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Stress testing of the non-financial corporations sector[1]

Contents

1 This methodology is valid as of 2020 but will be revised on an ongoing basis. The original methodology is based on an article by Vojtěch Siuda: CNB WP 12/2020 – A Top-down Stress-testing Framework for the Nonfinancial Corporate Sector.

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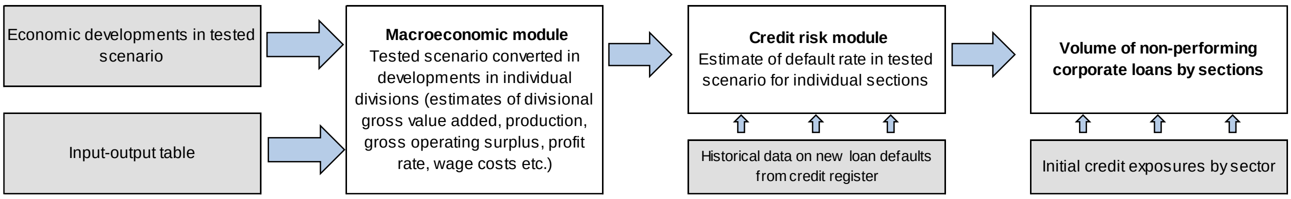
1. Introduction

The aim of stress testing the non-financial corporations (NFCs) sector is to assess the resilience of individual industries in this sector in a hypothetical macroeconomic scenario simulating adverse economic developments. Given the high share of loans to NFCs in credit institutions' balance sheets, analysing the risks associated with any difficulties in the sector is crucial from the financial stability perspective.

The test itself is dynamic and is usually conducted over a three-year horizon. In simple terms, the testing process can be divided into two main parts. In the first part, the underlying macroeconomic scenario is converted into developments in the individual divisions[2] of the economy. The impacts of the scenario and the degree of vulnerability at the division level are assessed using a set of industry-specific economic variables obtained with the help of input-output tables. These variables then enter the second part of the test, in which the sector-level default rates and the amount of non-performing bank loans at the test horizon are predicted. Figure 1 illustrates the whole process.

Figure 1
Simplified NFCs stress-testing process



2. Stress test scenarios

The first step of the test is to formulate the high-level macroeconomic scenario, which determines the type of risk tested and the degree of stress simulated. The adverse macroeconomic scenario usually captures the most important risks, ones which would have significant impact on the NFCs sector and indirectly also on the financial system once the underlying risks materialise. To compare the overall level of stress implied by the adverse scenario with the most probable outcome, the stress test is also run on a baseline macroeconomic scenario which is built around the first two years on the CNB's official forecast. The outputs from the CNB's official forecasting model are supplemented by projections of selected financial variables generated by the CNB satellite models. Of the variables generated by the CNB's official forecasting model, household consumption, government consumption, investment, imports, exports, unemployment, nominal wage growth, the CZK/EUR exchange rate and the PRIBOR are used. The stress test further uses property prices, the credit spread on the debt of NFCs (the difference between the loan rate and the return on risk-free assets) and the growth rate of loans to NFCs which are generated by the satellite models.

2 The NACE rev. 2 taxonomy is used throughout the methodology. It divides economic activity into 21 **sections**, which are further divided into 88 **divisions** (Eurostat, 2006).

3. Macroeconomic simulation

The input-output tables compiled by the Czech Statistical Office (CZSO) on an annual basis are used to capture the impact of the underlying macroeconomic scenario on the individual divisions. This table shows how total resources (production, imports and net taxes on products) are used in the economy for intermediate consumption (the value of the products and services consumed as inputs in the production process) and final use (final consumption, capital formation and exports). Intermediate consumption represents a crucial element as it defines the production linkages between the individual divisions. The difference between production and intermediate consumption then defines gross value added. Gross value added can also be viewed as the sum of income in the economy (the wages of employees and the operating surpluses of firms, which indicate the whole-economy profitability of firms and affect their credit quality), net taxes on production and capital depreciation.

