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Applying the input–output price model to identify inflation processes

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Abstract

We try to examine the potential of input–output price model to identify mechanisms of price formation and transmission. Contrary to previous research that focused on overcoming the specific limitations of the model, we test its overall performance. In the presented study, the historical values of the commonly used consumer price index were decomposed according to the classic input–output price model for an open economy. A sequence of ex post simulations under various assumptions was used to identify the sources of inflation. This study required the use of input–output tables in current and previous year's prices. The proposed method of decomposition might be a starting point to create a framework for studying different aspects of inflation process.

Keywords: Inflation, Input–output price model, Cost-push price formation, Exchange rate pass-through

JEL classification: C67, E31, E37

1 Introduction

Research on price sensitivity to external impulses is of great importance for inflation forecasting. Such analyses are often commissioned or supported by central banks, which aim is to achieve and maintain price stability. For practical reasons, studies on pass-through and price formation are concentrated on two main primary impulses, basing on the cost theory. The first one comes from changes in the prices of imports (due to changes in prices expressed in foreign currency or changes in exchange rate). The second is taxes, mainly VAT (e.g., Benedek et al. 2020; Ardalan and Kessing 2019). Other investigations concern interest rate pass-through (Cook 2008) and generally the effectiveness of monetary policies (Leszczyńska-Paczesna 2020).

Among the above-mentioned research trends, the most intense work is focused on exchange rate pass-through (ERPT), which means studying how exchange rate fluctuations influence domestic prices (e.g., Aron et al. 2014; Auer and Schoenle 2016; Pennings 2017). In general, these models are based on the cost formula in a more or less direct way. Some of them combine cost and demand factors (Shakeri and Gray 2013; Beckman et al. 2019). Other macroeconomic studies investigate the role of interest rates and money supply. Most of them are based on multi-equation econometric models, such as

VAR, SVAR or VEC. These research do not exploit the potential of a tool known for many decades, which is the input–output (IO) price model.

The model originated in the seminal paper by Leontief (1937), and he was also the first to employ it (Leontief 1946). We can find various studies where the initial impulse is a change in import prices (see, e.g., Wu et al. 2013) or unit value added and taxes not included there (e.g., Lee et al. 2000; Boratyński 2006; Sharify and Sancho 2011). ERPT can also be investigated, considering the prices of imported products as the external prices expressed in foreign currency multiplied by the exchange rate (Aydoğuş et al. 2017). Research done so far are focused on particular aspects of price formation, they do not test or discuss the overall performance of the model. The presented study is intended to be a step towards filling this gap.

In this paper, we present empirical calculations that examine the efficiency of the classical IO model in reproducing price formation mechanisms and its potential to forecast inflation. The study attempted to reproduce the historical values of the consumer price index (CPI), based on the classic IO price model. We start with the price level at the base year and, by sequentially updating particular elements of the model, we obtain a sequence of theoretical CPIs, finally arriving at the actual CPI value of the next year.

Differences in such calculated CPIs at each stage of this procedure can be interpreted as components of the overall forecast error. Each such component reflects a particular economic factor that influences inflation or formal (technical) discrepancies in processing the statistical data. From numerous variants of decomposition, we are trying to find a simple, convincing one with a clear economic meaning. We put special attention to widely discussed pass-through of import prices into domestic prices, which leads us to defining the "input–output pass-through".

The use of the method proposed below requires access to input–output tables expressed in current prices as well as in prices from the previous year. The use of tables in constant and current prices was analyzed in Dietzenbacher and Temurshoev (2012). This study focused on identifying differences in the results obtained for the same variables for Denmark data set between 2000 and 2007. Such tables are published more and more often, but at present there are very few cases where they constitute appropriate time series. Statistics Denmark is a notable exception, so we decided to base our empirical example on data made publicly available by this institution.

2 Methods

Empirical research on inflation is based on three dominant theoretical positions, namely monetary, demand and cost theory. The IO price model makes very detailed investigations into cost theory possible. There are hardly any reflections on the monetary or demand theories, but this imperfection might be turned into a strength when considering why simulation results differ from reality.

IO models describe the economy in a very detailed way, and they create more opportunities to analyze price changes in individual markets. This advantage is sometimes undervalued by macroeconomists because a single branch (or product group) has a limited impact on the aggregate price level.

