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A general equilibrium model with an asymmetric Armington function: Method and application

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In the modeling of imports, most CGE models use Armington functions with symmetric responses to increases and decreases in the ratio of prices of imports and domestic products. In this paper, we extend this by permitting asymmetric responses to changes in this price ratio. Specifically, we assume that it is easier to substitute imports for domestic products than vice versa. The rationale is that the ability of the outside world to supply close substitutes for domestic products may often be stronger than the ability of domestic producers to supply close substitutes for imports. The paper presents the mathematical structure of an asymmetric Armington treatment and embeds it in a simple static CGE model based on a Mongolian dataset. The model is used to analyze how the impacts of two external shocks – an increase in the foreign currency price of an import and the elimination of the current-account deficit – are influenced by whether a symmetric or asymmetric treatment is used for the Armington function; for the latter, the Armington elasticity is lowered if imports are reduced relative to domestic purchases. The application demonstrates that our asymmetric formulation is simple, robust and that, compared to the symmetric case, asymmetry may lead to important differences in the macro and sectoral impacts of import price shocks. Given this, the paper points to the need for econometric research that estimates Armington elasticities without imposing symmetry. If symmetry is rejected for one or more commodities, then it would be straightforward to switch to the asymmetric treatment proposed in this paper for these commodities.

JEL Codes: C68, D58, F11, F17

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1. Introduction

Two-way trade – the presence of both exports and imports – is observed for most products in the databases of CGE models. To address this phenomenon, most models use a constant-elasticity-of-substitution (CES) function – a treatment due to Armington (1969) – to capture demander choice between imperfectly substitutable imports and domestic outputs whereas, for the parallel supply-side choice between exports and domestic sales, the models tend to assume imperfect transformability with the help of a constant-elasticity-of-transformation (CET) function.

The Armington assumption of imperfect substitutability is justified in so for as demanders consider supplies from foreign and domestic sources as being so different that the law of one price does not apply even though, in the database, they appear as a single product. To the best of our knowledge, the Armington formulations that have been employed in models (CGE and others) have invariably assumed that, for any product, the same elasticity of substitution applies to increases and decreases in the ratio between the prices of imports and domestic output. The assumption of asymmetry also appears to be without exception in the econometric literature on Armington elasticities of substitution (Bajzik et al. 2020). While this assumption has the virtue of simplicity, it often suffers from a lack of plausibility: for most products, international markets offer a relatively wide variety of products, facilitating a demand switch from domestic products to imports that are close substitutes, whereas the range of varieties provided by domestic producers tends to be relatively narrow, making it more difficult for demanders to switch in the opposite direction, from imports to domestic output. From another angle, as long as countries tend to import products that are difficult to produce at home (due to a lack of skills, natural resources, appropriate climate, infrastructure and/or institutions), one would expect that import substitution often is relatively difficult.

The time frame for the analysis and the disaggregation of the database are related to the Armington elasticity values and need for the Armington approach – this also applies if the treatment is asymmetric. Just like for the symmetric case, we expect asymmetric elasticities to be higher in the long run. However, asymmetry is only expected to become irrelevant if imports and domestic output are (near) perfect substitutes, i.e., if product disaggregation is so fine that the Armington function also disappears, the law of one price is valid, and either an import or a domestic product is demanded, not both. Such fine disaggregation is rarely found in today's databases, as indicated by the presence of imports and domestic sales of domestic output for most products.

Empirically, the presence of asymmetry may matter both at the macro and sectoral levels. At the macro level, the extent of real exchange rate adjustments and/or changes in balance of payments deficits caused by shocks affecting the balance of payments (terms of trade or other) depend on these substitution elasticities; at the sector level, the ease of switching demands between imports and domestic output matters for trade, production, and factor employment and earnings, with impacts on household welfare and distribution.

To address this concern, this paper extends the Armington assumption by introducing an optional distinction between responses to increases and decreases in the price of imports relative to domestic products, i.e., it introduces the option of assuming that, for a subset of the products, demand-side substitution possibilities are asymmetric.

In this paper, we consider Armington functions in the context of the choice between purchasing imports or domestic products. However, the approach that is developed is also relevant to demander choice between two or more supply sources in other contexts, including choices between products from different regions (or countries) or between products produced with different technologies.

We proceed as follows. Section 2 presents the proposed asymmetric Armington treatment. Section 3 tests the new approach in a single-product partial-equilibrium model by parametrically varying the international import price. In Section 4, we switch to a CGE setting, imposing two shocks – an increase in the foreign-currency price of an import and the elimination of the current account deficit -- on two variants of a simple model, one with a standard symmetric Armington treatment and one with the proposed asymmetric treatment. For the latter, the Armington elasticity values are set to make it more difficult for domestic demanders to switch from imports to domestic products than vice versa. In Section 5, we present our conclusions. In appendices, we provide additional details on the mathematics of the different Armington formulations (Appendix A), and simulation results in table form (Appendix B).[1]

2. An asymmetric Armington formulation

The asymmetric Armington formulation developed in this paper is related to a literature that, since the late 1960s, has proposed CES production functions with endogenous elasticities of substitution that depend on a variety of variables, including capital-labor ratios, relative factor shares, marginal rates of substitution, and capital-output ratios.[2] However, our proposed formulation is distinct from the above-mentioned literature in that the elasticity of substitution depends on the direction of change in relative input prices as opposed to other determinants.

More specifically, under our approach, the elasticity of substitution between imports and domestic purchases takes on different values depending on whether, relative to the base, the ratio between the prices paid by demanders for imports and domestic purchases, PM/PDD, increases or decreases. For reasons related to differences in product variety between these two sources (see the introduction), we impose a lower elasticity if this price ratio increases and a higher if it decreases.

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[1] In Supplementary Material A, we provide a full mathematical statement of the CGE model used in Section 4.

[2] See for example, Revankar (1971), Lovell (1973), Antoni (2010), and Growiec and Mućk (2015), the two latter applying their CES functions in growth models.

Figure 1 shows a graphical illustration: The asymmetric case is represented by the indifference curve ABC while the symmetric case is represented by A'BC. Initially, the economy has import and domestic purchase quantities QM* and QD*, respectively, at a point B that is tangential to the initial budget line with a slope based on the initial PM/PDD ratio. For a given *increase* in the PM/PDD ratio (steeper budget line slope) with the economy remaining on the initial indifference curve, the decline in QM is smaller for the asymmetric case (ABC; lower elasticity of substitution) compared to the symmetric case (A'BC; higher elasticity of substitution); however, for any given *decrease* in this ratio, the increases in QM are identical for two cases (and so are the elasticities of substitution).

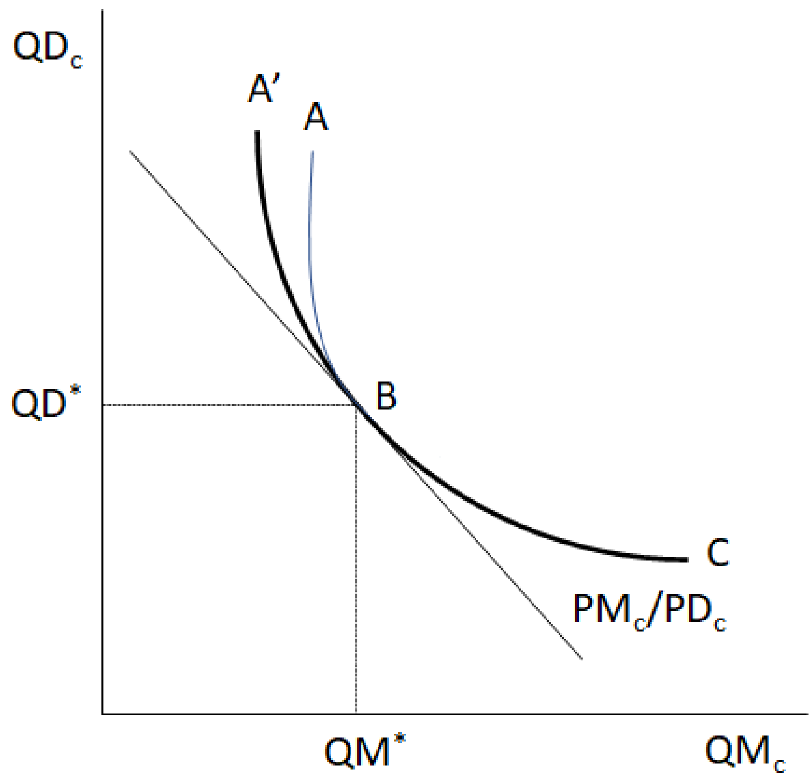

Figure 1. Asymmetric Armington indifference curve

Source: Authors' elaboration.

