IUU Fishing: Economic Effects of IUU Imports on U.S. Commercial Fishers

Species: Sardine, Herring, Anchovies, Mackerel

Model Release

Read Me :
This model accompanies the USITC report, *Seafood Obtained via Illegal, Unreported, and Unregulated Fishing: U.S. Imports and Economic Impact on U.S. Commercial Fisheries*, Inv. 332-575. The report includes a quantitative analysis of the economic impact of IUU imports on U.S. commercial fishers and U.S. commercial fishing production, trade, and prices. Economic effects are modeled by species, with each species-level model customized to fit the unique features of the U.S. domestic industry. Consumers of seafood products choose between domestic marine-capture sources, imports, and in some models, domestic aquaculture products. Imports include both legal and IUU sources that enter the U.S. at the same price, so consumers cannot distinguish an IUU from non-IUU product. 2018 data is used to establish an initial equilibrium with imports of IUU products included in the baseline. The model then removes the IUU imports, as estimated in chapter 3, and solves for a new equilibrium absent those products.

In the forage fish model, there are domestic and imported varieties of sardine, herring, anchovies, and mackerel species. The model includes cross-species substitution, so relative price changes in one species affects the other species. Annual catch limits (ACLs) are enforced in the model so modeled increases in domestic landings cannot exceed their legal limits. Catch limits are modeled as a vertical asymptote directly in the supply equation and not as a constraint.

There are two markets modeled: unprocessed and processed products. Landings flow to three destinations: the unprocessed market, the processed market, or are exported outside the country. The price of the processed product is a constant markup over the price of the unprocessed product, so increases in domestic prices of landed fish affect the price of processing. Initial consumption of unprocessed products, before the policy change was implemented, was calculated as a residual using 2018 conversion factors.

Data inputs in the simulation are in the BLUE-shaded cells (with sources for the input data listed in the cell above). Outputs are in the GREEN-shaded cells. The white cells are intermediate calculations.

Note: p_xDU is the price of the unprocessed product sold to consumers. q_xDU is the quantity of landings, not the unprocessed quantity sold to U.S. consumers. The unprocessed quantity sold to U.S. consumers must exclude exports and processed product * conversion rate.

This PDF is a printout of the Mathematica file “IUU Fishing Model - forage fish - model release.nb”

```
In[ ]:= ClearAll[f];
```

Table of Contents

1. Model Parameters

1.1 Within-Species Elasticity of Substitution

Source: USITC's econometric estimation using the trade cost method in Riker (2020). More information can be found in the technical appendix (appendix I).

Unprocessed Sardine: elasticity of substitution across varieties of unprocessed sardine

```
In[ ]:= sigmasu = 6.57295 ;
```

Processed Sardine: elasticity of substitution across varieties of processed sardine

```
In[ ]:= sigmasp = 6.57295 ;
```

Unprocessed Herring: elasticity of substitution across varieties of unprocessed herring

```
In[ ]:= sigmahu = 7.794977;
```

Processed Herring: elasticity of substitution across varieties of processed herring

In[ ]:=
```
sigmahp = 7.794977;
```

Unprocessed Anchovy: elasticity of substitution across varieties of unprocessed anchovy

In[ ]:=
```
sigmaau = 5.863256;
```

Processed Anchovy: elasticity of substitution across varieties of processed anchovy

In[ ]:=
```
sigmaap = 5.863256;
```

Unprocessed Mackerel: elasticity of substitution across varieties of unprocessed mackerel

In[ ]:=
```
sigmamu = 7.794977;
```

Processed Mackerel: elasticity of substitution across varieties of processed mackerel

In[ ]:=
```
sigmamp = 7.794977;
```

1.2 Cross-Species Elasticity of Substitution

Source: USITC Staff Estimate and Interviews with Industry Participants.

Unprocessed: elasticity of substitution across unprocessed products

In[ ]:=
```
betau = 3.0;
```

Processed: elasticity of substitution across processed products

In[ ]:=
```
betap = 3.0;
```

1.3 Industry Price Elasticity of Demand

Source: USITC Staff Estimate.