The price in the IO model is presented as the sum of all costs of production of a unit of a good. The model covers the whole economy, disaggregated into branches. Intermediate consumption is presented as bilateral flows between branches. In the matrix notation, the price equation can be presented in the following way:

$$\boldsymbol{p}^D = \boldsymbol{A}^{D'}\boldsymbol{p}^D + \boldsymbol{A}^{M'}\boldsymbol{p}^M + \boldsymbol{v}, \tag{1}$$

where $\boldsymbol{p}^D$—is the vector of domestic prices with elements that are output deflators, $\boldsymbol{A}^D$—is the matrix of direct intermediate consumption of domestic products per unit of output, $\boldsymbol{A}^M$—is the matrix of direct intermediate consumption of imported products per unit of output, $\boldsymbol{p}^M$—is the vector of import prices, expressed in domestic currency, $\boldsymbol{v}$—is the vector of unit value added.[1]

Changes in the exchange rate may be introduced as an adequate, identical change in all cells of vector $\boldsymbol{p}^M$. An important assumption posed on the above model is the homogeneity of prices. The prices of product group (p_i) are the same regardless of the buyer.

In the above equation, both matrices represent quantitative flows of intermediates (matrix $\boldsymbol{A}^D$ is often called a matrix of IO coefficients), therefore the production costs (i.e., the value of inputs) are obtained after multiplying these matrices by appropriate prices. For practical reasons (a lack of information on quantity), the contractual prices of products at a level of 1 are assumed, which allows us to assume that the quantities of flows are equal to their values. Under such an assumption, the matrix of the IO coefficients in monetary units can be treated like the matrix of IO coefficient in physical units (the same applies to $\boldsymbol{A}^M$). Another advantage is that the $\boldsymbol{p}^D$ and $\boldsymbol{p}^M$ vectors contain the price indices of year $t+1$ at base year t.

For calculation purposes, it is convenient to reduce the above model to the form:

$$\boldsymbol{p}^D = \left(\boldsymbol{I} - \boldsymbol{A}^{D\prime}\right)^{-1}\boldsymbol{A}^{M\prime}\boldsymbol{p}^M + \left(\boldsymbol{I} - \boldsymbol{A}^{D\prime}\right)^{-1}\boldsymbol{v}. \tag{2}$$

According to the above equation, domestic prices change under the influence of two exogenous factors: changes in import prices and changes in unit value added, while matrices are treated as parameters (price multipliers). Changes in unit value added are transmitted into prices according to transposed Leontief inverse matrix $\left(\boldsymbol{I} - \boldsymbol{A}^{D\prime}\right)^{-1}$. Similarly, the matrix $\left(\boldsymbol{I} - \boldsymbol{A}^{D\prime}\right)^{-1}\boldsymbol{A}^{M\prime}$ is decisive for the strength with which domestic prices will react on changes in import prices. Thus, the impact of import prices on the prices of domestic products depends on the import intensity of individual branches, but also on the structure of intermediate flows among them.

The $\boldsymbol{p}^D$ vector can be used to determine various macroeconomic deflators, using the appropriate set of weights. Here, in the case of the household consumption deflator (CPI*), the structure of household consumption (C) is used. The weighting formula contains three components: prices of domestic products, prices of imported products (both categories are basic prices) and change in taxes on final products p_T.[2]

$$\mathrm{CPI}^* = \left(\sum_{i=1}^{\mathrm{n}} p_i^D \cdot \frac{C_i^D}{C^D}\right) \cdot \frac{C^D}{C} + \left(\sum_{i=1}^{\mathrm{n}} p_i^{\mathrm{M}} \cdot \frac{C_i^M}{C^M}\right) \cdot \frac{C^M}{C} + p_T \cdot \frac{T}{C}, \tag{3}$$

[1] For practical reasons, it also includes taxes posed on intermediate products.

[2] As change in taxes, we understand the value of taxes in year $t+1$ divided by the value of taxes in $t+1$ expressed in previous years prices.

where $C = C^D + C^M + T$.

Subscript i means product group; lack of subscript—macroeconomic value; superscript D—domestic products; superscript M—imported products; lack of such superscript—total supply (i.e., $D+M$). T is the value of taxes imposed on households consumption.