Table 1 has a mathematical statement of our asymmetric treatment of the (Armington) allocation of domestic demands between imports and domestic products; for simplicity, the commodity index for variables and parameters is omitted in the table.

Together, equations (1)-(7) are used to impose σ^{ql} or σ^{qh} on $SIGMA^{Q}$. Figure 2 shows a graphical summary of how this works. Equation (1) defines the difference between the non-base and base import to domestic-price ratios, PM/PDD and

PM^0/PDD^0, as the difference between the variables $DEVP$ and $DEVN$ that, given equations (2) and (3), are non-negative. If the deviation between PM/PDD and PM^0/PDD^0 is positive – the relative price of imports increases -- then $DEVP > 0$, $DEVN = 0$, and equations (4)-(5) impose that $SIGMA^Q$ takes on the lower elasticity of substitution, σ^{ql}. In the opposite case of a negative deviation between the new and the base price ratios – a decrease in the relative price of imports – $DEVN > 0$, $DEVP = 0$, and equations (6) and (7) impose that $SIGMA^Q$ equals the higher elasticity of substitution, σ^{qh}. Together, equations (8)-(10) determine the demand for domestic and imported commodities, using the normalized (or calibrated share) form of the CES function that, as opposed to the more common representation in CGE models, does away with the need to explicitly (re)calibrate the other parameters of the Armington CES function when there is a change in the value of $SIGMA^Q$.[3] Appendix A discusses the origin of the normalized form and shows its derivation.

Table 1a. Equations for asymmetric Armington approach

(1)	$\frac{PM}{PDD} - \frac{PM^0}{PDD^0} = DEVP - DEVN$
(2)	$DEVP \geq 0$
(3)	$DEVN \geq 0$
(4)	$DEVP\left(SIGMA^Q - \sigma^{ql}\right) = 0$
(5)	$SIGMA^Q \geq \sigma^{ql}$
(6)	$DEVN\left(SIGMA^Q - \sigma^{qh}\right) = 0$
(7)	$SIGMA^Q \leq \sigma^{qh}$
(8)	$QM = QM^0 \cdot \frac{QQ}{QQ^0} \cdot \left(\frac{PM^0}{PM} \cdot \frac{PQ}{PQ^0}\right)^{SIGMA^Q}$
(9)	$QD = QD^0 \cdot \frac{QQ}{QQ^0} \cdot \left(\frac{PDD^0}{PDD} \cdot \frac{PQ}{PQ^0}\right)^{SIGMA^Q}$
(10)	$PQ = PQ^0 \cdot \left(\theta^m \cdot \left(\frac{PM}{PM^0}\right)^{1-SIGMA^Q} + \theta^{dd} \cdot \left(\frac{PD}{PD^0}\right)^{1-SIGMA^Q}\right)^{\frac{1}{1-SIGMA^Q}}$

Source: Authors' elaboration.

[3] Under the more common formulations, equations (4)-(5) are replaced by a CES aggregation function and an expression for the relationship between QM and QD: $QQ = \varphi^q \cdot \left(\delta^m \cdot QM^{-\rho^q} + \delta^{dd} \cdot QD^{-\rho^q}\right)^{-\frac{1}{\rho^q}}$; and $\frac{QM}{QD} = \left(\frac{PDD}{PM} \cdot \frac{\delta^m}{\delta^{dd}}\right)^{\frac{1}{1+\rho^q}}$, with the elasticity of subsitititution σ^q defined as $\sigma^q = 1/(1+\rho^q)$. Under this formulation, if the value of σ^q (ρ^q) is changed, it is necessary to redefine δ^m, δ^{dd} and φ^q. In addition, equation (10) is often replaced by a spending constraint that implicitly defines PQ: $PQ \cdot QQ = PM \cdot QM + PDD \cdot QD$.

Table 1b. Notation for the asymmetric Armington formulation

Name	Description
$DEVP$	positive deviation of PM/PDD ratio from base value (if > 0, imposes lower value of σ^{ql} for $SIGMA^{Q}$)
$DEVN$	negative deviation of PM/PDD ratio from base value (if > 0, imposes upper value of σ^{qh} for $SIGMA^{Q}$)
PDD	demander price for commodity produced and sold domestically
PM	demander price for import (domestic currency)
PQ	demander price composite commodity
QD	quantity of domestic sales of domestic output
QM	quantity of imports
QQ	quantity of commodity supplied to domestic market (composite supply)
$SIGMA^{Q}$	elasticity of substitution between domestic commodity and import that is used
σ^{ql}	low alternative for elasticity of substitution between domestic commodity and import
σ^{qh}	high alternative elasticity of substitution between domestic commodity and import
θ^{dd}	base share of domestic commodity in composite supply value
θ^{m}	base share of import in composite supply value
PDD^{0}	base demander price for commodity produced and sold domestically
PM^{0}	base demander price for import (domestic currency)
PQ^{0}	base demander price for composite commodity
QD^{0}	base quantity sold domestically of domestic output
QM^{0}	base quantity of imports
QQ^{0}	base quantity of commodity supplied domestically (composite supply)

Source: Authors' elaboration.

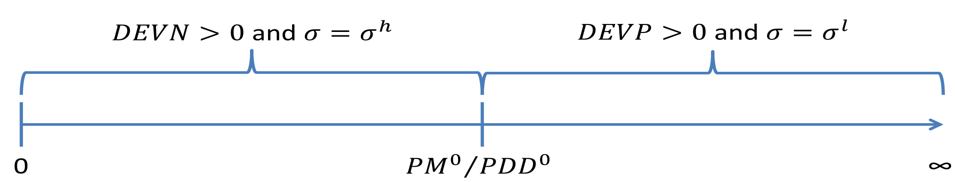

Figure 2. Segments for PM/PDD and their relation to SIGMA_Q

Source: Authors' elaboration.

3. A partial equilibrium test of the asymmetric formulation

To test this formulation, we first construct a partial equilibrium model and use it to derive the import demand curves for the symmetric and asymmetric cases. The asymmetric model consists of equations 1-8 and 10 in Table 1a. The endogenous variables are QM, $DEVP$, $DEVN$, $SIGMA^Q$, and PQ.[4] The symmetric model is made up of equations 8 and 10; its endogenous variables are QM and PQ. In both cases, PM, PDD, and QQ are all exogenous. (For both cases, equation 9 and the variable QD could also have been included although this is not needed to derive the import demand curve.). To derive the import demand functions, the world price of imports is changed exogenously for both cases, with the changes ranging from -80% to +110%.

For the asymmetric case, σ^{ql} and σ^{qh} are 0.5 and 4, respectively, while, for the symmetric case, $SIGMA^Q$ is 4 (= σ^{qh}). The resulting demand curves are shown in Figure 3. The initial value of PM is one. As intended, the two curves coincide for PM decreases. However, when PM increases, the decrease in import demand is smaller for the asymmetric case due to its lower substitution elasticity, yielding a steeper curve.

