Supply Constraints in a Heterogenous Agents Household Demand Model:

A Method for Assessing the Direct Impact of the COVID Lockdown

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Abstract: The COVID pandemic has led to worldwide short-term lockdowns that mostly affected services with personal contact (accommodation, hotels & restaurants, entertainment & culture, retail trade). In economic terms, the lockdown represents a supply shock that simultaneously leads to a demand restriction. The direct effect of the supply constraint is a change in both the structure and the level of consumption. The magnitude of both effects depends on the expected rebound of total consumption, when the lockdown is over. In a model with heterogenous agents that exhibit different consumption structures and different marginal propensities of consumption, it is reasonable to assume also different consumption rebounds after the lockdown across household income groups. The supply constraint acts at the level of single goods and therefore at different nests of most applied consumer demand models. This paper presents a method of consistent implementation of supply constraints via exogenous variables in a nested demand system, taking into account the links between the nests and consumption rebounds. The method also serves for calculating the direct consumption impact across household income groups which shows a significant degree of heterogeneity across household groups.

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Introduction

The macroeconomic literature of the last decades has emphasized the importance of dealing with heterogenous agents (for one of many recent examples, see: Ravn and Sterk, 2020). Pure macroeconomic models have – for example - introduced different household types in terms of their reaction in consumption to transitory income shocks. That led to the distinction between 'Keynesian' and 'Permanent Income' households as in Auerbach and Gorodnichenko (2012) as well as to the distinction between savers and borrowers as in Eggertson and Krugman (2012). These distinctions introduce heterogeneity in consumption propensities with respect to income and net assets and explain differences in fiscal multipliers. In disaggregated models with input-output cores (CGE or macroeconomic), household heterogeneity implies that different income-to-consumption reactions plus socio-demographic characteristics like age can have an impact on economic structure and on aggregate economic outcomes (Kim et al., 2015).

In this paper, a methodology for implementing the direct impact of the COVID lockdown into a complex nested model of private consumption with household heterogeneity, typically used in disaggregated models like CGE (Landis and Heindl, 2016) or macroeconomic input-output (Kim et al., 2015), is laid down. The changes in the level and structure of consumption will then further lead to general equilibrium feedbacks in the full model. These feedbacks are not the focus of this paper. Instead, only the direct effects of supply constraints like the COVID lockdown are presented. These results are derived in a way that is consistent with the properties of the consumption model and therefore can be seen as the exogenous input for simulating a 'COVID lockdown scenario' with any macroeconomic model and at the same time represent the direct effects of the lockdown.

The methodology presented is encompassing for nested models of consumption with three nests. The structure of these models usually describes a first nest that divides two main aggregates of consumption, the second splits up both parts into main categories applying demand systems and the third nest splits up the main categories applying simple allocation mechanisms. The degree of disaggregation of the second nest is usually limited due to limited operability of advanced demand systems with too many categories and due to the lack of viability of econometric estimation of parameters for too many categories. Therefore, in order to split up consumption to the individual good and service level, a third nest is needed. This third nest can be simply described by fixed volume shares of goods or by Cobb Douglas preferences, implying fixed expenditure shares of goods.

An additional dimension introduced is the number of different household groups, in the case of this paper, income groups. Heterogeneity in consumption across these groups can be based simply on different consumption patterns and on average propensities of consumption with respect to income or on different behavioral reactions of consumption with respect to prices or income. The model presented here covers both dimensions of heterogeneity. As far as the second dimension is concerned, the model exhibits different marginal propensities of consumption as well as different price and expenditure elasticities at the second nest across deciles of household income. Both are based on panel data regressions across EU countries (Kratena, et al., 2017).

For the exercise of introducing supply constraints in the model, one must additionally assume if and to what extent the short-term reduction in consumption will be compensated during the rest of the year in order to partially rebalance the transitory increase in the savings rate, leading to a rebound of consumption. According to the hypothesis that – besides liquidity constraints - uncertainty represents an import savings motive, it is reasonable to assume that low income groups facing higher risks of unemployment will exhibit a lower consumption rebound than high income groups. This assumption, in turn, leads to a change in the marginal propensities of consumption across household income groups. The percentage change in total consumption driven by these changes (including the consumption rebound) is about -8% for the lowest three deciles (lowest 30% of the income distribution) and slightly less than -2% for the highest 30% of the income distribution. For the middle income-groups the decrease in consumption is about 5%.

The supply constraint can either be effective at the level of categories of the second nest or at the individual goods and services level of the third nest, depending simultaneously on the nature of the shock and on the aggregation structure of the model. It is straightforward that supply constraints at the second nest change the consumption structure in terms of budget shares at this nest. Another result of the methodology presented is that supply constraints at the third nest also exert a feedback on the consumption structure at the second nest. Accounting for all these factors of influence, important substitution effects in terms of budget share changes can be observed at the second nest with simultaneously rising (food/beverages, durables, appliances, health and falling (clothing, other services) shares.

The combination of different consumption rebounds and different substitution effects leads to heterogeneity of consumption reactions across household income groups. That applies to different reductions of demand for categories and goods directly affected by the supply constraints across households as well as to demand categories that are positively affected by substitution effects. Substitution is purely driven by expenditure elasticities and prices do not change with supply constraints in the partial equilibrium framework presented in this paper.