The most recent input-output table is always used to convert the macroeconomic scenario into the divisions. This table defines the initial linkages between the divisions, the total resources used in production and the components of gross value added and final use.[3] Final use is then consistent with the scenario projected for the individual divisions for all periods of the stress test.

The propagation of the economic shock across divisions builds on the work of Leontief (1936).[4] It shows that with a known structure of production linkages in the economy, total resources used (the sum of production and imports) can be expressed as a linear combination of final use (*D*) and a technology matrix (*A*). This matrix consists of the ratios of the intermediate consumption of division *i* for the production of division *j* to the overall total resources used of division *i*. We can also use this relationship for increments, i.e. if we know the production linkages between the divisions, we can calculate the change in production from the change in final use. In the case of the Czech economy, which comprises 88 divisions, the economic system can be expressed as:

$X = (x_1, x_2, \ldots, x_{88})^T, x_i > 0$ as a vector of the resources of the individual divisions

$A = \begin{pmatrix} \frac{a_{1,1}}{x_1} & \cdots & \frac{a_{88,1}}{x_1} \\ \vdots & \ddots & \vdots \\ \frac{a_{88,1}}{x_{88}} & \cdots & \frac{a_{88,88}}{x_{88}} \end{pmatrix}$ as a technology matrix and

$D = (d_1, d_2, \ldots, d_{88})^T, d_i \geq 0$ as a vector of the final use of the individual divisions.

Resources are defined in accordance with the Leontief model as:

$$X = (I - A)^1 D = LD \qquad (1)$$

3 Available on the CZSO website – https://apl.czso.cz/pll/rocenka/rocenkaout.dod_uziti?mylang=EN.

4 Leontief, W. (1936). "Quantitative Input and Output Relations in the Economic System of the United States." Review of Economics and Statistics 18, pp. 105–125.

where I denotes a unit matrix and L is the Leontief inverse matrix. We define the increments as:

$$\Delta X = L \Delta D \tag{2}$$

This notation implies that a shock to the final use of division i of size Δd_i will change the total resources used in the economy by $\Delta d_i L(i)$, where $L(i)$ is the i-th column of matrix L.

A serious limitation of this model is its static character – the input coefficients of production are constant over time and the intensity of production stays the same. However, the economic theory and empirical evidence suggest that the intensity of production evolves over time in line with structural changes in the economy and technological progress. Moreover, these coefficients can be expected to change more significantly over time during periods of strong distress, which are often part of the scenarios applied, than they do in normal times. An adjustment of Leontief's analysis based on Alaniste Contreras and Fagiolo (2014)[5] is used to overcome this limitation.

Consider the previous definitions of *X, A, D* and *L* and a vector of shocks $Q = (q_1, q_2, \dots, q_S)^T, q_i \geq 0$. A division k hit by a shock q_k must supply less production to other divisions, which changes the whole composition of intermediate consumption and thus the technology matrix A. This leads to a new matrix A', where each element in the k-th row and the k-th column has been updated by q_k to:

$$a'_{k,j} = q_k a_{k,j} \tag{3}$$

$$a'_{i,k} = q_k a_{i,k} \tag{4}$$

where j is any division that uses a commodity produced by sector k as a production input and i is any division from which k buys a commodity as its production input. The result is a new total resources increments vector:

$$\Delta X = (I - A')^{-1} \Delta D = L' \Delta D \tag{5}$$

This mechanism assumes perfect foresight of firms about economic activity. It is a self-fulfilling process in which the production coefficients in the technology matrix adapt fully and immediately to the new level of final use. With the change of final use and imports defined by the macroeconomic scenario, it is thus possible to define the level of production, intermediate consumption and gross value added of the individual divisions of the economy in each period of the underlying scenario.

5 Alaniste Contreras, M., Fagiolo, G. (2014). "Propagation of Economic Shocks in Input-Output Networks." LEM Working Paper Series, 2014/09.