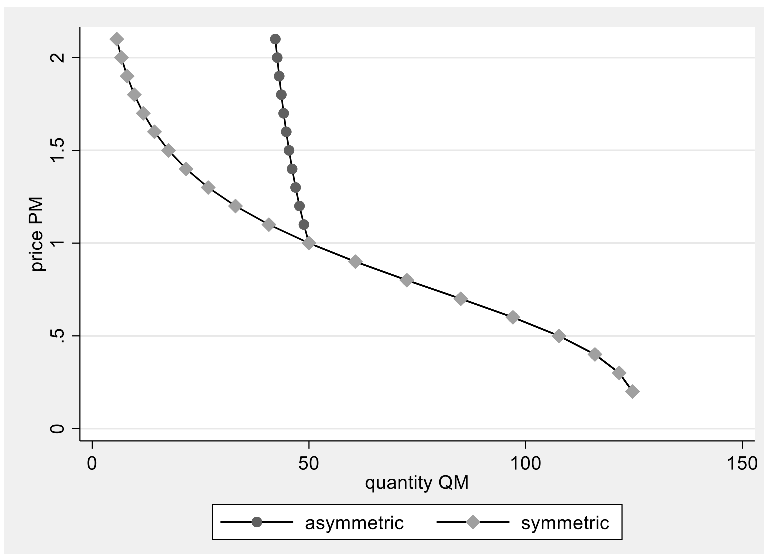

Figure 3. Import demand curves with symmetric and asymmetric Armington approaches derived from simulations with partial equilibrium model
Source: Authors' elaboration.

[4] If $DEVP > 0$, $DEVN = 0$, then equations 1, 3, 5, 8, and 10 are used to find the solution values for the endogenous variables. if $DEVN > 0$, $DEVP = 0$, then equations 1, 2, 7, 8, and 10 are used.

4. A general equilibrium test of the asymmetric formulation

In this section, we use simulations with a simple static single-region CGE model to test the asymmetric Armington formulation.[5] The model, which is applied to a 2015 dataset for Mongolia, is typical of models of small open economies with optimizing behavior for households and producers, domestic markets for commodities and factors cleared by flexible prices and wages, respectively, and a government that consumes, saves, taxes, and both receives and pays transfers. Our test consists in comparing the simulation results for symmetric and asymmetric versions of the model for two external shocks, an increase in the international price of a major import, machinery and equipment, and an elimination of the current account deficit (foreign savings reduced to zero).

To provide context for the analysis, we first present the model database and key model assumptions (Section 4.1), after this turning to the results for the shocks to the import price (Section 4.2) and foreign savings (Section 4.3).

4.1. The CGE model: structure, assumptions and database

4.1.1. Model structure and assumptions

We here summarize the assumptions of the CGE model that is used – they are important when the results are interpreted. (A full mathematical statement of this model is provided as Supplementary Material A.)

For the rest of the world (the current account of the balance of payments), the quantities of exports and imports are endogenous while world prices for exports and imports, and all other payments, including foreign savings (the current account deficit) are exogenous in foreign currency. More specifically, the allocation of output between exports and domestic sales is based on the standard constant-elasticity-of-transformation (CET) approach.[6] As noted, two alternative Armington approaches are used to model the demand-side choice between imports and domestic purchases. The rest-of-the-world account is cleared by a flexible real exchange rate.

Among the domestic receipts of the government, indirect (activity and commodity) taxes are determined by fixed rates times endogenous bases, capital rents are a fixed share of total capital rents, while transfers received from the household are a fixed share of household income net of direct taxes. On the side

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[5] In a multi-region model, it would be straightforward to apply the proposed approach to the choice of any region between domestic purchases and imports (aggregated across exporting regions). It could be limited to a subset of regions and/or commodities.

[6] While it is a separate empirical issue and not addressed in this paper, it is not out of the question that the allocations covered by the CET function also are asymmetric, i.e., that different elasticities apply to the supply responses to increases and decreases in the ratio between export and domestic sales prices.

of government domestic outlays, the real level of government consumption is fixed while transfers to households and government savings are CPI-indexed. The government account is cleared by changes in the direct tax rates for the household.

In addition to transfers, the domestic household (an aggregate domestic non-government institution) has earnings from labor and capital (both fixed shares of the total earning of each factor). Household spending other than transfers and direct taxes is made up of savings (with a rate that adjusts to clear the savings-investment balance) and consumption, the allocation of which is driven by the maximization of a Cobb-Douglas utility function. By construction, the total values for the household's expenditures and receipts are equal.

The remaining domestic final demands, fixed investment and stock changes, are both exogenous in real terms. Changes in their total value lead to changes in the household savings rate which, as noted above, is flexible; i.e., savings are driven by investment.

As in most CGE models, domestic markets for products and factors are cleared by flexible prices, wages, and rents. The employment of capital is fixed at the sector level whereas labor is mobile across sectors with a fixed level of total employment.

4.1.2. Model database

The model database includes an aggregated version of the 2015 SAM for Mongolia presented in Cicowiez and Lofgren (2018). The SAM has 4 factors (labor, capital, land, and an extractive natural resource), 7 sectors (agriculture, mining, food and beverages, machinery and equipment, other manufacturing, other industry, and services), and a single representative household. Each sector is represented by an activity and a product (or commodity) with a one-to-one mapping between the two.

Table 2 shows an aggregated version of the model SAM with percent of GDP as the unit (to make it easier to interpret the data). From its cells, it is straightforward to extract standard national account aggregates (private and government consumption and investment, exports, and imports) and the budgets of the government, the domestic non-government, and the rest of the world (the balance of payments). The simulations are focused on the account for the rest of the world -- as shown, in 2015 Mongolia had a small trade surplus (exports at 45.1 and imports at 44.1 percent of GDP) but a large deficit for non-trade payments (6.7 percent), together generating a current account deficit at 5.7 percent.

Table 2. Macro SAM for Mongolia, 2015 (% of GDP)

	act	com	marg	f-lab	f-cap	tax	hhd	gov	row	sav-inv	dstk	total
act		177.8										177.8
com	85.9		19.3				59.1	13.5	45.1	20.4	6.0	249.4
marg		19.3										19.3
f-lab	48.5								0.5			49.0
f-cap	42.9											42.9
tax	0.4	8.1					5.2					13.7
hhd				48.2	41.2			8.3	1.0			98.7
gov					1.7	13.7	8.4		0.5			24.3
row		44.1		0.8	0.0		5.6	2.2				52.8
sav-inv							20.4	0.3	5.7			26.4
dstk										6.0		6.0
total	177.8	249.4	19.3	49.0	42.9	13.7	98.7	24.3	52.8	26.4	6.0	

Source: Authors' elaboration.

Apart from, the SAM, the only data input is elasticities for value-added and trade, shown in Table 3 and based on Sadoulet and de Janvry (1995) and Aguiar et al. (2019). The value-added elasticities of substitution are in the range of 0.20-0.95, the Armington elasticities take the values 0.9 (low) or 3.0 (high)[7], and the CET elasticities are all 3.0. As noted above, for household consumption, we use a Cobb-Douglas utility function (i.e., all expenditure elasticities are 1.0 and uncompensated own-price elasticities -1).