2.1 The sequence of calculations

The experiment consisted of several ex post simulations, which varied by components of the IO price model (Formula 2) and the weighting formula 3. They reflected a series of forecasts, where the future was gradually revealed. The results of the simulations are numbered with the numbers given in the superscripts. The starting point is a "naive" forecast, where the prices are not expected to change:

$$\boldsymbol{p}_{t+1}^{D1} = \boldsymbol{p}_t^D = \left(\boldsymbol{I} - \boldsymbol{A}_t^{D\prime}\right)^{-1} \boldsymbol{A}_t^{M\prime} \boldsymbol{p}_t^M + \left(\boldsymbol{I} - \boldsymbol{A}_t^{D\prime}\right)^{-1} \boldsymbol{v}_t = \boldsymbol{i}. \tag{4}$$

Simulations no. 2 and 3 assume that parameters remain constant at the level of period t, but the exogenous variables are "revealed" and take the value of $t+1$:

$$\boldsymbol{p}_{t+1}^{D2} = \left(\boldsymbol{I} - \boldsymbol{A}_t^{D\prime}\right)^{-1} \boldsymbol{A}_t^{M\prime} \boldsymbol{p}_{t+1}^M + \left(\boldsymbol{I} - \boldsymbol{A}_t^{D\prime}\right)^{-1} \boldsymbol{v}_t, \tag{5}$$

$$\boldsymbol{p}_{t+1}^{D3} = \left(\boldsymbol{I} - \boldsymbol{A}_t^{D\prime}\right)^{-1} \boldsymbol{A}_t^{M\prime} \boldsymbol{p}_{t+1}^M + \left(\boldsymbol{I} - \boldsymbol{A}_t^{D\prime}\right)^{-1} \boldsymbol{v}_{t+1}. \tag{6}$$

The last simulation assumes that the parameters (***A*** matrices) are also revealed, so all values are taken from $t+1$:

$$\boldsymbol{p}_{t+1}^{D4} = \left(\boldsymbol{I} - \boldsymbol{A}_{t+1}^{D}{}'\right)^{-1} \boldsymbol{A}_{t+1}^{M}{}' \boldsymbol{p}_{t+1}^M + \left(\boldsymbol{I} - \boldsymbol{A}_{t+1}^{D}{}'\right)^{-1} \boldsymbol{v}_{t+1}. \tag{7}$$

Finally, let us define $\boldsymbol{p}_{t+1}^{D5}$ with elements:

$$P_{i,t+1}^{D5} = \frac{X_{i,t+1/t+1}}{X_{i,t+1/t}}, \tag{8}$$

where $X_{i,t+1/t}$ is the output in the year $t+1$ expressed in the prices of t, and $X_{i,t+1/t+1}$ is the same output in current prices. Assuming the homogeneity of prices, $\boldsymbol{p}_{t+1}^{D4}$ should be equal $\boldsymbol{p}_{t+1}^{D5}$. In the study presented below this assumption does not hold.

All the above price vectors, numbered from 1 to 5, were multiplied by the same set of weights, to get the households consumption deflators, according to Formula (3). In the sequence of calculations that reconstruct the actual CPI, the weights in Formula (3) must be changed from year t to $t+1$. We have used two variants. In the case of the Laspeyres sequence (CPI_L^{*k}), the weights from year t are kept, and the switch to Paasche formula is done in the last element of the sequence. In the case of the Paasche sequence (CPI_P^{*k}), the weights from $t+1$ (quantities of $t+1$ expressed in prices of year t) are applied from the beginning. The starting point of the sequence should be $\mathrm{CPI}^{*0} = 1$, which means that the prices are kept at the level of t:

$$\mathrm{CPI}^{*0} = \left(\sum_{i=1}^{\mathrm{n}} p_i^{D1} \cdot \frac{C_{i,t}^D}{C_t^D}\right) \cdot \frac{C_t^D}{C_t} + \left(\sum_{i=1}^{\mathrm{n}} p_i^{M1} \cdot \frac{C_{i,t}^M}{C_t^M}\right) \cdot \frac{C_t^M}{C_t} + 1 \cdot \frac{T_t}{C_t}. \tag{9}$$