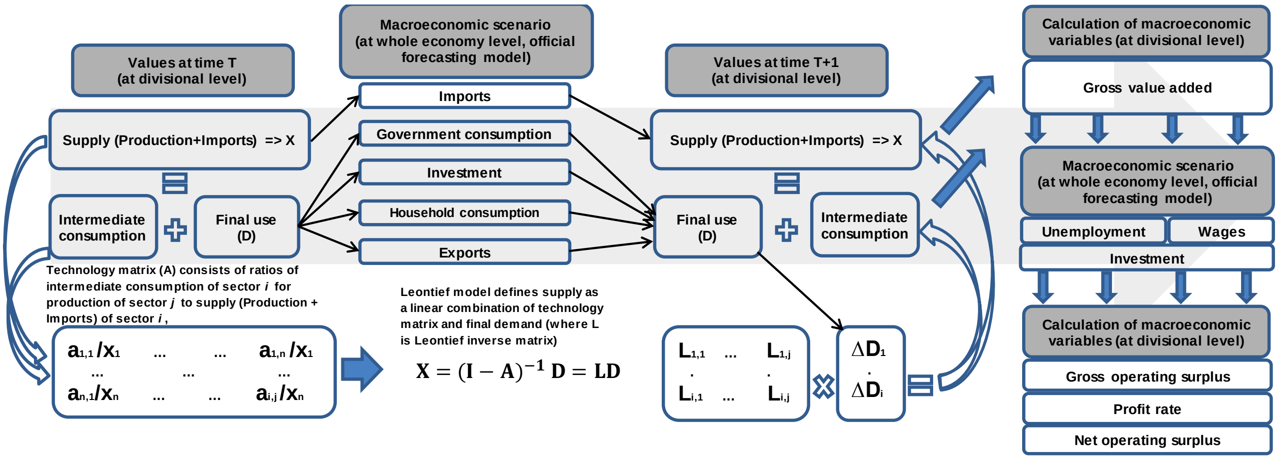
Before its application, the most recent input-output table is decomposed from annual to quarterly frequency drawing on knowledge of the quarterly evolution of the seasonally adjusted macroeconomic variables.[6] This should help capture the speed of the adjustment mechanisms in the supply chain more accurately.

The impact of the scenario can be projected at a divisional level in two ways depending on the purpose of use of the test:

- using a uniform impact on the divisions – in this case, each division is hit by an identical shock defined by an aggregate number;[7]
- using a differentiated impact on the divisions, with the intensity of the shock calibrated differently for each division. This opens up the possibility of simulating a higher level of stress on some divisions (or parts of the economy) and a lower level on others. However, the overall macroeconomic impact always respects the aggregate numbers defined by the underlying scenario.

One period of the macroeconomic simulation process is shown in Figure 2.

Figure 2
Simplified macroeconomic simulation



4. Default rate estimation

The variables obtained from the macroeconomic simulation (including various variable transformations into profitability, performance and interest ratios – see Table 1) are used in the second step to estimate section-specific default rates. These variables can be viewed as the

6 Seasonally adjusted whole-economy variables such as production, intermediate consumption and the components of GDP are available from the CZSO.

7 For example, when aggregate exports rise by 3%, the exports of each division increase by 3%. However, this does not mean that the shock will have identical impacts on the individual divisions, because each has a different composition of final use.

counterparts to the accounting indicators that are commonly used for credit-risk analysis at company level.

Table 1

Section-specific variables obtained from the macroeconomic simulation and their approximate accounting equivalents

Macro variables	Accounting variables
$\frac{Net\ operating\ surplus}{Production}$	EBIT/Sales
$\frac{Gross\ operating\ surplus}{Gross\ value\ added}$	EBITDA/(Gross profits + wages)
$\frac{Gross\ operating\ surplus}{Sales}$	EBITDA/Sales
$\frac{Gross\ operating\ surplus}{Average\ interest\ rate * volume\ of\ bank\ loans}$	Close to interest coverage ratio (EBITDA/Interest expenses)
$\frac{Gross\ value\ added_t}{Gross\ value\ added_{t-1}}$	Gross profit dynamics (excluding wages)

In addition to the section-specific variables obtained from the macroeconomic simulation, variables from an aggregate macroeconomic scenario tracking the exchange rate and property prices were added to the list of explanatory variables of the section-specific default rate. Given the nature of the Czech economy, these variables can significantly affect performance and credit quality in some sections of the economy. The list consists of 20 explanatory variables, a mix of aggregate and section-specific ones and their transformations and lags. They are listed in Table 2.