Table 3. Elasticities for value-added and trade

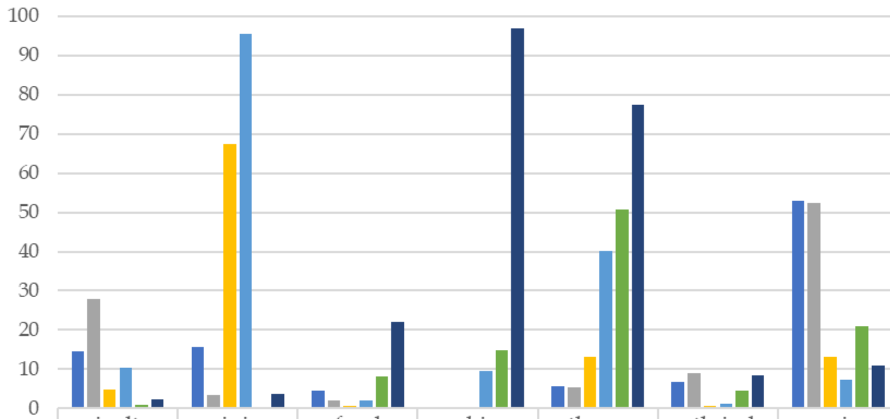
	Value added	Armington		CET	LES*
		low	high		
Agriculture	0.25	0.90	3.00	3.00	1.00
Mining	0.20	0.90	3.00	3.00	1.00
Food and beverages	0.95	0.90	3.00	3.00	1.00
Machinery and equipment	0.95	0.90	3.00	3.00	1.00
Other manufacturing	0.95	0.90	3.00	3.00	1.00
Other industry	0.95	0.90	3.00	3.00	1.00
Services	0.95	0.90	3.00	3.00	1.00

Source: Authors' elaboration.

On the basis of the disaggregated SAM used for the model and employment data, Figure 4 summarizes the sectoral structure of the Mongolian economy in 2015: it shows sectoral shares in value-added (VAshr), employment (EMPshr), exports and imports (EXPshr and IMPshr, respectively), as well as the

[7] The two values for the Armington elasticities are contained within the broad range identified in Bajzik et al. (2020).

split of domestic sectoral supplies between exports and domestic sales (EXP-OUTshr), and domestic sectoral demands between imports and domestic output (IMP-DEMshr). For instance, while (primary) agriculture represents a significant share of employment (around 27.8 percent), its shares of value added, and exports are much smaller (14.5 and 4.8 percent, respectively). For mining, the output share that is exported amounts to 95.4 percent. The share of exports due to mining (around 67.6 percent) is far above its share in total value added (15.6 percent). Machinery and equipment is a sector with very little domestic production (0.1 percent of value added) but a large share in total imports (14.8 percent as imports satisfy almost all domestic demands (a ratio of 0.97 between imports and total demand).



	agriculture	mining	food	machinery	oth-man	oth-ind	services
VAshr	14.5	15.6	4.5	0.1	5.5	6.7	53.0
EMPshr	27.8	3.4	1.9	0.0	5.5	8.9	52.4
EXPshr	4.8	67.6	0.7	0.1	13.1	0.6	13.1
EXP-OUTshr	10.3	95.4	2.0	9.7	40.2	1.3	7.3
IMPshr	0.8	0.1	8.2	14.8	50.8	4.4	20.8
IMP-DEMshr	2.3	3.7	22.2	97.0	77.4	8.5	10.9

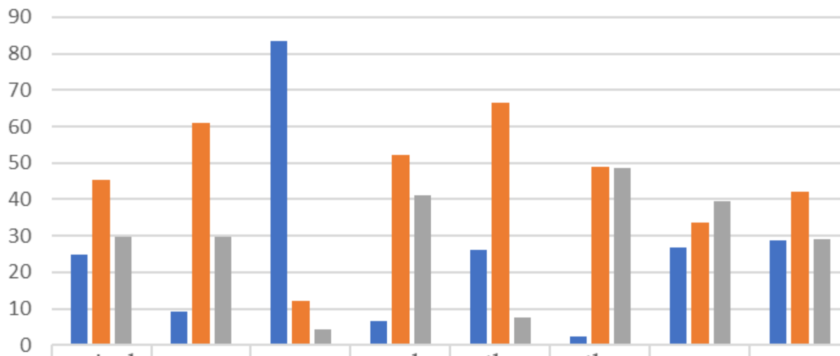
Figure 4. Sectoral structure, Mongolia, 2015 (%)

Source: Authors' elaboration.

Given model assumptions and elasticities, the domestic demands can be split into three categories on the basis of the extent to which these demands are price elastic: household consumption, intermediate demands, and others (government consumption, fixed investment, stock changes, and trade and transport margins). For household consumption demands, the (absolute) price elasticities are high, defined by Cobb-Douglas functions (i.e., the uncompensated own-price elasticities are all -1) whereas, given the assumption of fixed input coefficients, intermediate demands are not very price-responsive and, as noted in Section 4.1.1, the responsiveness is zero or near zero for the other demands.

To help in the interpretation of the simulation results, Figure 5, which also is based on the SAM, provides more details on domestic demands by sector according to this classification, meant to capture price responsiveness. Most importantly, in terms of the weight of household consumption, the sectors may be split into three categories: (a) high: food; (b) close to economywide average: agriculture, other manufacturing, and services; and (c) low: mining, machinery, and other industry.

Figure 5. Demand structure by sector, Mongolia, 2015 (%)



	agricul-ture	mining	food	mach-inery	other man.	other ind.	services	total
household	24.7	9.3	83.6	6.6	26.1	2.5	26.8	28.9
intermediate	45.5	61.0	12.2	52.1	66.4	49.0	33.8	42.1
other	29.7	29.7	4.2	41.3	7.5	48.5	39.4	29.0

Source: Authors' elaboration.

4.2. Increased import price for machinery and equipment

Under this scenario, we impose a 35 percent increase in the international (foreign-currency) price of imported machinery and equipment, henceforth referred to as machinery. The scenario is implemented using both the symmetric and the asymmetric model versions, for the former the Armington elasticity is 3.0, for the latter the elasticity is 0.9 if domestic output purchases increase relative to imports (due to an increase in the ratio between the domestic demander prices for imports and domestic output) and 3.0 for the opposite case.

The results are summarized in Figures 6.1-6.8: sym-pwm+ and asym-pwm+ refer to results for the symmetric and asymmetric model versions, respectively.

At the macro level (Figure 6.1), to maintain external balance in the face of this negative terms-of-trade shock, imports decrease while exports increase with the incentives provided by a real exchange rate depreciation. Given that total value added and output are fixed (apart from marginal effects due to labor reallocation), these quantity adjustments require a cut in absorption and its only flexible part, private consumption. For the asymmetric version, the lower Armington elasticities make it more difficult to reduce imports; to make up for this, the export increase is stronger, incentivized by a stronger depreciation. In addition, the declines in private consumption and total absorption are slightly smaller; the reason is that these demands are oriented toward relatively non-traded outputs and thus benefit from a stronger relative price decline when the real exchange rate depreciates more strongly.

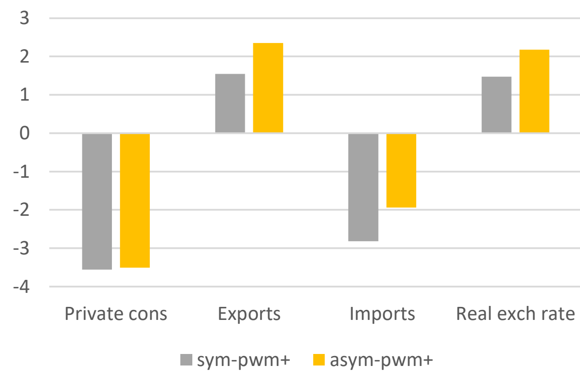


Figure 6.1. Scenario pwm+: Macro Indicators (% change)

Source: Authors' elaboration.

At the commodity (or product) level, the changes in prices, exports, imports, domestic output, and domestic sales are obviously interrelated. It is expected the ratio between the prices of imports and domestic sales (PM/PDD) would increase for the different commodities given the real exchange rate depreciation and, for machinery, also due to the import price increase. This is also the outcome for all products except mining, for which the price ratio declines very slightly (Figure 6.2). Accordingly, the asymmetric model switches to the lower substitution elasticity of 0.9 for all products except mining (Figure 6.3).