Next steps of the sequence may be written as follows:

$$\mathrm{CPI}_L^{*k} = \left(\sum_{i=1}^{\mathrm{n}} p_i^{Dk} \cdot \frac{C_{i,t}^D}{C_t^D}\right) \cdot \frac{C_t^D}{C_t} + \left(\sum_{i=1}^{n} p_i^{Mk} \cdot \frac{C_{i,t}^M}{C_t^M}\right) \cdot \frac{C_t^M}{C_t} + p_T \cdot \frac{T_t}{C_t}, \quad k = 1, \ldots 5, \tag{10}$$

$$\mathrm{CPI}_P^{*k} = \left(\sum_{i=1}^{n} p_i^{Dk} \cdot \frac{C_{i,t+1}^D}{C_{t+1}^D}\right) \cdot \frac{C_{t+1}^D}{C_{t+1}} + \left(\sum_{i=1}^{n} p_i^{Mk} \cdot \frac{C_{i,t+1}^M}{C_{t+1}^M}\right) \cdot \frac{C_{t+1}^M}{C_{t+1}} + p_T \cdot \frac{T_{t+1}}{C_{t+1}} \quad k = 1, \ldots, 5. \tag{11}$$

Let us also define:

$$\mathrm{CPI}^{*6} = \frac{C_{t+1/t+1}}{C_{t+1/t}}, \tag{12}$$

where the numerator is the nominal consumption in period $t+1$, and the denominator is the consumption in period $t+1$ expressed in prices of period t. CPI^{*6} is thus the household consumption deflator derived from the IO tables, and it may be referred to as the "input–output CPI". In this sequence of deflators, the actual value of the CPI should be denoted as CPI^{*7}.The most important deviations of National Accounts prices (CPI^{*6}) from the CPI come from the different ways of treating public services, insurance, and illegal activities. In case of public services, the CPI basket covers what citizens pay, while the National Accounts measure what the citizens consume. Illegal activities are included in the National Accounts, but not in CPI.

The differences between the consecutive deflators were then calculated as:

$$E^k = \mathrm{CPI}^{*k} - \mathrm{CPI}^{*k-1}, \quad k = 1, \ldots, 7 \tag{13}$$

Thus:

$$\mathrm{CPI}^{*7} - \mathrm{CPI}^{*0} = \sum_{k=1}^{7} E^k. \tag{14}$$

The decomposition is additive and complete. The last difference (14) might be interpreted form two points of view:

1. It is the ex post error of a naive forecast.
2. As $\mathrm{CPI}^{*0} = 1$, it is the actual inflation (CPI-1).

Thus, the procedure described above decomposes inflation (or error) into seven components (types of errors), which are:

E1: Changes in taxes imposed on consumer goods and the balance of consumption by non-residents and consumption by domestic residents abroad. In the Paasche sequence it includes also changes in the structure of consumption.

E2: Changes in (homogenous) import prices.

E3: Changes in unit value added (other taxes, wages and gross operating surplus).

E4: Changes in the parameters of the model ($\boldsymbol{A}$ matrices).

E5: The assumption of the homogeneity of domestic prices (the prices of the output are the same for all buyers).

E6: The assumption of the homogeneity of prices (the prices of consumer goods are the same as prices of output)[3] and, in the Laspeyres sequence, also the changes in structure of consumption.

E7: Difference between the CPI and the household consumption deflator derived from the IO table.

The last component has no economic meaning, but is relevant for practical problems of economic modeling. When running the IO-based models, like the INFORUM or CGE type, this component bridges the gap between the CPI derived from the IO price system and the official CPI data used in other equations.

This sequence of components is not the only possibility for decomposition. It was chosen because of its economic meaning. In a small open economy, the prices of imports seem to be the "most exogenous" factor, which is why this component goes before value added and parameters, which adjust (to some extent) to changes in external prices.

3 Results and discussion

The simulations required tables of flows of domestic products and (separate) tables of flows of imported products, both expressed in current and previous year's prices. The widest available statistical material that enables such a study can be found at Statistics Denmark, where input–output-based price measures have a long tradition (e.g., Hansen and Knudsen 2005; Abildgren 2006). The sets of IO tables cover the period 1966–2019.[4] The CPI, however, was first published in 1980, which is why our study was limited to the period 1980–2019. The tables used in the study represent the aggregation at the level of 69 product groups. The category "Tourism", which is the balance of consumption by non-residents in Denmark and consumption by Danish residents in the rest of the world, was included in taxes on household consumption (variables T and p_T).

The results are presented in Fig. 1. Actual CPI increments are compared with the contributions of each component. Components E5 and E6 were added together and placed in one graph. Their values were substantially lower than other components, another reason for putting them together was interpreting them. Both components reflect the changes in the intra-industry structures of prices.