1. Private consumption of heterogenous households

The model comprises different dimensions of disaggregation. In general, consumption is split up into categories and goods on the one hand and into consumption of different household income groups on the other hand. At the top level, total consumption of household group *h* (CP^h) can be split up into a group of specific demand categories $CP^h{}_O$ that are for the specific purpose of the model or due to their specific nature, separated from the bundle of other goods, $CP^h{}_D$. In many models, $CP^h{}_O$ is made up of certain durable categories (housing) or energy, for example. The aggregate $CP^h{}_D$ is then split up further within two nests of a demand system. The bundle of $CP^h{}_O$ is split up via several single equations.

$$CP^h = CP_O^h + CP_D^h \qquad (1)$$

The additivity of both bundles implies full separability with unitary substitution elasticity. For $m \in$ O, consumption of *m* is described as a function of total consumption, of the price for good *m* and of a vector of socio-demographic variables plus supply constraints (δ_m).

$$cp_m^h = cp_m^h[p_m, CP^h, \delta_m^h] \qquad (2)$$

One could equally think of supply constraints represented by a change in the shadow price, $p_{S,m}$, which could be treated as an additional price component, not entering in the definition of the aggregate price PC_m^h of aggregate expenditure C_O^h.

$$cp_m^h = cp_m^h\left[p_m, p_{S,m}, CP^h, \mu_m^h\right] \qquad (2a)$$

$$logPC_m^h = \sum_m w_m^h logp_m \quad ; \qquad C_O^h = \sum_m p_m cp_m^h \qquad (3)$$

The consumption CP_O^h is then simply given as (C_O^h/PC_m^h). Note that due to different consumption structures across household groups, h, the aggregate price index PC_m^h is household group-specific, though the market prices that households face are identical for all groups. When supply constraints are dealt with via an increase in the shadow price, the vector $\mu^h{}_m$ only contains socio-demographic variables.

In (3) w_m^h are the budget shares of those goods covered in the bundle CP_O^h. Defining the supply constraint as a percentage change $r_m < 0$ in consumption of m, the shadow price is given by:

$$p_{S,m} = \begin{cases} 1 \; for\ no\ supply\ constraint \\ \left(1 + \frac{r_m}{\varepsilon_m}\right) \; for\ supply\ constraint\ on\ m \end{cases} \tag{4}$$

where ε_m is the price elasticity of demand for m (assumed to be identical across household groups h). The total consumption impact of supply constraints affecting goods in the bundle CP_O^h is given with $\sum_m r_m\, cp_m^h$. This is the calculated annual impact that the temporary supply constraint, which is only active during the lockdown, would *ceteris paribus* have on consumption. This is only part of the full impact, as consumption rebounds after the lockdown and part of the consumption losses are regained. Due to this recovery of part of the enforced consumption reduction, only one part ($1 - \rho^h$) of the consumption loss affects total consumption ($0 < \rho^h < 1$). The parameter ρ^h is the rebound share and is household group-specific.

In general, the methodology presented here is suitable for identifying different sources of the consumption rebound of supply constraints. First, a consumption rebound taking place at the same nest as the corresponding supply constraint can be identified. If this consumption rebound were zero, the consumption losses would fully pass through to total consumption of the same nest. This rebound therefore reduces a potential negative impact. As the nested structure of the model links the different nests, a consumption rebound affecting the upper nest of where the supply constraint is effective, is also identified. This upstream consumption rebound works through aggregation of rebounds at the lower level, affecting the bundle at the next level nest. In the model presented here, goods demand in bundle CP_O is described via single equations and not by an additive demand system. Therefore, no substitution effects within the categories m take place, but the consumption rebound directly only affects total consumption, CP^h (expenditure effect), i.e. only the upstream rebound is effective:

$$\overline{cp}_m^h = (1 + r_m) cp_m^h; \tag{5}$$

$$\overline{CP}^h = \sum_m p_m \overline{cp}_m^h - exp(\sum_m w_m^h log p_m) - \rho^h \sum_m r_m\, cp_m^h + CP_D^{h*} \tag{6}$$

In (5), $\overline{cp}_m^h$ is the level of each of the constrained consumption categories and $\rho^h \sum_m r_m\, cp_m^h$ is the sum of the constrained consumption in bundle O (with $r_m < 0$). For $\rho^h = 1$, the temporary consumption losses are completely compensated by higher total consumption. In (6) all impacts of constraints with rebound on total consumption are taken into account. That refers not only to the rebound of temporary consumption losses in the bundle O, but also to the losses in bundle D and at the third nest (s. below). Therefore, CP_D^{h*} represents the constrained demand for bundle D after taking into account the consumption rebound at level two and three.

In the unconstrained model, total consumption by household group CP^h is given by two different functions, depending on the income group. The upper groups of the household income distribution are optimizers according to the PIH (Permanent Income Hypothesis) and their consumption follows the Euler equation derived from the solution of the dynamic optimization problem:

$$\frac{1}{CP_t^h} = \beta E_t \frac{1+i_t}{CP_{t+1}^h} \tag{7}$$

with β as the discount factor, defined as one plus the discount rate and i_t as the interest rate on risk-free assets and E_t as the expectation in year *t*. This specification implies that total consumption growth of these household groups is linked to expected permanent income growth and no marginal propensity of consumption with respect to current disposable income exists. All other household income groups are Keynesian consumers with different marginal propensities of consumption with respect to disposable income and the actual change in household debt. Consumption of these households is simply described by a log-linear function with real disposable income (YD^h/PC^h) and the change in household debt (ΔD^h):

$$logCP^h = c_0^h + mpc\ log\left(\frac{YD^h}{PC^h} + \Delta D^h\right) \tag{8}$$

This is a general static short-run formulation of a consumption function, which could be extended towards different dynamic specifications. The *mpc* in (8) measures the short-run impact on consumption, which is consistent with the objective of quantifying the consequences of a transitory lockdown in one period (year).

In the constrained model, total consumption by household group is given by equation (6), so that the *mpc* becomes endogenous:

$$\overline{mpc} = \frac{log\overline{CP}^h - c_0^h}{log\left(\frac{YD^h}{PC^h} + \Delta D^h\right)} \tag{9}$$

The full impact on $\overline{CP}^h$ and in turn on *mpc* can only be calculated, once the supply constraints and their impact - including all consumption rebounds - on $\overline{CP}_D^h$ have been considered.

