptions and the ability to directly test model relationships in the data, combined with the ability to explicitly account for the multiproduct structure of the economy. Moreover, trader agents are described by the same CES functions used in the model decomposition scheme, thereby allowing models of this kind to be estimated on the data obtained with the multiproduct decomposition proposed in chapter two.

There are several features of the producer description that distinguish it from generally used models in the literature. First, we divide investment into two parts: investment in the maintenance of capital and investment in the build-up of new capital. This approach allows us to explain output fluctuations more effectively, while keeping the results interpretable by treating these investments as transaction costs and capital costs, respectively. Second, the production function depends on the amount of used capital, adjusted for the level of investment in capital maintenance. Third, an original scheme for describing the producer's use of labour is used, which in a sense allows it to be interpreted as human capital.

The formation of capital by the producer is described by the equation:

$$\frac{d}{dt}M(t) = Jm(t) - \delta_{am}M(t)$$

Where $M(t)$ is capital, $Jm(t)$ - investment in building up new capital, δ_{am} - depreciation rate. Note that this ratio allows reconstructing $Jm(t)$ series based on statistics on the level of capital and depreciation (such statistics are available, provided by the Federal State Statistics Service). And the use of the ratio for investment $J(t) = Ju(t) + Jm(t)$, where $J(t)$ is the general level of investment (gross fixed capital formation), allows to reconstruct a series of investments in the maintenance of fixed assets $Ju(t)$. The prices of both kinds of investments are determined by the price of investment as such, however, they differ by a constant, thus, the costs of investment $Ju(t)$ can be written as $p_J(t)Ju(t)u_J$, and those of $Jm(t)$ investment as $p_J(t)Jm(t)m_J$.

The formation of labour is described in a similar way to fixed assets:

$$\frac{d}{dt}R(t) = fR(t) - \delta_{ar}R(t)$$

Where $R(t)$ is the labour input (number of employees), $fR(t) \geq 0$ - hiring of new workers, δ_{ar} - rate of employee attrition (change of job, retirement, leaving the labour force for other reasons).

At the same time, the producer as an employer pays a fixed wage $w_w(t)$ per unit of labour cost, thus, spending $w_w(t)R(t)$ on the current level of labour, as well as costs of finding new workers or dismissing old workers (depending on the sign) $w_d(t)$, due to which its total labour costs are changed by $w_d(t)\,fR(t)$.

The production function proposed in the thesis has the general form

$$Y(t) = Ae^{\delta t}(u(t)M(t))^{\alpha} R(t)^{1-\alpha}$$

Where $u(t)$ is the capacity utilisation rate, $u(t) = (\frac{Ju(t)}{M(t)} + u0)^b$. Loading a unit of capacity requires an investment, and there is a certain level of capacity $u0$ capable of operating without additional costs. Non-linearity is added by the coefficient $b < 1$ showing that the efficiency of investment decreases as it grows (first the most productive capacity is invested, then the less and less productive ones). Combining these two considerations yields the production function described below.

The consumer maximises her utility of consumption in a continuous time on the time interval $[0,T]$

$$\int_0^T u(C(t), R(t))\exp\{-\delta t\}dt \to \max_{C(t),R(t),S(t)} ,$$

by choosing the trajectories of consumption $C(t)$, employment $R(t)$, the dynamics of cash $M(t)$, deposits $S(t) \ge 0$, in the framework of a financial balance

$$\frac{d}{dt}M(t) = \omega(t)R(t) - p(t)C(t) + r_S S(t) - \frac{d}{dt}S(t) - OC(t),$$

where $OC(t)$ is other expenditure, under the constraint

$$M(t) \ge 0$$

and the variables known on the interval $[0,T]$: $R^*(t)$ - economically active population $R^*(t) \ge R(t)$, wages $\omega(t)$, consumption deflator $p(t)$, deposit interest rate $r_S(t)$, and other money balances $OC(t)$ are exogenously given. The utility function of the aggregate consumer is

$$u(C(t),R(t)) = \frac{1}{1-\beta}\left(\frac{C(t)}{C^*(t)}\right)^{1-\beta} - \frac{1}{1-\alpha}\left(\frac{R(t)}{R^*(t)}\right)^{1-\alpha}$$

where $C^*(t) = \dfrac{\omega(t)R^*(t)}{p(t)}$, for the values of the parameters $\alpha < 0$, $\beta > 0$.

It is shown that relationships obtained in the process of solving agents' problems and finding equilibrium are sufficient to identify all endogenous variables of the models. Parameters of both agents' problems are estimated using real data. Model estimates of endogenous variables show good accuracy

Contribution

1. The requirements for seasonal adjustment procedure, which are necessary for correct estimation of models using indicators in current and constant prices at the same time, are formulated. An example of a procedure meeting these requirements is presented and its properties are investigated.
2. One of the most comprehensive studies of accuracy of Russian GDP nowcasting models is presented, including the most advanced approaches, such as Bayesian vector autoregressions of mixed frequency, in terms of the set of models used at the moment of writing.
3. A new procedure of nowcasting based on unrestricted MIDAS-models and regularization by adaptive LASSO is proposed, which allows to ensure preservation of oracle property. It is shown that on Russian data the proposed procedure demonstrates higher accuracy than standard MIDAS-models.
4. A new scheme of multiproduct decomposition is proposed, which does not imply binding one of the model products to observed indicators and is able to solve a number of problems (non-invariance to base year choice, instability of estimates, non-interpretability of estimation results) arising in

multiproduct models estimation. A description and analytical solution to the problem are given and a methodology for evaluating this decomposition scheme on real data using numerical methods is described. The performance of the proposed methodology is evaluated on simulated data and calculations are performed on real data.

5. The possibility of using the proposed methods in a multiproduct model of the Russian economy which reproduces elements of GDP by expenditure and labor market indicators with high accuracy has been demonstrated. The model proposes a new way to account for multiproduct structure of the economy: through a system of agents-traders of model products, which allows to separate the problems of product aggregation and those of the main agents (consumer and producer) and maintain a more compact description for the latter.

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[1] Personal contribution: development and analytical solution of agents-traders model component; numerical solution of decomposition problem

[2] Personal contribution: method of numerical estimation of model parameters on real data

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[3] Personal contribution: development and analytical solution of agents-traders model component; integration of traders into the bigger model
[4] Personal contribution: analytical solution of decomposition problem; numerical procedure for decomposition on real data
[5] Personal contribution: method of numerical estimation of model parameters on real data
[6] Personal contribution: model of Firm behaviour
[7] Personal contribution: development and program realization of seasonal adjustment procedure

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