Table 2

List of all variables entering the default rate learning algorithm

	Variable	Abbreviation	Restriction
Dependent variable	Default rate$_t$ => default rate at time t	DF_t	
Section-specific explanatory variables	Constant	Const.	
	Default rate$_{t-1}$ => default rate at time t-1 (AR1 process)	DF_{t-1}	>0
	Net operating surplus$_t$/Production$_t$	$(NOS/P)_t$	<0
	Net operating surplus$_{t-1}$/Production$_{t-1}$	$(NOS/P)_{t-1}$	<0
	Gross operating surplus$_t$/Gross value added$_t$	$(GOS/GVA)_t$	<0
	Gross operating surplus$_{t-1}$/Gross value added$_{t-1}$	$(GOS/GVA)_{t-1}$	<0
	Gross operating surplus$_t$ /Production$_t$	$(GOS/P)_t$	<0
	Gross operating surplus$_{t-1}$/Production$_{t-1}$	$(GOS/P)_{t-1}$	<0

	(Net operating surplus$_t$ – Net operating surplus$_{t-1}$)/Production$_{t-1}$	$\Delta(NOS/P)_t$	<0
	(Net operating surplus$_{t-1}$ – Net operating surplus$_{t-2}$)/Production$_{t-2}$	$\Delta(NOS/P)_{t-1}$	<0
	(Gross operating surplus$_t$ – Gross operating surplus$_{t-1}$)/Gross value added$_{t-1}$	$\Delta(GOS/GVA)_t$	<0
	(Gross operating surplus$_{t-1}$ – Gross operating surplus$_{t-2}$)/Gross value added$_{t-2}$	$\Delta(GOS/GVA)_{t-1}$	<0
	(Gross operating surplus$_t$ – Gross operating surplus$_{t-1}$)/ Production$_{t-1}$	$\Delta(GOS/P)_t$	<0
	(Gross operating surplus$_{t-1}$ – Gross operating surplus$_{t-2}$)/ Production$_{t-2}$	$\Delta(GOS/P)_{t-1}$	<0
	Gross value added$_t$/Gross value added$_{t-1}$	ΔGVA	<0
	Gross value added$_{t-1}$/Gross value added$_{t-2}$	ΔGVA_{t-1}	<0
	Gross operating surplus$_t$/Interest paid$_t$	ICR_t	<0
	Gross operating surplus$_{t-1}$/Interest paid$_{t-1}$	ICR_{t-1}	<0
Aggregate explanatory variables	Property prices$_t$/Property prices$_{t-1}$	ΔCN_t	
	Property prices$_{t-1}$/Property prices$_{t-2}$	ΔCN_{t-1}	
	$(CZK/EUR)_t/(CZK/EUR)_{t-1}$	ΔFX_t	

The LASSO (Tibshirani, 1996)[8] was used to select the optimal variables from the list and to estimate the parameters in the linear regression model. In addition to satisfying the criterion for traditional linear regression model (the ability to explain the observed data), this method penalises the sum of the absolute values of the parameters, shrinking the parameter estimates of less relevant variables to zero (equation 7).

$$min\left(\sum_{t=1}^{T}(y_t-\beta X_t)^2+\lambda\sum_{j=1}^{p}\left|\beta_j\right|\right) \qquad (7)$$

In our case, y_t is the default rate at time *t*, β is the vector of estimated parameters and X_t is the vector of explanatory variables at time *t.*

Parameter λ regulates the degree of shrinkage of the regression parameters. Its value was optimised by cross-validation minimising the root mean square cross-validation error. To make the model more meaningful and the estimates more stable, prior logical restrictions (listed in Table 2) were imposed

8 Tibshirani, R. (1996). "Regression Shrinkage and Selection via the Lasso." Journal of the Royal Statistical Society, Volume 58, pp. 267–288.

on the parameter values to ensure that they are in line with the conventional economic logic (for example, strong growth in profitability cannot lead to higher default rates).