[3] The source of error is the intra-industry specificity of household spending. For example, in the case of agricultural products, household purchases include apples and bananas, but do not include rapeseed or flax, which are mainly intermediate products. If the prices of apples and bananas go in different direction than the prices of rapeseed and flax, the consumers price index for agricultural products will be different than the producers' price index. The deflator of output will only show the average change.

[4] https://www.dst.dk/en/Statistik/emner/oekonomi/nationalregnskab/input–output [access 2021-11-23].

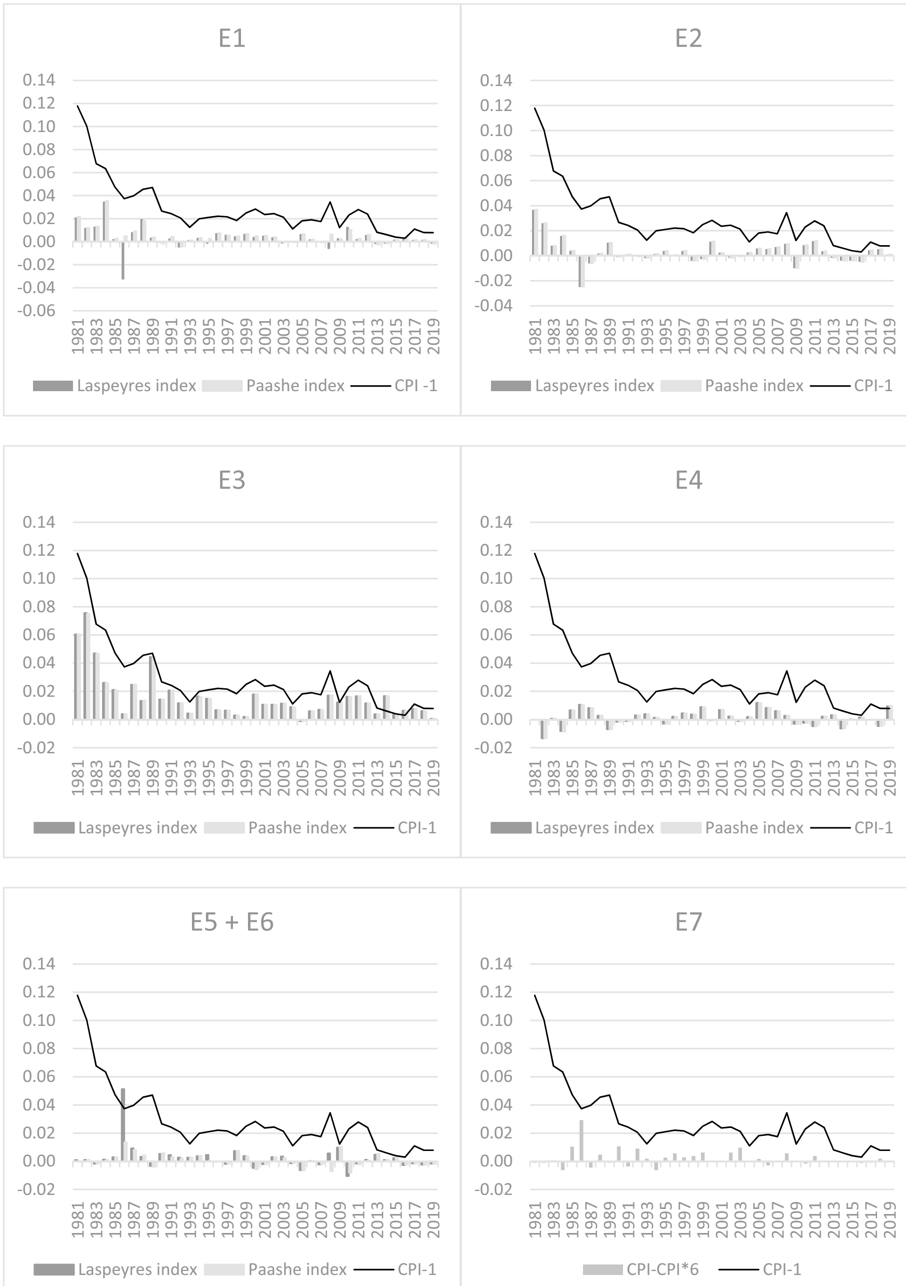

Fig. 1 Danish CPI and its components. The sum of *E*1…*E*7 equals to CPI-1. Source: own calculations based on Statistics Denmark data

There is no significant difference between results obtained with Laspeyres approaches. That means that the structure of household consumption does not change much from year to year. In the case of E1, three observations can be identified in which the differences are noticeable, namely for the years 1986, 1995 and 2008. Their source lays in the exceptional fluctuations in the "Tourism" item. These differences are compensated in E6, where the structure of consumption is switched in the Laspeyres sequence to $t+1$.