Unprocessed

In[ ]:=
```
etau = -1.0;
```

Processed

In[ ]:=
```
etap = -1.0;
```

1.4 Illegal Imports Replacement Rates

Source: USITC Staff Estimate. Further discussion on qualitative factors and rate determination can be found in appendix I of the USITC's report.

Sardine: fraction of illegal imports replaced by legal imports of sardine

In[ ]:=
```
repls = 0.30 ;
```

Herring: fraction of illegal imports replaced by legal imports of herring

In[ ]:=
```
replh = 0.50;
```

Anchovy: fraction of illegal imports replaced by legal imports of anchovy

In[ ]:=
```
repla = 0.50;
```

Mackerel: fraction of illegal imports replaced by legal imports of mackerel

In[ ]:=
```
replm = 0.30;
```

1.5 Price Elasticity of Supply

Source: USITC Staff Estimate and Interviews with Industry Participants.

U.S. landings of Sardine

In[ ]:=
```
esd = 1.0;
```

U.S. landings of Herring

In[ ]:=
```
ehd = 2.0;
```

U.S. landings of Anchovy

In[ ]:=
```
ead = 5.0;
```

U.S. landings of Mackerel

In[ ]:=
```
emd = 5.0;
```

1.6 Conversion Factors

Source: Conversion factors were obtained from NOAA Fisheries

In[ ]:=
```
cr = 1.0;
```

2. Data Inputs

2.1 U.S. Landings Quantities and Prices

Source: National Oceanic and Atmospheric Administration. National Marine Fisheries Service (NOAA Fisheries). Fisheries of the United States 2018. Current Fishery Statistics No. 2018. U.S. Department of Commerce. Silver Spring MD: NOAA, February 2020. https://www.fisheries.noaa.gov/resource/document/fisheries-united-states-2018-report.

Sardine

In[ ]:=
```
qsdu0 = 1 005 000; (*kg*)
```

In[ ]:=
```
psdu0 = 0.44776119; (*$/kg*)
```

Herring

In[ ]:=
```
qhdu0 = 66 719 000; (*kg*)
```

In[ ]:=
```
phdu0 = 0.49371244; (*$/kg*)
```

Anchovy

In[ ]:=
```
qadu0 = 17 360 000; (*kg*)
```

In[ ]:=
```
padu0 = 0.11388249; (*$/kg*)
```

Mackerel

In[ ]:=
```
qmdu0 = 87 333 209; (*kg*)
```

In[ ]:=
```
pmdu0 = 0.90390598; (*$/kg*)
```

2.2 U.S. Processing Production Quantities and Prices

Sources:
National Oceanic and Atmospheric Administration. National Marine Fisheries Service (NOAA Fisheries). Fisheries of the United States 2018. Current Fishery Statistics No. 2018. U.S. Department of Commerce. Silver Spring MD: NOAA, February 2020. https://www.fisheries.noaa.gov/resource/document/fisheries-united-states-2018-report.

National Oceanic and Atmospheric Administration. National Marine Fisheries Service (NOAA Fisheries). NOAA Processed Products database. Accessed September 1, 2020.https://www.fisheries.noaa.gov/foss/f?p=215:3:5412288074334::NO:::

Processed Sardine

In[ ]:=
```
qsdp0 = 42 925; (*kg*)
```

In[ ]:=
```
psdp0 = 1.1706711; (*$/kg*)
```

Processed Herring

In[ ]:=
```
qhdp0 = 2 857 406; (*kg*)
```

In[ ]:=
```
phdp0 = 1.1706713; (*$/kg*)
```

Processed Anchovy

In[ ]:=
```
qadp0 = 7 229 685;(*kg*)
```

In[ ]:=
```
padp0 = 0.4867994;(*$/kg*)
```

Processed Mackerel

In[ ]:=
```
qmdp0 = 40 331 122;(*kg*)
```

In[ ]:=
```
pmdp0 = 3.0128494;(*$/kg*)
```

2.3 Import Quantities and Prices

Source: IUU Estimate Database as described in Chapter 3 of the report.