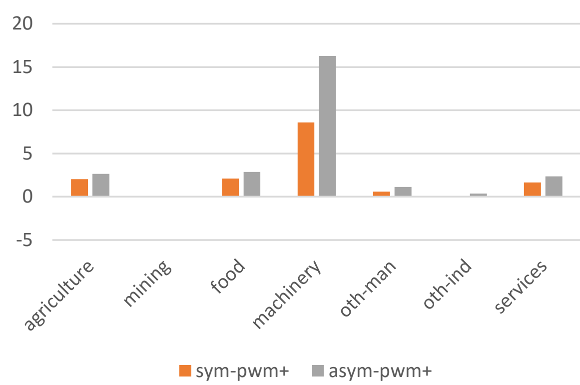


Figure 6.2. Scenario pwm+: PM/PDD (% change)

Source: Authors' elaboration.

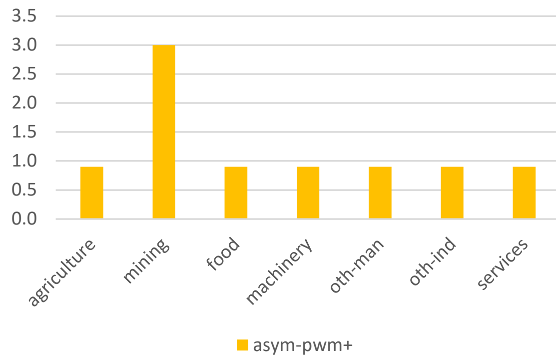


Figure 6.3. Scenario pwm+: Armington elasticities

Source: Authors' elaboration.

The mining exception, i.e., the slight decline in the PM/PDD ratio for this sector, is explained by the fact that (a) total domestic demand increases (the net of increased intermediate demands for the mining product and reduced household consumption) (Figure 6.4 - QQ); this occurs in spite of an increase in the relative price of mining output (due to the depreciation and a strong export-orientation of mining (cf. Figure 4); and (b) this increase in demand leads to increased imports (Figure 6.5 - QM) since the domestic supply, as well as exports and domestic sales from the sector are virtually fixed (Figures 6.6-6.8 – QD, QE, and QX).[8] In the absence of a sufficiently strong increase in domestic sales, meeting the increase in domestic demand requires an increase in imports, both in absolute quantity and relative to the quantity of domestic sales, an outcome that is associated with a decrease in the relative price of imports, i.e., a decline in the PM/PDD ratio.

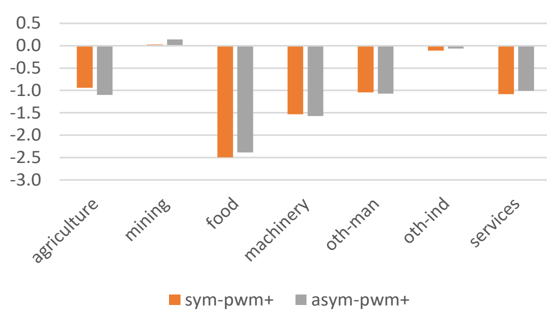


Figure 6.4. Scenario pwm+: Composite demand by commodity

Source: Authors' elaboration.

[8] In general, given fixed total factor employment, aggregate output and value-added is virtually fixed. The scope for reallocation of output is also limited given that labor is the only mobile factor. The potential for increased output from mining is particularly constrained given that labor is a small part of mining value added and the elasticity of substitution in value-added is low (0.2). Furthermore, the minimal increase in mining output is primarily allocated to exports, given large export share and the incentive from the real depreciation.

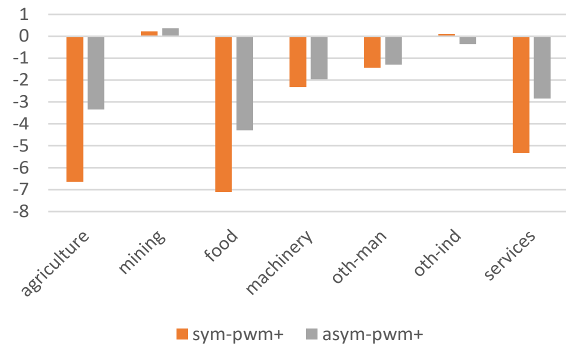


Figure 6.5. Scenario pwm+: Imports by commodity (% change)

Source: Authors' elaboration.

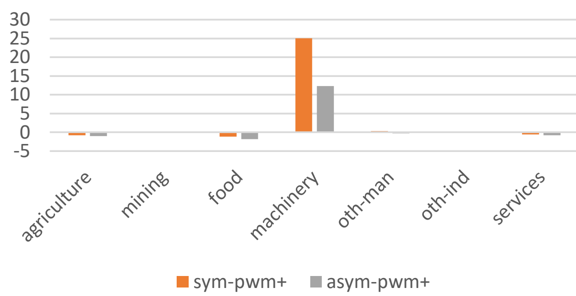


Figure 6.6. Scenario pwm+: Domestic output sales and purchases by commodity (% change)

Source: Authors' elaboration.

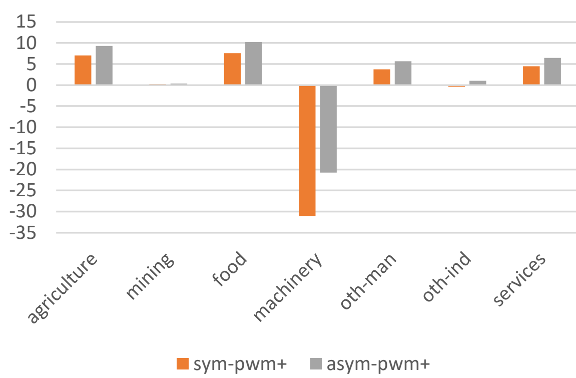


Figure 6.7. Scenario pwm+: Exports by commodity (% change)

Source: Authors' elaboration.

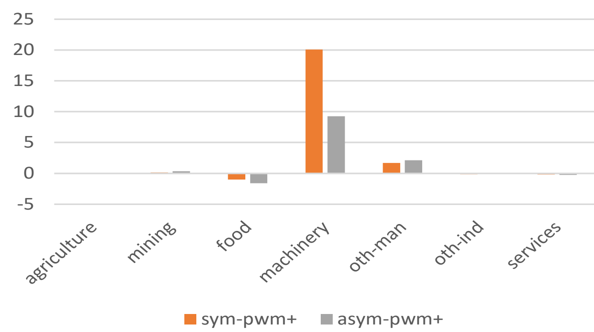


Figure 6.8. Scenario pwm+: Output by commodity (% change)

Source: Authors' elaboration.

For sectors other than mining, composite domestic demands decline across the board (Figure 6.4). These declines and the relatively small differences between the two variants were expected given the macro results for absorption. Among the products, the declines are strong for machinery (due to the import price increase) and food (the product with the highest overall price elasticity due to the high share of household demand).

Turning to imports and domestic sales (Figures 6.5 and 6.6), the degrees to which these demands decline vary and are related to changes in domestic output and exports. For example, the import decline is particularly sharp for food, for which domestic sales also decline, reflecting discouraged production of this relatively non-traded output (Figure 6.8). As expected (cf. the macro results in Figure 6.1), import reductions tend to be smaller for the asymmetric version. For machinery, the smaller import reduction for the asymmetric variant and an initially large import share are associated with a smaller increase in domestic sales.

Exports increase for most products (Figure 6.7). Across all products, they are larger for the asymmetric case which has the stronger aggregate export increase. The only product with an export decline is machinery for which, in the absence of any increase in the foreign-currency export price for machinery, the import price increase tilts incentives in favor of import-substituting domestic sales. Apart from mining (discussed above), exports are roughly unchanged for other industry since, for this sector, incentives for production are unfavorable given low exposure to trade and domestic demands are relatively fixed (cf. Figures 4 and 5).