The projections of the individual default rates are then obtained as a linear combination of the estimated parameters and the corresponding values of explanatory variables obtained from the macroeconomic simulation. To make the estimated parameters more stable and reduce noise, the default rate estimation is conducted at the sectional level (NACE level 1).[9]

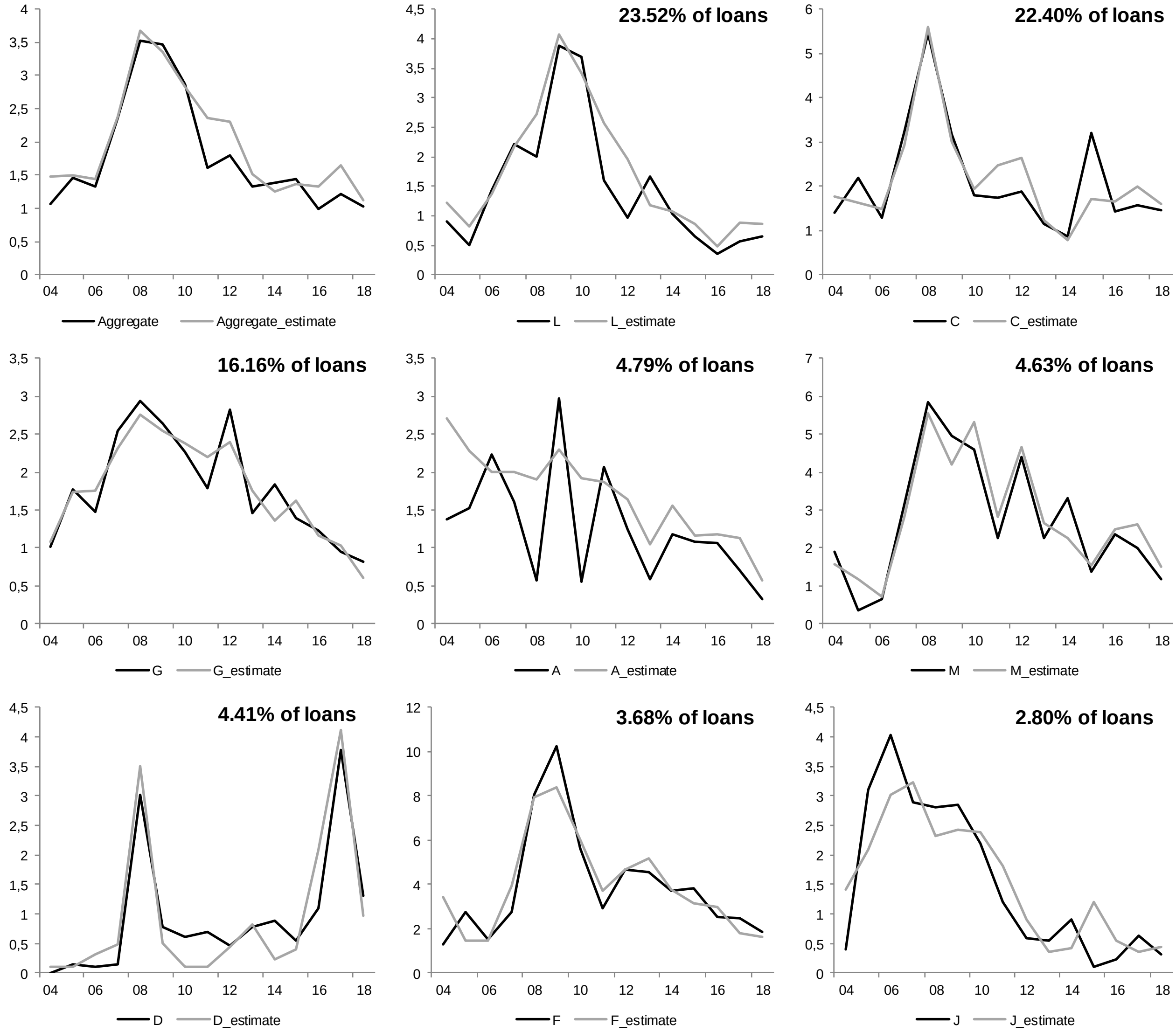
9 The values for the individual sections are obtained by summing up the values of appropriate divisions. In some cases, for example, in manufacturing industry, it would be possible to estimate the default rates at a divisional level. Nonetheless, higher aggregation was chosen with a view to striking a balance between modelling the real signals and pure noise.