The first three components change in accordance with inflation, while the other four seem to be stable over time, regardless of the CPI. Undoubtedly, the main driving force for inflation is the unit value added (E3). The second important component is import prices (E2), but its contribution is much lower. These results confirm the price formation process reflected by the IO model. Taxes (E1) are correlated with inflation and the role of this component is ambiguous; changes in tax rates are a cause of inflation, but inflation itself rises tax revenues. The "Tourism" item obscures the image.

The linear correlation coefficients between individual components are shown in Table 1.The high correlation between E2 and E3 suggests that changes in the prices of imports force the adjustment mechanisms that influence value added. The correlation is positive, which means, that value added amplifies the primary impulse coming from abroad. One might suspect that other adjustments relate to change in the model parameters, i.e., the $\boldsymbol{A}^D$ and $\boldsymbol{A}^M$ matrices (E4), in this case the correlation with E2 is negative. Domestic firms keep their real incomes (and wages) constant and try to reduce the price shock by changing the production technology, which means substitution between intermediate products.

The small values of E5 and E6 mean that the assumption of the homogeneity of prices does not seem to be a significant source of errors when projecting the CPI. This is an argument that encourages the use of the IO model. The last component (E7) also has a "technical" character. A strong negative correlation between E2 and E6 may suggest the existence of a substitution effect, i.e., that the structure of consumption depends on import prices.

Trying to relate our results to the mainstream, mainly econometric studies on the pass-through of import prices to domestic CPI, we should stress that the method presented above shows this phenomenon from a different angle.

Explaining the pass-through of import prices into CPI should start from comparing the actual CPI with CPI^{*2}, which shows the hypothetical reaction of domestic prices to external price shocks according to the model, ceteris paribus. The difference between these two time series, shown in Fig. 2, especially the Laspeyres version, might be considered to be a result of all other phenomena. Unfortunately, we cannot distinguish those that are triggered by the changes in import prices from autonomous changes that result from monetary or fiscal policy, an unstable labor market (wages), or changes in consumer preferences, among others. For example, changes in the consumption structure of households may be a reaction to changes in prices or a result of marketing campaigns. Similarly, policies implemented by central banks are influenced by various economic factors, including movements in import prices and exchange rates.

Thus, applying the presented decomposition method for research on the pass-through of import prices into CPI might be based on distinguishing three components of inflation:

1. Input–output theoretical pass-through of import prices into CPI, namely CPI^{*2},
2. other effects being the reaction for changes in import prices,
3. other exogenous economic factors.