Sardine

Total unprocessed imports

In[ ]:=
```
qstu0 = 14 991 943; (*kg*)
```

In[ ]:=
```
pstu0 = 0.641524; (*$/kg*)
```

Total processed imports

In[ ]:=
```
qstp0 = 35 602 018; (*kg*)
```

In[ ]:=
```
pstp0 = 4.17392; (*$/kg*)
```

Illegal imports

In[ ]:=
```
qsiu0 = 2 943 611;(*kg*)
```

In[ ]:=
```
qsip0 = 7 470 902;(*kg*)
```

Herring

Total unprocessed imports

In[ ]:=
```
qhtu0 = 2 459 463;(*kg*)
```

In[ ]:=
```
phtu0 = 1.50032; (*$/kg*)
```

Total processed imports

In[ ]:=
```
qhtp0 = 11 509 060;(*kg*)
```

In[∘]:=
```
phtp0 = 3.75706; (*$/kg*)
```

Illegal imports

In[∘]:=
```
qhiu0 = 176 774;(*kg*)
```

In[∘]:=
```
qhip0 = 799 269; (*kg*)
```

Anchovy

Total unprocessed imports

In[∘]:=
```
qatu0 = 1 761 278;(*kg*)
```

In[∘]:=
```
patu0 = 2.39253; (*$/kg*)
```

Total processed imports

In[∘]:=
```
qatp0 = 4 890 903; (*kg*)
```

In[∘]:=
```
patp0 = 8.04725; (*$/kg*)
```

Illegal imports

In[∘]:=
```
qaiu0 = 249 603; (*kg*)
```

In[∘]:=
```
qaip0 = 797 667; (*kg*)
```

Mackerel

Total unprocessed imports

In[∘]:=
```
qmtu0 = 12 751 352;(*kg*)
```

In[∘]:=
```
pmtu0 = 2.76512; (*$/kg*)
```

Total processed imports

In[∘]:=
```
qmtp0 = 20 583 069; (*kg*)
```

In[∘]:=
```
pmtp0 = 3.63618; (*$/kg*)
```

Illegal imports

In[∘]:=
```
qmiu0 = 1 575 693; (*kg*)
```

```
In[ ]:= qmip0 = 3 350 876; (*kg*)
```

Calculation of legal imports

```
In[ ]:= qslu0 = qstu0 - qsiu0;
In[ ]:= qslp0 = qstp0 - qsip0;
In[ ]:= qhlu0 = qhtu0 - qhiu0;
In[ ]:= qhlp0 = qhtp0 - qhip0;
In[ ]:= qalu0 = qatu0 - qaiu0;
In[ ]:= qalp0 = qatp0 - qaip0;
In[ ]:= qmlu0 = qmtu0 - qmiu0;
In[ ]:= qmlp0 = qmtp0 - qmip0;
```

2.4 Export Quantities

Source:National Oceanic and Atmospheric Administration. National Marine Fisheries Service (NOAA Fisheries). NOAA US Trade in Fishery Products database. Accessed September 1, 2020. https://foss.nmfs.noaa.gov/apexfoss/f?p=215:2:14884747663545::NO

```
In[ ]:= qsdue0 = 0; (*kg*)
In[ ]:= qsdpe0 =  0; (*kg*)
In[ ]:= qhdue0 = 24 393 816; (*kg*)
In[ ]:= qhdpe0 =  70 366; (*kg*)
In[ ]:= qadue0 = 976 448; (*kg*)
In[ ]:= qadpe0 =  920 018; (*kg*)
In[ ]:= qmdue0 = 44 884 808; (*kg*)
In[ ]:= qmdpe0 =  19 330; (*kg*)
```

2.5 Catch Limits

Sardine

Source: 82 Fed. Reg. 29776 (June 30, 2018)

```
In[ ]:= qsdcap = 8 000 000; (*kg*)
```

Herring

No aggregate ACL available, inserted arbitrarily high limit so it doesn't affect calculation.