1.1. The second nest: A demand system

The bundle $CP^h{}_D$ is further split up into several demand categories *k*, which in turn are aggregates of the lowest level of goods, *i*. A widely used demand system is the Almost Ideal Demand System (AIDS), which is based on an expenditure function and an indirect utility function. The AIDS model of the constrained model is defined in terms of budget shares, that are derived via Shephard's Lemma from the expenditure function:

$$\overline{w}_k^h = \alpha_k^h + \sum_j \gamma_{kj} logp_j^h + \beta_k log\left(CP_D^h\right) + \xi_k \tag{10}$$

The nominal budget shares of each household group with supply constraints $\overline{w}_k^h$ are functions of prices, total expenditure and a supply constraint, ξ_k. The supply constraint is usually given as above, namely as a percentage change in consumption of *k*, $r_k < 0$, so that $\overline{cp}_k^h = (1 + r_k)cp_k^h$. This can be directly converted into a change in the budget share:

$$\bar{\xi}_k = \frac{r_k cp_k^h}{CP_D^h} \frac{p_i}{PC_D^h} \quad (11)$$

In (11) $\bar{\xi}_k$ is the exogenously fixed supply constraint at the level of nest 2 (categories *k*). The first term describes the impact of the supply constraint on the volume share of consumption and the second term converts that into the budget share impact by multiplying with the relative price (with PC_D^h as the household group-specific price of bundle *D*). Note that the categories *k* are different aggregates of the single goods for each household group, so that their prices p_k are household group-specific. Introducing the supply constraint $\bar{\xi}_k$ at this nest, implies that no supply constraint at the lower level of the *i* goods of which this category *k* is composed, is introduced simultaneously. In the case of a category *k* that consists only of a few goods which are just different specifications of *k* (e.g. wearing apperal and leather/shoes as goods of the category 'clothing'), it is more likely that the supply constraint will be introduced at the level of *k* than of *i*. In the case of broad categories at the level of *k* (e.g. 'services'), the introduction of supply constraints at goods level *i* becomes more likely. Therefore, supply constraints may be effective at both nests, but the introduction at nest two or nest three is exclusive and depends on how the actual supply constraints match with the aggregation structure of the model.

In (10), CP_D^h is the real consumption of the aggregate *D*, which is equal to deflated expenditure. The Translog price index for PC_D^h that is derived from the AIDS expenditure function has been approached by the Stone price index that is identical with the Divisia price index of equation (3).

$$logPC_D^h = \sum_i w_k^h logp_k \quad ; \quad CP_D^h = \frac{\sum_k p_k cp_k^h}{PC_D^h} \quad (12)$$

where w_k^h are the budget share without supply constraints. For the implementation of the direct impact of supply constraints, the Divisia price index is calculated with the unconstrained nominal budget shares. In the full-fledged CGE or macroeconomic input-output model, the change in the aggregate price due to budget share changes is taken into account.

The price and expenditure elasticities are not relevant for the exercise presented here, as the supply constraints directly do not lead to price and expenditure changes. This is only the case in the full-fledged model. In principle, the supply constraint could also have been implemented via a change in a shadow price that is equal to unity when supply constraints are absent. Once the supply constraint has been implemented into (10) for those categories *k* where it applies to, the other budget shares *j* need to be adjusted proportionally:

$$\bar{w}_j^h = \left(\frac{w_j^h}{1 - \sum_i w_k^h}\right)\left(1 - \sum_i \bar{w}_k^h\right) \quad (13)$$

Equations (10) and (13) describe the substitution effects within the bundle *D* triggered by supply constraints. Due to additivity, all consumption losses in categories *k* are fully compensated by consumption increases in categories *j*, if total consumption of the bundle *D* does not change. Taking into account that the consumption losses also change total consumption of the bundle *D*, the level of constrained consumption of category *k* is given by the definition:

$$\overline{cp}_k^h = \bar{w}_k^h \overline{CP}_D^h \left(\frac{PC_D}{p_i}\right) \quad (14)$$

The constrained demand for bundle D ($\overline{CP}_D^h$) is the sum of the deflated expenditures as defined in (12) plus the consumption loss at the level of the second nest of the model that is not compensated by a consumption rebound. The second term in (15) takes into account consumption rebounds at the same level of total demand for bundle D. The parameter ρ^h is household group-specific and therefore the same as in the last section and (1 - ρ^h) is the share of consumption losses that passes through on the level of total consumption of the bundle D.

$$\overline{CP}_D^h = CP_D^h + (1 - \rho^h) \sum_k r_k \, cp_k^h \tag{15}$$

The equations (10), (13), (14) and (15) suffice to derive all direct changes triggered by the supply constraints at this level in a way that is fully consistent with the properties of the demand system. The budget shares derived from equations (10) and (13) can be combined with the constrained total consumption level of bundle D from equation (15) in order to calculate levels of single consumption categories according to (14). This would yield the direct impact of the supply constraints on the consumption levels of categories. Note that this is not the final solution of the model, as $\overline{CP}_D^h$ exerts a feedback on the budget shares. The single variables need to be inserted into a full-fledged model in order to derive a new consistent equilibrium.

1.2. The third nest: Fixed shares of consumption goods

The third level of aggregation corresponds to the level of single goods, i. The splitting up is simply given by fixed volume shares, $s_{i,k}^h$. Alternatively, one could assume Cobb-Douglas preferences at this nest, implying fixed nominal shares. For the case of the exercise shown here, this would not change outcomes, as prices do not change directly with the implementation of supply constraints. Actually, in an approach with Cobb-Douglas preferences the supply constraint could be introduced via a shadow price, in analogy to equation (4). The level of consumption of good i when a supply constraint is active at the third nest is given by:

$$\overline{cp}_i^h = \bar{s}_{i,k}^h cp_k^h \tag{16}$$

where cp_k^h is the unconstrained demand for category k. As the introduction of supply constraints at nest two or three is exclusive, the demand at nest two is unconstrained in the case of a supply constraint at the goods level i. The supply constraint at the third nest can be again defined via a rate of change ($r_i < 0$):

$$\overline{cp}_i^h = (1 + r_i) cp_i^h \tag{17}$$

The third nest is modeled via a demand system so that substitution effects between the shares are induced by the implementation of the supply constraints. The shares for which a supply constraint is binding, are defined as:

$$\bar{s}_{i,k}^h = \frac{\overline{cp}_i^h}{cp_k^{h*}} \tag{18}$$

The definition of $\bar{s}_{i,k}^h$ includes the potential consumption rebound at the upper level nest from changes at the third nest. The consumption level cp_k^{h*} contains the consumption loss not compensated by the rebound at the third nest and is given by:

$$cp_k^{h*} = cp_k^h + (1 - \rho^h) \sum_i r_i \, cp_i^h \qquad \text{for } i \in k \tag{19}$$