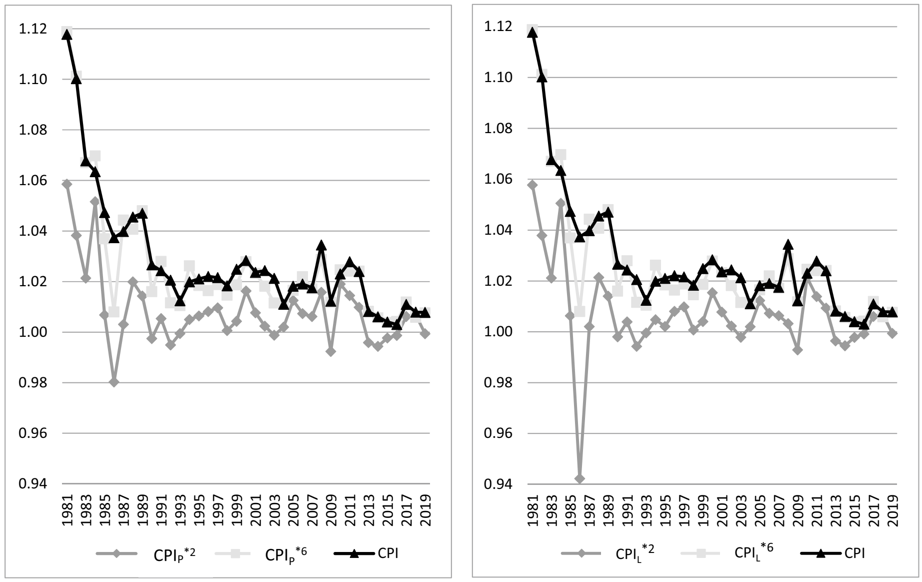

Fig. 2 Input–output pass-through of import prices into CPI (CPI^{*2}) versus input–output CPI (CPI^{*6}) and actual CPI (*based on Paasche [left] and Laspeyres [right] formula*). Source: own calculations based on Statistics Denmark data

Additionally, a correction resulting from the difference in definitions between the IO deflator (CPI^{*6}) and the actual CPI should be considered (Table 1).

As can be seen from Fig. 2, the differences between the CPI and CPI^{*2} are always positive, which means that increasing costs of imported products is not the only justification for CPI growth. These differences might be a starting point for identifying factors 2 and 3 from the above list. Concentrating on differences between CPI^{*2} and CPI^{*6} eliminates the discrepancy in definitions between the IO CPI and actual CPI.

4 Conclusions

This paper empirically examined the potential of standard input–output model to forecast and simulate inflation, pointing out particular sources of errors. Each error has an economic meaning, and it reflects some factors of the price formation mechanism, although the correspondence is not always clear as the factors are interdependent.

The authors consider this study to be a contribution to the discussion on inflation, its sources, and means of transmission—a discussion that should lead to improvements in current forecasting methods. The frequency of data we have used seems to be a significant limitation for practical implementation of the decomposition method. We believe, however, that the price formation model could be modified for producing forecasts of shorter horizon, for example by including the seasonality effects.

The price formation mechanism is a very complex phenomenon, and most studies concentrate on particular aspects. Our study suggests that the IO price model might be used as a framework to integrate research on these aspects. Although the model shows only the pure cost push side of inflation, other factors might be analyzed by explaining the components of the proposed decomposition. Studies that investigate the role

Table 1. Linear correlation between the components

Laspeyres / Paasche	E1	E2	E3	E4	E5	E6	E7
CPI - 1	0.47** / 0.70**	0.69** / 0.69**	0.88** / 0.88**	-0.30 / -0.31	0.17 / 0.17	0.03 / -0.05	-0.02 / -0.02
E1		0.64** / 0.5**	0.42** / 0.49**	-0.35* / -0.24	-0.09 / -0.08	-0.59** / -0.04**	-0.65** / -0.24**
E2			0.7** / 0.7**	-0.45** / -0.45**	0.09 / 0.09	-0.59** / -0.6**	-0.48** / -0.47**
E3				-0.58** / -0.58**	0.15 / 0.15	-0.14 / -0.15	-0.24 / -0.24
E4					-0.08 / -0.08	0.27 / 0.17	0.31 / 0.31
E5						-0.06 / -0.19	0.18 / 0.18
E6							0.68** / 0.33*

Source: own calculations based on Statistics Denmark data

* and ** denote coefficients significantly different from 0 at the significance level of 5% and 1%, respectively

of macroeconomic variables, such as interest rate, exchange rate, or monetary supply, which are usually based on econometric models, such as VAR, SVAR, or VEC, could also be put into this framework.

The study was limited to the example of Denmark, which resulted from the availability of statistical material. Thanks to a unified methodology for creating IO tables, the described procedure can be applied universally. Necessary time series of IO tables expressed in previous year's prices will certainly become widely available, and the level of detail will almost certainly increase.

It seems, therefore, that the presented analysis is a good starting point for undertaking further activities in this area. In the light of the results, the most interesting directions seem to be considering more components, e.g., elements of value added, separating matrices of parameters, the exchange rate, and investigating the interdependencies between them. Obtaining more empirical material in the form of time series should allow more sophisticated statistical and econometric methods to be used instead of simple correlation coefficients.

Abbreviations
CGE: Computable General Equilibrium; CPI: Consumer price index; I–O: Input–output; ERPT: Exchange rate pass-through; SVAR: Structural vector autoregressive; VAR: Vector autoregression; VEC: Vector error correction.

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Author contributions
MP, AG contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors read and approved the final manuscript.

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Declarations

Competing interests

The authors declare that they have no competing interests.

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