Finally, domestic output changes (Figure 6.8) are most positive for machinery (given the above-mentioned incentive to substitute for imports) and, to a lesser extent, for other manufacturing (the product with the second largest import share in domestic demand; Figure 4). The output increase for machinery is less positive for the asymmetric variant since the import reduction is smaller. For other sectors, the changes in output and the differences between the two variants are less significant.

4.3. Reduced foreign savings

For this scenario, the shock is represented by the elimination of a current account deficit (at 5.7 percent of GDP); in other words, foreign savings is reduced to zero. The assumptions are identical to those used in Section 4.2. The results are summarized in Figures 7.1-7.8: sym-fsav- and asym-fsav- refer to results for the symmetric and asymmetric model versions, respectively. Given that the qualitative results for the most part are very similar to those of Section 4.2., they will be analyzed more briefly.

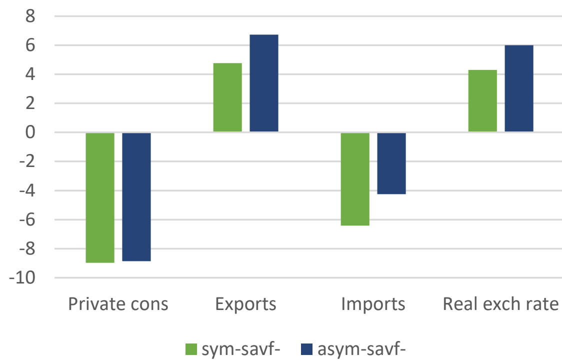


Figure 7.1. Scenario fsav-: Macro indicators (% change)

Source: Authors' elaboration.

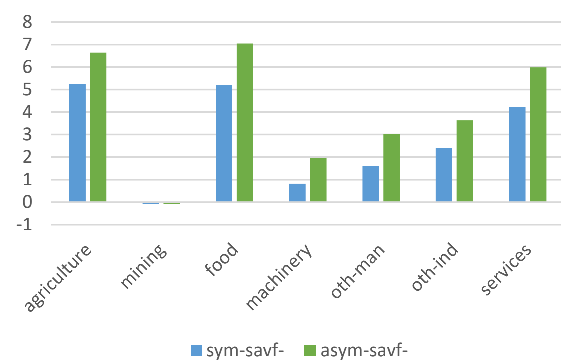


Figure 7.2. Scenario fsav-: PM/PDD (% change)

Source: Authors' elaboration.

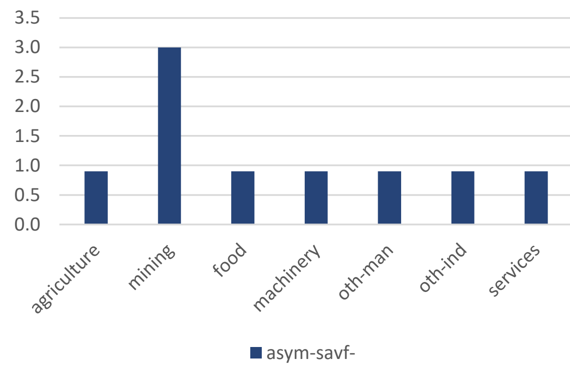


Figure 7.3 Scenario fsav-: Armington elasticies

Source: Authors' elaboration.

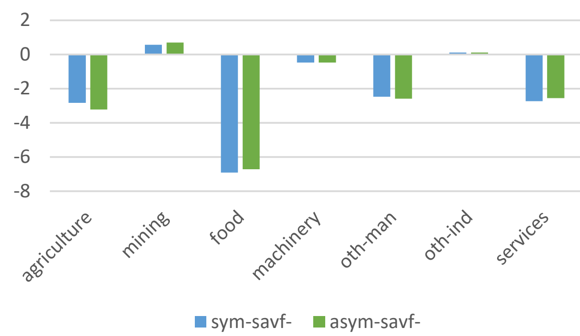


Figure 7.4 Scenario fsav-: Composite demand by commodity

Source: Authors' elaboration.

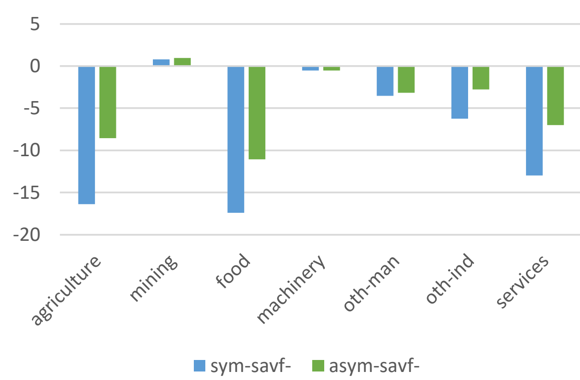


Figure 7.5 Scenario fsav-: Imports by commodity (% change)

Source: Authors' elaboration.

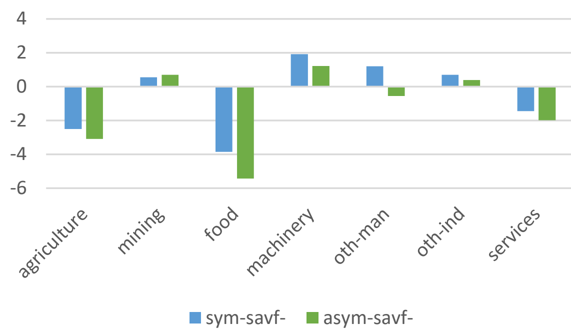


Figure 7.6 Scenario fsav-: Domestic output sales and purchases by commodity (% change)

Source: Authors' elaboration.

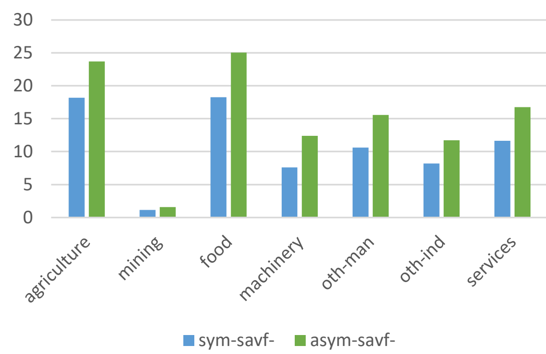


Figure 7.7 Scenario fsav-: Exports by commodity (% change)

Source: Authors' elaboration.

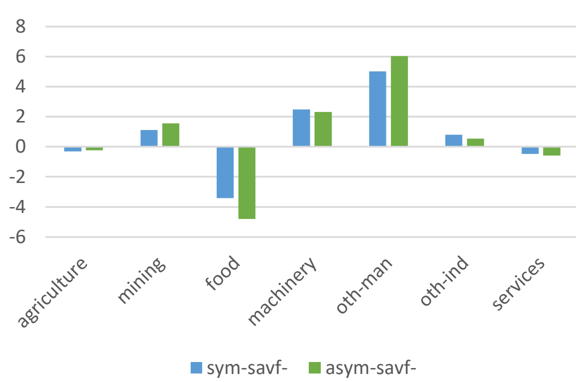


Figure 7.8 Scenario fsav-: Output by commodity (% change)

Source: Authors' elaboration.

The patterns of change are identical to those of Section 4.2 for macro indicators, the PM/PDD ratio, and Armington elasticities, including the differences between the symmetric and asymmetric model versions (Figures 7.1-7.3) – this follows from the fact that both shocks require reduced trade deficits. At the product level, the only changes in patterns are due to the fact that the machinery sector no longer is singled out by an import price shock, resulting in a different configuration of sector-level incentives for trade and domestic demands and supplies. The result is that, relative to other sectors, domestic demands and imports for machinery decline less (Figures 7.4 and 7.5) as the relative prices of machinery is lower. The fact that the import price now is lower, leads to smaller increase in machinery sales of domestic output (Figure 7.6) and creates space for a larger export increase (Figure 7.7). Finally, in the absence of the increase in the import price, the push to increase sector output is smaller (Figure 7.8).