Equation (19) is analogous to (15), but represents a feedback from the third nest towards consumption at the second nest (categories *k*). Inserting (19) into (18), yields for the shares with supply constraint:

$$\bar{s}_{i,k}^{h} = \frac{\overline{cp}_i^h}{cp_k^h + (1-\rho^h)\sum_i r_i cp_i^h} \tag{20}$$

Therefore, the introduction of supply constraints at the different nests follows a sequence. The starting point is the calculation of $\overline{CP}_D^h$ according to equation (15). Note that this is only necessary, if supply constraints are actually active at the second nest (bundle *D*). The next step consists of adding the rebound of equation (19) to $\overline{CP}_D^h$:

$$CP_D^{h*} = \overline{CP}_D^h + (1-\rho^h)\sum_i r_i\, cp_i^h \tag{21}$$

The new level of total consumption of bundle D (CP_D^{h*}) then finally feeds back into equation (6) and determines the new level of total consumption $\overline{CP}^h$ and, in turn, the adjustment in the *marginal propensity of consumption*, according to (9). Once this has been implemented, the other budget shares $s_{j,k}^h$ need to be adjusted proportionally:

$$\bar{s}_{j,k}^{h} = \left(\frac{s_{j,k}^h}{1-\sum_i s_{i,k}^h}\right)\left(1-\sum_i \bar{s}_{i,k}^h\right) \tag{22}$$

Equation (22) defines the substitution effects triggered by the supply constraints at the third nest.

An impact from consumption losses at the third nest ($(1-\rho^h)\sum_i r_i\, cp_i^h$) to the budget shares can be identified. In that case, the residual in equation will be defined differently, i.e. by:

$$\xi_k = \frac{cp_k^h + (1-\rho^h)\sum_i r_i cp_i^h}{\overline{CP}_D^h + (1-\rho^h)\sum_i r_i cp_i^h} - \frac{cp_k^h}{CP_D^h} = \frac{cp_k^{h*}}{CP_D^{h*}} - \frac{cp_k^h}{CP_D^h} \tag{23}$$

Therefore, the residual ξ_k for any *k* is either simply given exogenously by the supply constraints directly acting at the level of *k* categories or by the feedbacks on consumption of *k* driven by supply constraints at the level of goods *i*:

$$\xi_k = \begin{cases} \bar{\xi}_k \; for\ no\ supply\ constraint\ at\ level\ i \\ \frac{cp_k^{h*}}{CP_D^{h*}} - \frac{cp_k^h}{CP_D^h}\; for\ supply\ constraint\ at\ level\ i \end{cases} \quad \text{for } i \in k \tag{24}$$

2. Empirical results of the full consumption model

The model laid down above follows a partial equilibrium perspective and offers two options of application. The first is the derivation and calculation of the direct impact on the level of consumption by good, by category, and on total consumption. The second is converting these changes into changes in those exogenous variables that can be introduced into the model in a consistent way without directly disturbing those mechanisms that determine consumption by good, by category, and total consumption.

At the upper level, for calculating consumption impacts the following equations are needed:

$$\overline{cp}_m^h = (1 + r_m) cp_m^h;$$

$$\overline{CP}^h = \overline{CP}_m^h - \rho^h \sum_m r_m \, cp_m^h + CP_D^{h*}$$

Here, the term for total consumption of the m categories at the first nest $\sum_m p_m \overline{cp}_m^h - exp(\sum_m w_m^h log p_m)$ has been substituted by $\overline{CP}_m^h$.

At the second nest (bundle D), the full model comprises the equations for budget shares and for the calculation of the pass through of consumption losses to total consumption of bundle D:

$$\overline{w}_k^h = \alpha_k^h + \sum_j \gamma_{kj} log p_j^h + \beta_k log\left(CP_D^h\right) + \xi_k$$

$$\xi_k = \begin{cases} \bar{\xi}_k \; for \; no \; supply \; constraint \; at \; level \; i \\ \frac{cp_k^{h*}}{CP_D^{h*}} - \frac{cp_k^h}{CP_D^h} \; for \; supply \; constraint \; at \; level \; i \end{cases} \qquad \text{for } i \in k$$

$$\overline{w}_j^h = \left(\frac{w_j^h}{1 - \sum_i w_k^h}\right)\left(1 - \sum_i \overline{w}_k^h\right)$$

$$\overline{cp}_k^h = \overline{w}_k^h \overline{CP}_D^h \left(\frac{PC_D}{p_i}\right)$$

$$\overline{CP}_D^h = CP_D^h + (1 - \rho^h) \sum_k r_k \, cp_k^h$$

At the third nest (goods i), the model is made up by the equations for the sub-shares and for the feedback of consumption losses both on single categories k (aggregates of the corresponding goods i) as well as on total consumption of bundle D:

$$\overline{cp}_i^h = (1 + r_i) cp_i^h$$

$$cp_k^{h*} = cp_k^h + (1 - \rho^h) \sum_i r_i \, cp_i^h \qquad \text{for } i \in k$$

$$\bar{s}_{i,k}^h = \frac{\overline{cp}_i^h}{cp_k^h + (1 - \rho^h) \sum_i r_i cp_i^h}$$

$$\bar{s}_{j,k}^h = \left(\frac{s_{j,k}^h}{1 - \sum_i s_{i,k}^h}\right)\left(1 - \sum_i \bar{s}_{i,k}^h\right)$$

$$CP_D^{h*} = \overline{CP}_D^h + \sum_k \left(cp_k^{h*} - cp_k^h\right)$$

These equations can be used to calculate the solution for constrained consumption levels at all levels of the model, i.e. for $\overline{cp}_m^h$, $\overline{cp}_k^h$, $\overline{cp}_i^h$, cp_k^{h*}, CP_D^{h*}, and $\overline{CP}^h$.