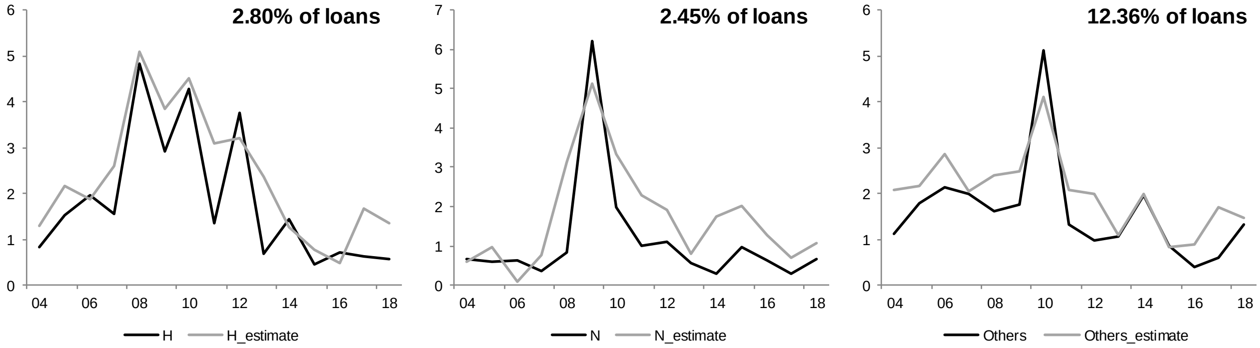
Appendix: Currently used parameters and historical estimates

Chart P.1

Historical 12-month default rate modelling

(x-axis: default rate in %; y-axis: years)





Note: A – Agriculture, forestry and fishing, C – Manufacturing, D – Electricity, gas, heat and air-conditioned air supply, F – Construction, G – Wholesale and retail trade, repair and maintenance of motor vehicles, H – Transportation and storage, J – Information and communication activities, L – Real estate activities, M – Professional, scientific and technical activities, N – Administrative and support service activities. Due to low materiality, sections B – Mining and quarrying, E – Water supply, sewerage and waste management, I – Accommodation and food service activities, K – Financial and insurance activities, O – Public administration and defence, compulsory social security, P – Education, Q – Human health and social work activities, R – Arts, entertainment and recreation and S – Other service activities were combined with unclassified loans (about 7%) as Others. Percentages in subplots present share of individual sections in NFCs' stock of performing loans as of 31 December 2019.