5. Conclusions

This paper demonstrates how the Armington assumption used in most CGE models can be adapted to permit asymmetric response to increases and decreases in the ratio between the import and domestic output prices that are faced by domestic demanders. For the shocks and elasticity values used in the simulations, some of the differences between the two approaches seem important – not surprisingly, in an asymmetric world like the one presented in our model, it is more difficult for countries to adapt themselves to negative external shocks affecting the current account as a whole or import prices.

While we believe that there are strong a priory reasons for expecting asymmetries, the real-world significance of this treatment (or lack thereof) can only be determined by econometric research that draws on approaches that test for asymmetry and permit the estimation of the asymmetric elasticities that are needed for empirical applications of this approach.[9] If asymmetry turns out to be relevant, it will be important to try to understand the relationships that may exist between asymmetric elasticity estimates and the large literature with estimates made under the assumption of symmetry. Furthermore, if econometric analysis generates empirical support of Armington asymmetry, the extension of the approach to multi-region and dynamic settings should also be a priority.

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[9] For examples of econometric estimation that address the question of asymmetry, see Adeyemi et al. (2014; industrial energy demand and price changes); Demian and di Mauro (2018; export response to appreciation and depreciation episodes); Apanisile and Oloba (2020; trade and exchange rate changes); Iizuka and Shigeoka (2021; child health care demand and price changes); Biondi et al. (2020; asymmetric own and cross-price demand response for sugar-sweetened beverages in Great Britain); Sharimakin (2021; industrial energy demand and price changes); Huang et al. (2022; asymmetric price effects on food demand for rural households); and Yaman and Offiaeli (2022; asymmetries in own-price elasticities of travel demand on the London Underground).

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Appendix A: Normalized CES function

On a brief historical note, De La Grandville (1989) may have been the first to propose the normalized (or calibrated share form) of the CES function, using it in the context of a neoclassical growth model. Rutherford (1995, 2002) pioneered it in a CGE context. For a survey, see Klump et al. (2012).

In this appendix, we derive the formulas for the form that, in the main text, is used to model the Armington function. To simplify the derivation of the formulas, we omit the commodity set. The CES Armington function combines domestic products (QD) with imports (QM) to form the so-called Armington composite commodity (QQ). Mathematically, the optimization problem is to minimize the cost of purchasing the domestic products and imports subject to a CES production or utility function, i.e.,

$$\min PM \cdot QM + PDD \cdot QD$$

$$\text{s.t.}\, QQ = \left(\delta^{m} \cdot QM^{\rho^q} + \delta^{dd} \cdot QD^{\rho^q}\right)^{\frac{1}{\rho^q}}$$

$$\sigma^q = \frac{1}{1-\rho^q}$$

where

PDD: demander price for commodity produced and sold domestically
PM: demander price for import (domestic currency)
QD: quantity of domestic sales of domestic output
QM: quantity of imports
QQ: quantity of commodity supplied to domestic market (composite supply)
δ^{dd}: share parameter for domestic purchases in Armington function
δ^{m}: share parameter for imports in Armington function
σ^{q}: elasticity of substitution between purchases of domestic output and imports in Armington function

The Lagrangian is

$$\mathcal{L} = PM \cdot QM + PDD \cdot QD + \lambda \left[QQ - \left(\delta^{m} \cdot QM^{\rho^q} + \delta^{dd} \cdot QD^{\rho^q}\right)^{\frac{1}{\rho^q}} \right]$$

and the first-order conditions (FOCs) become

$$\frac{\partial \mathcal{L}}{\partial QM} = PM - \lambda \cdot \left(\frac{1}{\rho^q}\right) \cdot \left(\delta^{m} \cdot QM^{\rho^q} + \delta^{dd} \cdot QD^{\rho^q}\right)^{\frac{1}{\rho^q}-1} \cdot \delta^{m} \cdot \rho^q \cdot QM^{\rho^q - 1} = 0$$

$$\frac{\partial \mathcal{L}}{\partial QD} = PDD - \lambda \cdot \left(\frac{1}{\rho^q}\right) \cdot \left(\delta^{m} \cdot QM^{\rho^q} + \delta^{dd} \cdot QD^{\rho^q}\right)^{\frac{1}{\rho^q}-1} \cdot \delta^{dd} \cdot \rho^q \cdot QD^{\rho^q - 1} = 0$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} = QQ - \left(\delta^m \cdot QM^{\rho^q} + \delta^{dd} \cdot QD^{\rho^q}\right)^{\frac{1}{\rho^q}} = 0$$

From the first FOC,

$$PM = \lambda \cdot \left(\delta^m \cdot QM^{\rho^q} + \delta^{dd} \cdot QD^{\rho^q}\right)^{\frac{1-\rho^q}{\rho^q}} \cdot \delta^m \cdot QM^{\rho^q - 1}$$

$$QM^{\rho^q - 1} = \frac{PM}{\lambda} \cdot \left(\delta^m \cdot QM^{\rho^q} + \delta^{dd} \cdot QD^{\rho^q}\right)^{\frac{\rho^q - 1}{\rho^q}} \cdot \frac{1}{\delta^m}$$

$$QM = \left(\frac{PM}{\lambda}\right)^{\frac{1}{\rho^q - 1}} \cdot \left(\delta^m \cdot QM^{\rho^q} + \delta^{dd} \cdot QD^{\rho^q}\right)^{\frac{1}{\rho^q}} \cdot \left(\frac{1}{\delta^m}\right)^{\frac{1}{\rho^q - 1}}$$

$$QM = \left(\frac{\lambda}{PM}\right)^{\sigma^q} \cdot (\delta^m)^{\sigma^q} \cdot QQ$$

Similarly, from the second FOC,

$$QD = \left(\frac{\lambda}{PDD}\right)^{\sigma^q} \cdot \left(\delta^{dd}\right)^{\sigma^q} \cdot QQ$$

To show that the Lagrange multiplier, λ, is equal to the price of the Armington composite commodity PQ, we insert the optimal demands into the zero-profit condition

$$PQ \cdot QQ = PM \cdot QM + PDD \cdot QD$$

$$PQ \cdot QQ = PM \cdot \left(\frac{PQ}{PM}\right)^{\sigma^q} \cdot (\delta^m)^{\sigma^q} \cdot QQ + PD \cdot \left(\frac{PQ}{PD}\right)^{\sigma^q} \cdot \left(\delta^{dd}\right)^{\sigma^q} \cdot QQ$$

$$PQ = PM \cdot \left(\frac{PQ}{PM}\right)^{\sigma^q} \cdot (\delta^m)^{\sigma^q} + PD \cdot \left(\frac{PQ}{PD}\right)^{\sigma^q} \cdot \left(\delta^{dd}\right)^{\sigma^q}$$

$$PQ = PQ^{\sigma^q} \cdot \left(PM^{1-\sigma^q} \cdot (\delta^m)^{\sigma^q} + PD^{1-\sigma^q} \cdot \left(\delta^{dd}\right)^{\sigma^q}\right)$$

$$PQ^{1-\sigma^q} = \left(PM^{1-\sigma^q} \cdot (\delta^m)^{\sigma^q} + PD^{1-\sigma^q} \cdot \left(\delta^{dd}\right)^{\sigma^q}\right)$$

$$PQ = \left(PM^{1-\sigma^q} \cdot (\delta^m)^{\sigma^q} + PD^{1-\sigma^q} \cdot \left(\delta^{dd}\right)^{\sigma^q}\right)^{\frac{1}{1-\sigma^q}}$$

In turn, from the FOC, the calibration formulas for δ^m and δ^{dd} can be written as

$$\delta^m = \left(\frac{QM_0}{QQ_0}\right)^{\frac{1}{\sigma^q}} \cdot \left(\frac{PM_0}{PQ_0}\right)$$

$$\delta^{dd} = \left(\frac{QD_0}{QQ_0}\right)^{\frac{1}{\sigma^q}} \cdot \left(\frac{PDD_0}{PQ_0}\right)$$

where we again replaced λ with PQ, the price of the Armington composite commodity.