In[ ]:=
```
qhdcap = 200 000 000; (*kg*)
```

Anchovy

Source: Pacific Fishery Management Council, "Annual Season Management," accessed November 19, 2020. https://www.pcouncil.org/current-season-management/

In[ ]:=
```
qadcap = 34 750 000; (*kg*)
```

Mackerel

Source: Aggregated several ACLs for jack, Atlantic, chub, king, Spanish, and atka mackerel species.

In[ ]:=
```
qmdcap = 180 605 093; (*kg*)
```

2.6 Import Market Share Statistics

Imports percent in market for unprocessed sardine

In[ ]:=
```
N[qstu0 / (qstu0 + (qsdu0 - qsdue0 - cr qsdp0))]
```

Out[ ]= 0.939697

Imports percent in market for processed sardine

In[ ]:=
```
N[qstp0 / (qstp0 + (qsdp0 - qsdpe0))]
```

Out[ ]= 0.998796

Imports percent in market for unprocessed herring

In[ ]:=
```
N[qhtu0 / (qhtu0 + (qhdu0 - qhdue0 - cr qhdp0))]
```

Out[ ]= 0.0586603

Imports percent in market for processed herring

In[ ]:=
```
N[qhtp0 / (qhtp0 + (qhdp0 - qhdpe0))]
```

Out[ ]= 0.805049

Imports percent in market for unprocessed anchovy

In[ ]:=
```
N[qatu0 / (qatu0 + (qadu0 - qadue0 - cr qadp0))]
```

Out[ ]= 0.161361

Imports percent in market for processed anchovy

In[ ]:=
```
N[qatp0 / (qatp0 + (qadp0 - qadpe0))]
```

Out[ ]= 0.436666

Imports percent in market for unprocessed mackerel

In[ ]:= N[qmtu0 / (qmtu0 + (qmdu0 - qmdue0 - cr qmdp0))]

Out[ ]= 0.857601

Imports percent in market for processed mackerel

In[ ]:= N[qmtp0 / (qmtp0 + (qmdp0 - qmdpe0))]

Out[ ]= 0.33801

3. Calibration

Baseline values of unprocessed and processed apparent consumption and imports

```
In[ ]:= vstu0 = qstu0 pstu0;
In[ ]:= vstp0 = qstp0 pstp0;
In[ ]:= vhtu0 = qhtu0 phtu0;
In[ ]:= vhtp0 = qhtp0 phtp0;
In[ ]:= vatu0 = qatu0 patu0;
In[ ]:= vatp0 = qatp0 patp0;
In[ ]:= vmtu0 = qmtu0 pmtu0;
In[ ]:= vmtp0 = qmtp0 pmtp0;
In[ ]:= vsdu0 = (qsdu0 - qsdue0 - cr qsdp0) psdu0;
In[ ]:= vsdp0 = (qsdp0 - qsdpe0) psdp0;
In[ ]:= vhdu0 = (qhdu0 - qhdue0 - cr qhdp0) phdu0;
In[ ]:= vhdp0 = (qhdp0 - qhdpe0) phdp0;
In[ ]:= vadu0 = (qadu0 - qadue0 - cr qadp0) padu0;
In[ ]:= vadp0 = (qadp0 - qadpe0) padp0;
In[ ]:= vmdu0 = (qmdu0 - qmdue0 - cr qmdp0) pmdu0;
In[ ]:= vmdp0 = (qmdp0 - qmdpe0) pmdp0;
```

In[ ]:= 3.1 Supply Parameters

In[ ]:= $esdu = N\left[esd \frac{qsdu0}{(qsdcap - qsdu0)}\right];$

In[ ]:= $asdu = (qsdcap - qsdu0)\ psdu0^{esdu};$

In[ ]:= $ehdu = N\left[ehd \frac{qhdu0}{(qhdcap - qhdu0)}\right];$

In[ ]:= $ahdu = (qhdcap - qhdu0)\ phdu0^{ehdu};$

In[ ]:= $$\text{eadu} = N\left[\text{ead}\,\frac{\text{qadu0}}{(\text{qadcap} - \text{qadu0})}\right];$$