Table P.1
Estimates of parameters of dependent variables

Variable/NACE	A	B	C	D	E	F	G	H	I	J
Const.	0.02	0.002	0.021	0.003	0.001	0.027	0.018	0.025	0.082	0.008
DF_{t-1}	0	0	0	0	0	0.009	0	0	0	0.007
$\Delta(NOS/P)_t$	-0.001	-0.001	-0.002	-0.012	0	-0.004	0	0	0	-0.001
$\Delta(NOS/P)_{t-1}$	-0.002	-0.014	0	-0.006	0	-0.013	-0.003	0	0	-0.002
$\Delta(GOS/GVA)_t$	0	0	0	-0.011	0	0	0	0	-0.001	0
$\Delta(GOS/GVA)_{t-1}$	0	0	-0.002	-0.001	0	0	0	0	0	0
$\Delta(GOS/P)_t$	0	-0.004	0	0	0	0	-0.001	-0.005	0	0
$\Delta(GOS/P)_{t-1}$	0	-0.009	0	-0.001	0	0	0	0	0	0
$(NOS/P)_t$	0	0	0	0	0	0	-0.001	0	0	0
$(NOS/P)_{t-1}$	-0.003	-0.004	0	0	0	0	0	-0.018	0	0
$(GOS/GVA)_t$	0	0	0	0	0	0	0	0	0	0
$(GOS/GVA)_{t-1}$	-0.001	0	0	0	0	0	0	0	0	0
$(GOS/P)_t$	-0.006	0	0	0	0	0	0	0	0	0
$(GOS/P)_{t-1}$	0	0	0	0	0	0	0	0	0	0
ΔGVA_t	-0.001	0	-0.007	0	0	0	-0.001	-0.003	0	0

ΔGVA_{t-1}	0	-0.004	-0.003	0	0	-0.006	-0.002	0	-0.016	0
ΔPP_t	0	0	0	0	0	0	0	0	0	0
ΔPP_{t-1}	0	0	0	0	0	-0.004	0	0	0	0
ΔFX_t	0	-0.001	0	0	0	0	0	0	0	0
ICR_t	-0.003	-0.002	0	0.004	0	0	0.001	-0.001	0	-0.006
ICR_{t-1}	0	0.002	0.004	0	0	0.016	0.004	0.016	0.009	0
Lambda	0.000035	0.000025	0.000148	0.000043	0.006	0.001023	0.000171	0.000102	0.008249	0.000924

Variable/NACE	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**Unclass.**
Const.	0.001	0.016	0.028	0.019	0	0.038	0.017	0.037	0.037	0.007
DF_{t-1}	0	0	0	0	0	0	0	0	0	0
$\Delta(NOS/P)_t$	0	0	-0.002	0	0	0	0	0	-0.025	0
$\Delta(NOS/P)_{t-1}$	0	-0.001	0	0	0	0	-0.007	0	-0.006	-0.005
$\Delta(GOS/GVA)_t$	0	0	0	-0.011	0	0	0	0	0	0
$\Delta(GOS/GVA)_{t-1}$	0	0	-0.008	0	0	0	0	0	0	0
$\Delta(GOS/P)_t$	0	-0.004	0	0	0	0	0	0	-0.034	-0.005
$\Delta(GOS/P)_{t-1}$	0	-0.004	0	-0.005	0	0	0	0	-0.022	-0.01
$(NOS/P)_t$	0	0	0	0	0	0	0	0	0	0
$(NOS/P)_{t-1}$	0	0	0	0	0	0	0	0	0	0
$(GOS/GVA)_t$	0	0	0	0	0	0	0	0	0	0
$(GOS/GVA)_{t-1}$	0	0	0	0	0	0	0	0	0	0
$(GOS/P)_t$	0	0	0	0	0	0	0	0	0	0
$(GOS/P)_{t-1}$	0	0	0	0	0	0	0	0	0	0
ΔGVA_t	0	0	-0.009	0	0	-0.006	0	-0.005	0	-0.005
ΔGVA_{t-1}	0	0	0	-0.006	0	0	-0.001	-0.002	0	-0.002
ΔPP_t	0	-0.002	0	0	0	0	0	0	0	0
ΔPP_{t-1}	0	-0.006	0	0	0	0	0	0	0	0
ΔFX_t	0	0	0	0	0	0	0	0	0	0
ICR_t	0	0.004	-0.005	-0.006	0	0	0	-0.004	-0.006	-0.025
ICR_{t-1}	0	0.004	0	0.004	0	0	0	0.001	0.005	0.008
Lambda	0.001543	0.000066	0.000650	0.000112	0.000025	0.009704	0.000888	0.001932	0.000166	0.000042

Note: Variable abbreviations defined in Table 2; NACE abbreviations defined in note to previous chart in appendix.