Now, to derive the CES calibrated share form, we replace the calibration formulas for δ^m and δ^{dd} into the CES Armington function, i.e.,

$$QQ = \left[\left(\frac{QM_0}{QQ_0}\right)^{1-\rho^q} \cdot \left(\frac{PM_0}{PQ_0}\right) \cdot QM^{\rho^q} + \left(\frac{QD_0}{QQ_0}\right)^{1-\rho^q} \cdot \left(\frac{PDD_0}{PQ_0}\right) \cdot QD^{\rho^q}\right]^{\frac{1}{\rho^q}}$$

$$QQ = \left[\left(\frac{QM_0}{QQ_0}\right)^{1-\rho^q} \cdot \left(\frac{QM_0^{\rho^q}}{QM_0^{\rho^q}}\right) \cdot \left(\frac{PM_0}{PQ_0}\right) \cdot QM^{\rho^q} + \left(\frac{QD_0}{QQ_0}\right)^{1-\rho^q} \cdot \left(\frac{QD_0^{\rho^q}}{QD_0^{\rho^q}}\right) \cdot \left(\frac{PDD_0}{PQ_0}\right) \cdot QD^{\rho^q}\right]^{\frac{1}{\rho^q}}$$

$$QQ = \left[QM_0\left(\frac{1}{QQ_0}\right)^{1-\rho^q} \cdot \left(\frac{PM_0}{PQ_0}\right) \cdot \left(\frac{QM}{QM_0}\right)^{\rho^q} + QD_0\left(\frac{1}{QQ_0}\right)^{1-\rho^q} \cdot \left(\frac{PDD_0}{PQ_0}\right) \cdot \left(\frac{QD}{QD_0}\right)^{\rho^q}\right]^{\frac{1}{\rho^q}}$$

$$QQ = \left[\frac{PM_0 \cdot QM_0}{PQ_0 \cdot QQ_0} \cdot \left(\frac{1}{QQ_0}\right)^{-\rho^q} \cdot \left(\frac{QM}{QM_0}\right)^{\rho^q} + \frac{PDD_0 \cdot QD_0}{PQ_0 \cdot QQ_0} \cdot \left(\frac{1}{QQ_0}\right)^{-\rho^q} \cdot \left(\frac{QD}{QD_0}\right)^{\rho^q}\right]^{\frac{1}{\rho^q}}$$

$$QQ = \left[QQ_0^{\rho^q}\left(\frac{PM_0 \cdot QM_0}{PQ_0 \cdot QQ_0} \cdot \left(\frac{QM}{QM_0}\right)^{\rho^q} + \frac{PDD_0 \cdot QD_0}{PQ_0 \cdot QQ_0} \cdot \left(\frac{QD}{QD_0}\right)^{\rho^q}\right)\right]^{\frac{1}{\rho^q}}$$

$$QQ = QQ_0\left[\theta^m \cdot \left(\frac{QM}{QM_0}\right)^{\rho^q} + \theta^{dd} \cdot \left(\frac{QD}{QD_0}\right)^{\rho^q}\right]^{\frac{1}{\rho^q}}$$

where

$$\theta^m = \frac{PM \cdot QM}{PM \cdot QM + PDD \cdot QD}$$

$$\theta^{dd} = \frac{PDD \cdot QD}{PM \cdot QM + PDD \cdot QD}$$

Similarly, it is possible to show that

$$PQ = PQ_0 \cdot \left[\theta^m \cdot \left(\frac{PM}{PM_0}\right)^{1-\sigma^q} + \theta^{dd} \cdot \left(\frac{PDD}{PDD_0}\right)^{1-\sigma^q}\right]^{\frac{1}{1-\sigma^q}}$$

Therefore, we see that, in the CES calibrated share form, the demand and cost functions explicitly incorporate benchmark demands, benchmark prices, the elasticity of substitution, benchmark cost, benchmark output, and benchmark value shares

Appendix B. Simulation results in table form

Table B.1. Table with selected simulation results (% change from base)*

		sym-pwm+	asym-pwm+	sym-savf-	asym-savf-			sym-pwm+	asym-pwm+	sym-savf-	asym-savf-
Macro	**Private cons**	-3.56	-3.50	-8.98	-8.86	**Imports**	**Agriculture**	-6.65	-3.35	-16.36	-8.54
	Exports	1.55	2.35	4.76	6.72		**Mining**	0.22	0.37	0.80	0.97
	Imports	-2.82	-1.94	-6.42	-4.25		**Food**	-7.11	-4.30	-17.40	-11.05
	GDP at f.c.	-0.02	-0.02	0.06	0.05		**Machinery**	-2.32	-1.97	-0.54	-0.53
	Real exch rate	1.47	2.18	4.29	6.00		**Other manuf.**	-1.44	-1.30	-3.55	-3.18
							Other industry	0.11	-0.36	-6.25	-2.79
							Services	-5.32	-2.84	-12.96	-6.99
PM/PDD	**Agriculture**	2.05	2.65	5.24	6.64	**Domestic sales of domestic output**	**Agriculture**	-0.80	-1.04	-2.50	-3.09
	Mining	-0.07	-0.08	-0.08	-0.09		**Mining**	0.02	0.13	0.55	0.69
	Food	2.09	2.86	5.19	7.04		**Food**	-1.16	-1.84	-3.86	-5.44
	Machinery	8.58	16.29	0.82	1.96		**Machinery**	25.06	12.30	1.92	1.22
	Other manuf.	0.59	1.13	1.62	3.02		**Other manuf.**	0.31	-0.30	1.21	-0.55
	Other industry	-0.08	0.36	2.41	3.63		**Other industry**	-0.13	-0.04	0.70	0.38
	Services	1.65	2.36	4.23	5.99		**Services**	-0.56	-0.78	-1.45	-1.99
Armington elastiicity*	**Agriculture**	3.0	0.9	3.0	0.9	**Exports**	**Agriculture**	7.07	9.30	18.17	23.67
	Mining	3.0	3.0	3.0	3.0		**Mining**	0.15	0.36	1.15	1.60
	Food	3.0	0.9	3.0	0.9		**Food**	7.55	10.20	18.27	25.03
	Machinery	3.0	0.9	3.0	0.9		**Machinery**	-31.05	-20.73	7.61	12.38
	Other manuf.	3.0	0.9	3.0	0.9		**Other manuf.**	3.74	5.69	10.61	15.58
	Other industry	3.0	0.9	3.0	0.9		**Other industry**	-0.37	1.05	8.17	11.73
	Services	3.0	0.9	3.0	0.9		**Services**	4.46	6.44	11.63	16.74
Composite supply	**Agriculture**	-0.94	-1.10	-2.83	-3.22	**Output**	**Agriculture**	0.02	0.04	-0.32	-0.24
	Mining	0.03	0.14	0.56	0.70		**Mining**	0.14	0.35	1.12	1.55
	Food	-2.49	-2.39	-6.92	-6.71		**Food**	-0.99	-1.59	-3.41	-4.81
	Machinery	-1.53	-1.57	-0.47	-0.48		**Machinery**	20.06	9.26	2.47	2.32
	Other manuf.	-1.04	-1.07	-2.48	-2.59		**Other manuf.**	1.70	2.12	5.02	6.03
	Other industry	-0.11	-0.06	0.11	0.11		**Other industry**	-0.13	-0.02	0.80	0.53
	Services	-1.08	-1.01	-2.73	-2.55		**Services**	-0.19	-0.25	-0.47	-0.59

*Level of elasticity, not % change from base