In[ ]:= $$\text{aadu} = (\text{qadcap} - \text{qadu0})\,\text{padu0}^{\text{eadu}};$$

In[ ]:= $$\text{emdu} = N\left[\text{emd}\,\frac{\text{qmdu0}}{(\text{qmdcap} - \text{qmdu0})}\right];$$

In[ ]:= $$\text{amdu} = (\text{qmdcap} - \text{qmdu0})\,\text{pmdu0}^{\text{emdu}};$$

In[ ]:=
3.2 Demand Parameters

In[ ]:= $$\text{bstu} = \frac{\text{vstu0}}{\text{vsdu0}}\left(\frac{\text{pstu0}}{\text{psdu0}}\right)^{\text{sigmasu-1}};$$

In[ ]:= $$\text{Psu0} = \left(\text{psdu0}^{1-\text{sigmasu}} + \text{bstu}\,\text{pstu0}^{1-\text{sigmasu}}\right)^{\frac{1}{1-\text{sigmasu}}};$$

In[ ]:= $$\text{bhtu} = \frac{\text{vhtu0}}{\text{vhdu0}}\left(\frac{\text{phtu0}}{\text{phdu0}}\right)^{\text{sigmahu-1}};$$

In[ ]:= $$\text{Phu0} = \left(\text{phdu0}^{1-\text{sigmahu}} + \text{bhtu}\,\text{phtu0}^{1-\text{sigmahu}}\right)^{\frac{1}{1-\text{sigmahu}}};$$

In[ ]:= $$\text{batu} = \frac{\text{vatu0}}{\text{vadu0}}\left(\frac{\text{patu0}}{\text{padu0}}\right)^{\text{sigmaau-1}};$$

In[ ]:= $$\text{Pau0} = \left(\text{padu0}^{1-\text{sigmaau}} + \text{batu}\,\text{patu0}^{1-\text{sigmaau}}\right)^{\frac{1}{1-\text{sigmaau}}};$$

In[ ]:= $$\text{bmtu} = \frac{\text{vmtu0}}{\text{vmdu0}}\left(\frac{\text{pmtu0}}{\text{pmdu0}}\right)^{\text{sigmamu-1}};$$

In[ ]:= $$\text{Pmu0} = \left(\text{pmdu0}^{1-\text{sigmamu}} + \text{bmtu}\,\text{pmtu0}^{1-\text{sigmamu}}\right)^{\frac{1}{1-\text{sigmamu}}};$$

In[ ]:= $$\text{bhu} = \frac{\text{vhdu0} + \text{vhtu0}}{\text{vsdu0} + \text{vstu0}}\left(\frac{\text{Phu0}}{\text{Psu0}}\right)^{\text{betau-1}};$$

In[ ]:= $$\text{bau} = \frac{\text{vadu0} + \text{vatu0}}{\text{vsdu0} + \text{vstu0}}\left(\frac{\text{Pau0}}{\text{Psu0}}\right)^{\text{betau-1}};$$

In[ ]:= $$\text{bmu} = \frac{\text{vmdu0} + \text{vmtu0}}{\text{vsdu0} + \text{vstu0}}\left(\frac{\text{Pmu0}}{\text{Psu0}}\right)^{\text{betau-1}};$$

In[ ]:= $$\text{Pu0} = \left(\text{Psu0}^{1-\text{betau}} + \text{bhu}\,\text{Phu0}^{1-\text{betau}} + \text{bau}\,\text{Pau0}^{1-\text{betau}} + \text{bmu}\,\text{Pmu0}^{1-\text{betau}}\right)^{\frac{1}{1-\text{betau}}};$$

In[ ]:= $$\text{bstp} = \frac{\text{vstp0}}{\text{vsdp0}}\left(\frac{\text{pstp0}}{\text{psdp0}}\right)^{\text{sigmasp-1}};$$