For introducing these changes in a consistent way via exogenous variables into the model, the following calculations need to be carried out. First, the level of constrained consumption $\overline{cp}_m^h$ leads to an adjustment of the exogenous factors δ_m^h:

$$\delta_m^h = r_m cp_m^h \tag{25}$$

Then, the exogenous variables for the budget shares at the second nest and the new sub-shares at the third nest are to be inserted:

$$\xi_k = \begin{cases} \bar{\xi}_k \; for\ no\ supply\ constraint\ at\ level\ i \\ \frac{cp_k^{h*}}{CP_D^{h*}} - \frac{cp_k^h}{CP_D^h} \; for\ supply\ constraint\ at\ level\ i \end{cases} \qquad \text{for } i \epsilon k$$

$$\bar{s}_{i,k}^h = \frac{\overline{cp}_i^h}{cp_k^h + (1-\rho^h)\sum_i r_i cp_i^h}$$

$$\bar{s}_{j,k}^h = \left(\frac{s_{j,k}^h}{1-\sum_i s_{i,k}^h}\right)\left(1-\sum_i \bar{s}_{i,k}^h\right)$$

Further, the total impact on total consumption of bundle *D* needs to be inserted into equation (6):

$$\overline{CP}^h = \overline{CP}_m^h + CP_D^h - \rho^h \sum_m r_m\, cp_m^h + (1-\rho^h)\sum_k r_k\, cp_k^h + \sum_k\left(cp_k^{h*} - cp_k^h\right) \quad (26)$$

The new level of total consumption $\overline{CP}^h$ that results from that is finally used to adjust the marginal propensities of consumption.

$$\overline{mpc} = \frac{log\overline{CP}^h - c_0^h}{log\left(\frac{YD^h}{PC^h} + \Delta D^h\right)}$$

The model has been applied to a model of private consumption for the Austrian economy that comprises three nests (for the exact aggregation structure see the Appendix) and ten groups of household income (deciles), based on data for 2014. The model represents the consumption block of the large macroeconomic IO model MIO-ES (Macroeconomic Input-Output Model with Integrated Energy System) that is frequently used for energy and climate policy evaluation and energy scenarios in Austria. The underlying data are the aggregate results of the Austrian HBS (Household Budget Survey) published by Statistics Austria (wave 2009/2010), which have been adjusted and made consistent with the National Accounts and input-output table for 2014. At the aggregate level, total consumption is given according to equations (7) and (8). The first nest (*m*) determines energy relevant consumption expenditure by decile, which is linked in both directions to data used in bottom-up models for private transport and private buildings (and their respective energy consumption). This nest comprises two durable spending categories and four non-durables. The second nest determines spending on eight non-durable non-energy categories and is specified as an Almost Ideal Demand System (AIDS). In a third nest, the six energy relevant consumption categories and the eight non-durable non-energy categories are further distributed across the 82 CPA categories, applying *fixed* sub-shares in volume terms (for the classification see the Appendix). All that is done at the level of the ten income groups of households (deciles).

The marginal propensity of consumption (*mpc*) by decile is set with:

decile 1 and 2:	1
decile 3:	0.8
decile 4:	0.7
decile 5:	0.6
decile 6:	0.5
decile 7:	0.4

The households in deciles 8 to 10 are PIH consumers according to equation (7). The average *mpc* following from the distribution for the Keynesian consumers is 0.5.

The supply constraints (in terms of r_m, r_k and r_i) that are active due to the COVID lockdown according to several studies carried out in Austria are shown in Table 1. These are the annualized rates of change of real consumption in the corresponding consumption categories without taking into account any rebound after the lockdown has ended. The consumption rebound is decile-specific and can only be assumed. The general logic followed is that the rebound depends on uncertainty in expectations about future income and risk of unemployment. That is consistent with a heterogenous agent model and with recent literature on the effect of post-lockdown recovery measures (Bayer et al., 2020). In theory, one could assume a full rebound for the PIH consumers, as consumption of these households does in general not depend on transitory shocks. Given that the lockdown is an extreme event, uncertainty prevails for all consumers. Therefore, the rebound is set in relation to income, assuming higher income uncertainty and thereby lower consumption rebounds for lower income groups.

The consumption rebound by decile is set with:

decile 1 to 3: 20%

decile 5 to 7: 50%

decile 8 to 10: 80%

The total consumption-weighted average of the consumption rebound following from this distribution is about 60%.

The results for consumption levels show a considerable degree of heterogeneity across income deciles. Graph 1 and Table 2 reveal the aggregate impact of the supply constraints on total consumption and the implicit new *mpc* by decile. The results for total consumption reduction clearly mimic the assumptions about the distribution of the rebound across income groups. One can observe three different groups that correspond to the groups of the consumption rebound. The low income-households face considerable reduction in total consumption as a consequence of the lockdown of about 6%, whereas this reduction only amounts to about 4% for the middle income-households. The necessary adjustments in the *mpc* for model simulations are rather small on average. For the lowest income-group the adjustment is about 0.008 and for higher incomes only about 0.004.

All household income-groups face significant substitution effects at the second nest (*k*) of consumption (Graph 2 and 3). This substitution effect (measured in percentage points changes in budget shares for *k* categories) is either homogenous across income deciles (clothing) or varies considerably (food, beverages). This effect depends on the interplay between income and consumption patterns. The changes in budget shares for the category 'Health' show an almost continuously decreasing pattern with income. The budget shares for the category 'Other services' mostly follow the pattern of total consumption effects across deciles. One can clearly observe three groups of impact which correspond with the three groups of the assumed consumption rebound. Substitution effects therefore are the result of a complex interplay of income and consumption structures with the assumed consumption rebound. In order to test for sensitivity of results, another set of results has been produced by generally assuming a consumption rebound of zero for all household income-groups. In that case the consumption reductions are almost uniform across income-groups and total consumption decreases by about

8% in general. The substitution effects show almost the same magnitude as in the case with rebound, but practically no heterogeneity across income- groups.

The effects for the budget shares and for the *mpc* can be directly plugged in into a full-fledged model (CGE or macroeconomic IO). Additionally, the new sub-shares for the third nest (*i*) need to be calculated according to equation (20) and (22) and then inserted into the full model. The solution of the full model yields the final consumption effects, taking into account indirect feedbacks between demand, income and prices.

Graph 4 shows the impact at the third nest, i.e. at the level of selected CPA categories. The changes in the sub-shares induced by the supply constraints are significant and magnify the substitution effects at the second nest. This magnification effect works in both directions, i.e. for negative and positive changes. As a result, large positive and negative changes in consumption at the level of individual goods and services are induced by the supply constraints. These changes clearly represent a significant challenge for the structural adjustment potential of an economy, especially for the issue of labor mobility.