In[ ]:= $$\text{Psp0} = \left(\text{psdp0}^{1-\text{sigmasp}} + \text{bstp}\,\text{pstp0}^{1-\text{sigmasp}}\right)^{\frac{1}{1-\text{sigmasp}}};$$

In[ ]:= $$\text{bhtp} = \frac{\text{vhtp0}}{\text{vhdp0}}\left(\frac{\text{phtp0}}{\text{phdp0}}\right)^{\text{sigmahp-1}};$$

In[ ]:= $$\text{Php0} = \left(\text{phdp0}^{1-\text{sigmahp}} + \text{bhtp}\,\text{phtp0}^{1-\text{sigmahp}}\right)^{\frac{1}{1-\text{sigmahp}}};$$

In[ ]:= $$\text{batp} = \frac{\text{vatp0}}{\text{vadp0}} \left(\frac{\text{patp0}}{\text{padp0}}\right)^{\text{sigmaap}-1};$$

In[ ]:= $$\text{Pap0} = \left(\text{padp0}^{1-\text{sigmaap}} + \text{batp}\ \text{patp0}^{1-\text{sigmaap}}\right)^{\frac{1}{1-\text{sigmaap}}};$$

In[ ]:= $$\text{bmtp} = \frac{\text{vmtp0}}{\text{vmdp0}} \left(\frac{\text{pmtp0}}{\text{pmdp0}}\right)^{\text{sigmamp}-1};$$

In[ ]:= $$\text{Pmp0} = \left(\text{pmdp0}^{1-\text{sigmamp}} + \text{bmtp}\ \text{pmtp0}^{1-\text{sigmamp}}\right)^{\frac{1}{1-\text{sigmamp}}};$$

In[ ]:= $$\text{bhp} = \frac{\text{vhdp0} + \text{vhtp0}}{\text{vsdp0} + \text{vstp0}} \left(\frac{\text{Php0}}{\text{Psp0}}\right)^{\text{betap}-1};$$

In[ ]:= $$\text{bap} = \frac{\text{vadp0} + \text{vatp0}}{\text{vsdp0} + \text{vstp0}} \left(\frac{\text{Pap0}}{\text{Psp0}}\right)^{\text{betap}-1};$$

In[ ]:= $$\text{bmp} = \frac{\text{vmdp0} + \text{vmtp0}}{\text{vsdp0} + \text{vstp0}} \left(\frac{\text{Pmp0}}{\text{Psp0}}\right)^{\text{betap}-1};$$

In[ ]:= $$\text{Pp0} = \left(\text{Psp0}^{1-\text{betap}} + \text{bhp}\ \text{Php0}^{1-\text{betap}} + \text{bap}\ \text{Pap0}^{1-\text{betap}} + \text{bmp}\ \text{Pmp0}^{1-\text{betap}}\right)^{\frac{1}{1-\text{betap}}};$$

In[ ]:= $$\text{ku} = \frac{\text{qstu0}\ \text{Pu0}^{-\text{etau}-\text{betau}}\ \text{Psu0}^{\text{betau}-\text{sigmasu}}\ \text{pstu0}^{\text{sigmasu}}}{\text{bstu}};$$

In[ ]:= $$\text{kp} = \frac{\text{qstp0}\ \text{Pp0}^{-\text{etap}-\text{betap}}\ \text{Psp0}^{\text{betap}-\text{sigmasp}}\ \text{pstp0}^{\text{sigmasp}}}{\text{bstp}};$$

4. New Equilibrium Calculation

In[ ]:= $$\text{Psu} = \left(\text{psdu}^{1-\text{sigmasu}} + \text{bstu}\ \text{pstu}^{1-\text{sigmasu}}\right)^{\frac{1}{1-\text{sigmasu}}};$$

In[ ]:= $$\text{Phu} = \left(\text{phdu}^{1-\text{sigmahu}} + \text{bhtu}\ \text{phtu}^{1-\text{sigmahu}}\right)^{\frac{1}{1-\text{sigmahu}}};$$