3. Conclusions

This paper presents a method of calculating the consequences of the COVID lockdown on consumption across household income groups (deciles) by treating the lockdown as a number of supply constraints. The method serves for assessing either only the direct effect of the supply constraints on consumption – as in this paper - or for a consistent implementation of supply constraints via exogenous variables in a nested demand system. In both cases, the results derived by this methodology can be further used as input data either in macroeconomic forecasts or in model simulations.

The underlying consumption model is a heterogenous model with Keynesian consumers and optimizing households according to the Permanent Income Hypothesis (PIH). The marginal propensity of consumption with respect to current disposable income as well as the consumption rebound after the lockdown vary considerably between these consumers. One very important assumption that drives the results is the consumption rebound after the lockdown and its distribution across household income-groups. The methodology is applied with Austrian data and yields results with a significant degree of heterogeneity across household income groups. On the one hand, the heterogeneity just mimics the assumptions about the distribution of the consumption rebound after the lockdown. On the other hand, important substitution effects between consumption categories take place and their magnitude varies considerably across household income-groups as well, mainly depending on consumption patterns. The reduction in total consumption as a consequence of the lockdown is about 6% for low income-households and about 4% for the middle income-households. The substitution effects are either homogenous across income deciles (‘Clothing’) or vary considerably (‘Food/beverages’, ‘Health’ and ‘Other services’). That, in turn, leads to large positive and negative changes in consumption at the level of individual goods and services which might represent an important challenge for structural adjustment, especially in the labor market.

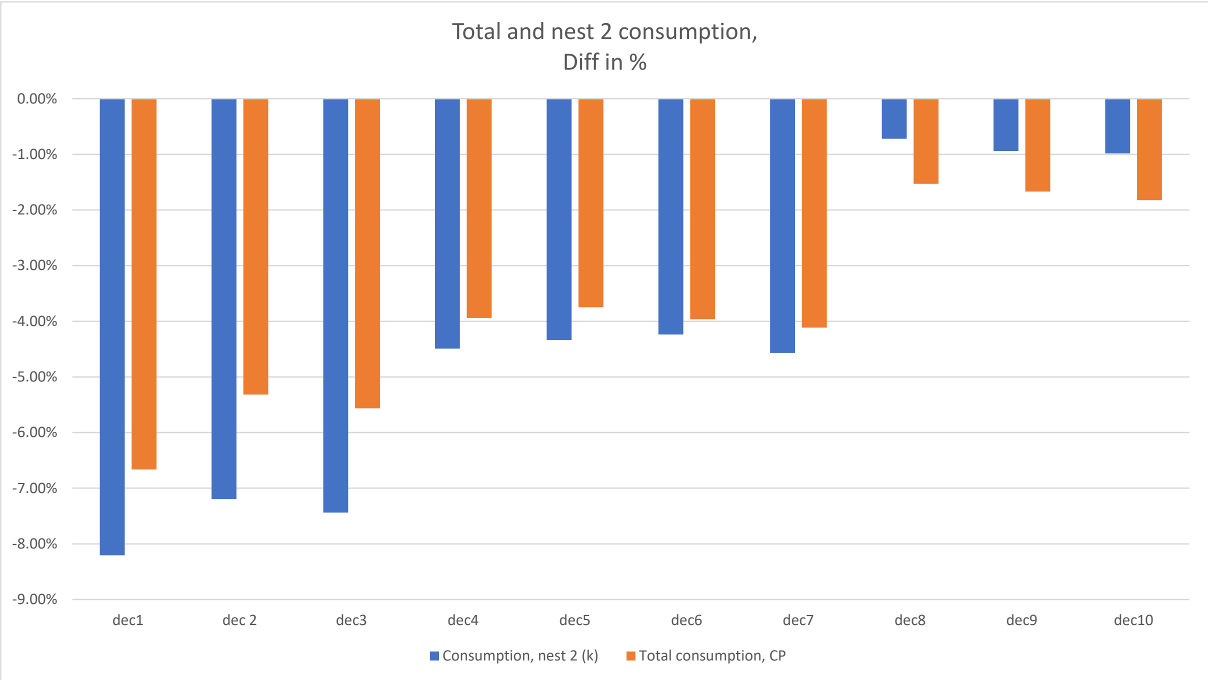
Table 1: Supply constraints due to the COVID lockdown in Austria (rates of change)

	r
nest 1 (*m*)	
Vehicles	-0.15
Other public transport	-0.1
Air transport services	-0.25
nest 2 (*k*)	
Clothing	-0.25
nest 3 (*i*)	
Textiles	-0.25
Accommodation services	-0.35
Travel agency, tour operator	-0.45
Creative, arts and entertainment	-0.35
Library, archive, museums	-0.35
Sporting services and recreation	-0.35
Other personal services	-0.35

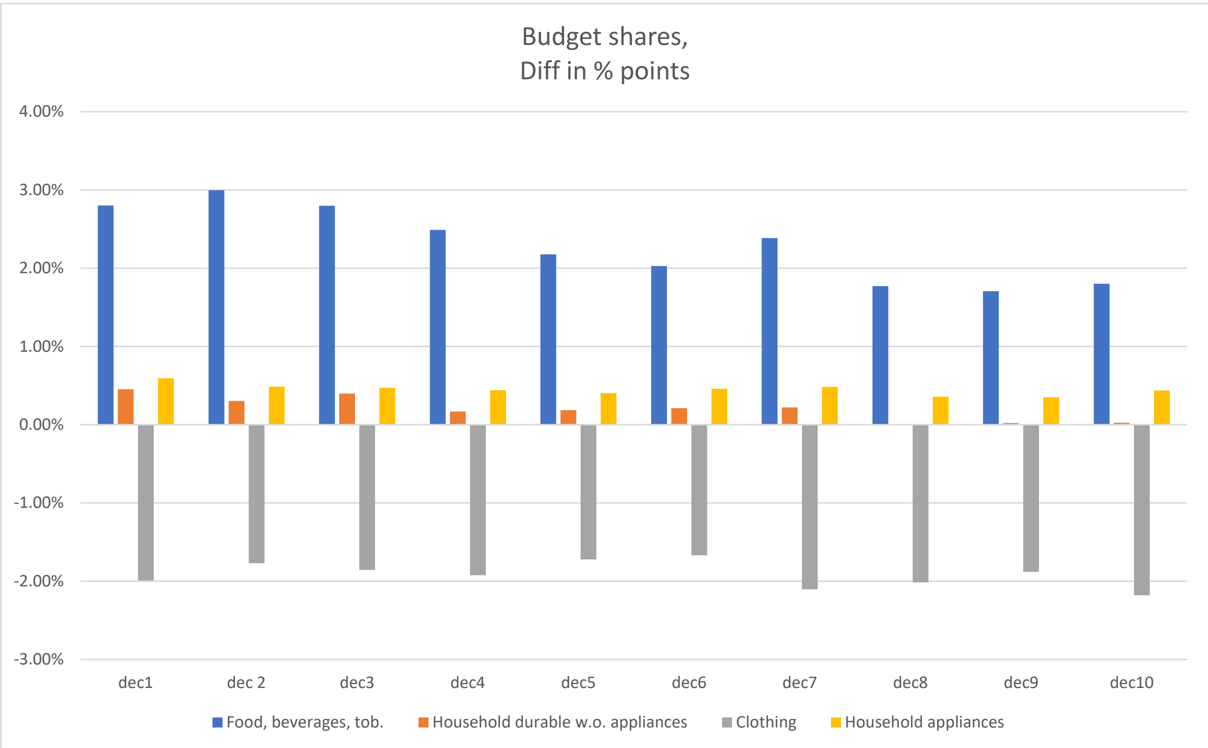
Table 2: Aggregate consumption effects (rates of change) and adjusted mpc of the COVID lockdown in Austria

	Consumption nest 2 (*k*)	**Total consumption**	**Adjusted *mpc***
dec1	-8.20%	-6.66%	0.992
dec 2	-7.20%	-5.32%	0.994
dec3	-7.44%	-5.57%	0.794
dec4	-4.49%	-3.94%	0.696
dec5	-4.34%	-3.75%	0.596
dec6	-4.24%	-3.96%	0.496
dec7	-4.57%	-4.11%	0.396
dec8	-0.72%	-1.53%	0
dec9	-0.94%	-1.67%	0
dec10	-0.98%	-1.82%	0

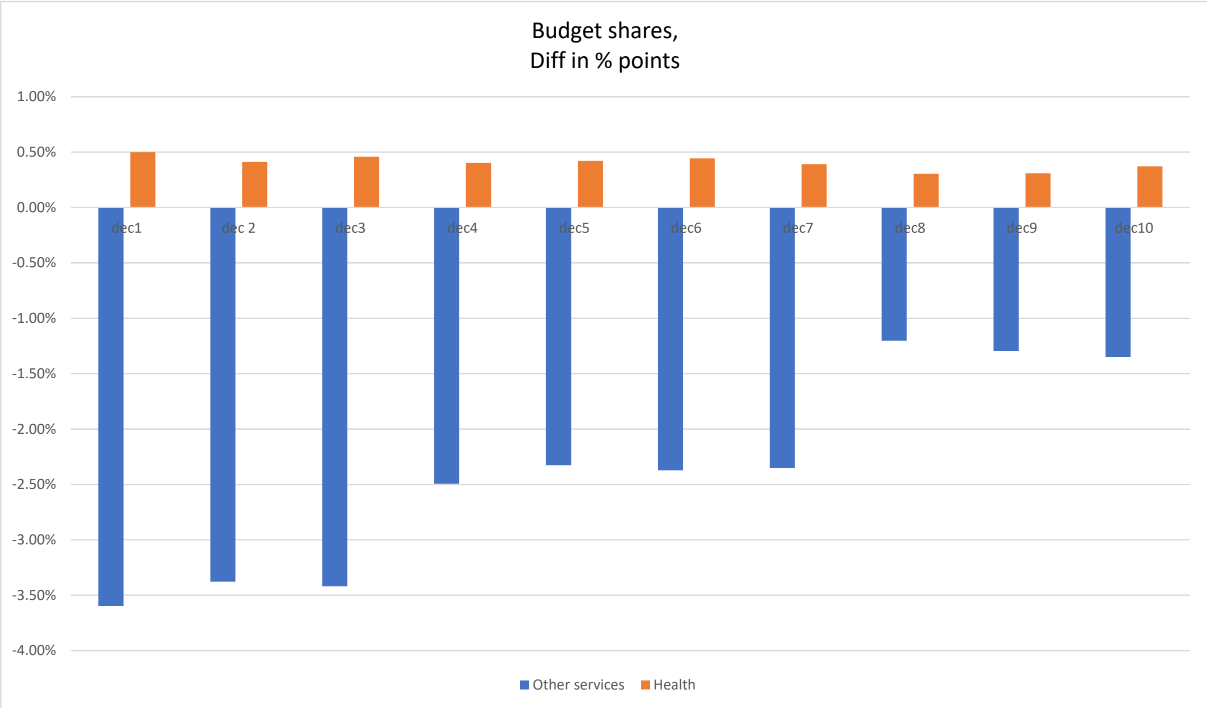
Graph 1: Aggregate consumption effects (rates of change) of the COVID lockdown in Austria



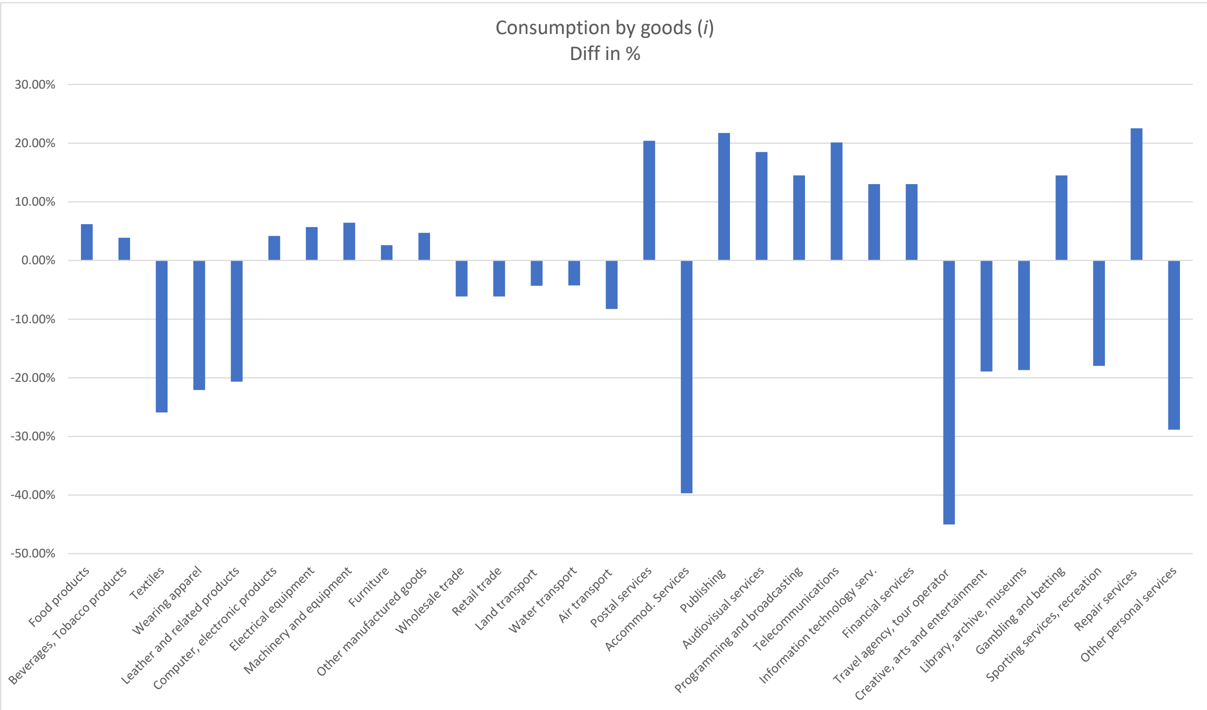
Graph 2: Substitution in consumption (change in budget shares in nest 2(k)) due to the COVID lockdown in Austria: Food, Durables, Clothing, Appliances



Graph 3: Substitution in consumption (change in budget shares in nest 2(k)) due to the COVID lockdown in Austria: Health, Other Services



Graph 4: Consumption effects by good (rates of change) of the COVID lockdown in Austria



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Appendix: Aggregation structure and classifications

The nested model of consumption deals with energy in a separate way, inserting physical results for energy from bottom-up energy models and converting them into monetary consumption expenditure by implicit prices. The categories of energy comprise:

Table A.1: Energy goods in the consumption model

Energy & primary
Coal, lignite
Crude petroleum
Natural gas
Coke
Refined petroleum products
Electricity
Other electricity
Gas
Steam and air conditioning

The general structure as described in the paper is defined by energy relevant expenditure (categories *m*) of durable and non-durable spending on the one hand and the non-energy bundle *D* of non-durables (categories *k*) on the other hand:

*Table A.2: Aggregation structure (*categories *m and k) of the consumption model*

Energy relevant (durables)
Rents
Vehicles
Energy relevant (nondurables)
Maintainance of vehicles
Air transport
Other (public) transport
Non-energy
Food, beverages, tobacco
Maintainance of dwelling
Household durable w.o. appliances
Clothing
Household appliances
Other manufacturing
Other housing
Health
Other services

Finally, the third nest comprises the level of single goods and services, as shown in Table A.3.

Table A.3: Goods and services of the consumption model

NACE/CPA	
01	Products of agriculture, hunting and related services
02	Products of forestry, logging and related services
03	Fish and fishing products
08-09	Other mining a. quarrying prod.; mining support services
10	Food products
11-12	Beverages, Tobacco products
13	Textiles
14	Wearing apparel
15	Leather and related products
16	Wood and products of wood and cork
17	Paper and paper products
18	Printing and recording services
20	Chemicals and chemical products
21	Basic pharmaceutical products and preparations
22	Rubber and plastic products
23	Other non-metallic mineral products
241 - 243	Iron & Steel
244 - 245	Other basic metals
25	Fabricated metal products, exc. machinery and equipment
26	Computer, electronic and optical products
27	Electrical equipment
28	Machinery and equipment n.e.c.
29	Motor vehicles, trailers and semi-trailers
30	Other transport equipment
31	Furniture
32	Other manufactured goods
33	Repair a.installation services of machinery a.equipment
36	Natural water; water treatment and supply services
37-39	Sewerage, waste management a. remediation services

Table A.3: continued

NACE/CPA	
41	Buildings and building construction works
42	Constructions a.construction works for civil engineering
43	Specialised construction works
45	Wholesale- a. retail trade, repair of motor vehicles
46	Wholesale trade, exc. o.motor vehicles a. -cycles
47	Retail trade, exc. o.motor vehicles a. -cycles
49	Land transport services a. transport services via pipelines
50	Water transport services
51	Air transport services
52	Warehousing and support services for transportation
53	Postal and courier services
55-56	Accommod. services; food a.beverage serving services
58	Publishing activities
59	Audiovisual services
60	Programming and broadcasting services
61	Telecommunications services
62-63	Information technology serv., communication services
64	Financial services
65	Insurance, reinsurance and pension funding services
66	Services auxiliary to financial a. insurance services
68	Real estate services
69	Legal and accounting services
70	Serv. of head offices; management consulting services
71	Architectural and engineering services
72	Scientific research and development services
73	Advertising and market research services
74-75	Other prof., scientific, technical serv.; veterinary services
77	Rental and leasing services
78	Employment services
79	Travel agency, tour operator and related services
80-82	Other business support services
84	Public administration, defence, social security services
85	Education services
86	Human health services
87-88	Residential care services, social work services
90	Creative, arts and entertainment services
91	Library, archive, museum and other cultural services
92	Gambling and betting services
93	Sporting services, amusement and recreation services
94	Services furnished by membership organisations
95	Repair services of computers, pers. a. household goods
96	Other personal services
97	Services of households as employers of dom. personnel