In[ ]:= $$\text{Pau} = \left(\text{padu}^{1-\text{sigmaau}} + \text{batu}\ \text{patu}^{1-\text{sigmaau}}\right)^{\frac{1}{1-\text{sigmaau}}};$$

In[ ]:= $$\text{Pmu} = \left(\text{pmdu}^{1-\text{sigmamu}} + \text{bmtu}\ \text{pmtu}^{1-\text{sigmamu}}\right)^{\frac{1}{1-\text{sigmamu}}};$$

In[ ]:= $$\text{Pu} = \left(\text{Psu}^{1-\text{betau}} + \text{bhu}\ \text{Phu}^{1-\text{betau}} + \text{bau}\ \text{Pau}^{1-\text{betau}} + \text{bmu}\ \text{Pmu}^{1-\text{betau}}\right)^{\frac{1}{1-\text{betau}}};$$

In[ ]:= $$\text{psdp} = \frac{\text{psdu}\ \text{psdp0}}{\text{psdu0}};$$

In[ ]:= $$\text{phdp} = \frac{\text{phdu}\ \text{phdp0}}{\text{phdu0}};$$

In[ ]:= $$\text{padp} = \frac{\text{padu}\ \text{padp0}}{\text{padu0}};$$

In[ ]:= $$\text{pmdp} = \frac{\text{pmdu}\ \text{pmdp0}}{\text{pmdu0}};$$

In[ ]:= $$\text{Psp} = \left(\text{psdp}^{1-\text{sigmasp}} + \text{bstp}\ \text{pstp}^{1-\text{sigmasp}}\right)^{\frac{1}{1-\text{sigmasp}}};$$

In[ ]:= $$Php = \left(phdp^{1-sigmahp} + bhtp\ phtp^{1-sigmahp}\right)^{\frac{1}{1-sigmahp}};$$

In[ ]:= $$Pap = \left(padp^{1-sigmaap} + batp\ patp^{1-sigmaap}\right)^{\frac{1}{1-sigmaap}};$$

In[ ]:= $$Pmp = \left(pmdp^{1-sigmamp} + bmtp\ pmtp^{1-sigmamp}\right)^{\frac{1}{1-sigmamp}};$$

In[ ]:= $$Pp = \left(Psp^{1-betap} + bhp\ Php^{1-betap} + bap\ Pap^{1-betap} + bmp\ Pmp^{1-betap}\right)^{\frac{1}{1-betap}};$$

Equilibrium equations

Supply (landings) of sardine = exports + consumer demand for unprocessed fish + consumer demand for processed fish

In[ ]:= $$E1 = qsdcap - asdu\ psdu^{-esdu} == qsdue0 + cr\ qsdpe0 + ku\ Pu^{etau+betau}\ Psu^{sigmasu-betau}\ psdu^{-sigmasu} + cr\ kp\ Pp^{etap+betap}\ Psp^{sigmasp-betap}\ psdp^{-sigmasp};$$

Supply (landings) of herring = exports + consumer demand for unprocessed fish + consumer demand for processed fish

In[ ]:= $$E2 = qhdcap - ahdu\ phdu^{-ehdu} == qhdue0 + cr\ qhdpe0 + ku\ bhu\ Pu^{etau+betau}\ Phu^{sigmahu-betau}\ phdu^{-sigmahu} + cr\ bhp\ kp\ Pp^{etap+betap}\ Php^{sigmahp-betap}\ phdp^{-sigmahp};$$

Supply (landings) of anchovy = exports + consumer demand for unprocessed fish + consumer demand for processed fish

In[ ]:= $$E3 = qadcap - aadu\ padu^{-eadu} == qadue0 + cr\ qadpe0 + ku\ bau\ Pu^{etau+betau}\ Pau^{sigmaau-betau}\ padu^{-sigmaau} + cr\ bap\ kp\ Pp^{etap+betap}\ Pap^{sigmaap-betap}\ padp^{-sigmaap};$$

Supply (landings) of mackerel = exports + consumer demand for unprocessed fish + consumer demand for processed fish

In[ ]:= $$E4 = qmdcap - amdu\ pmdu^{-emdu} == qmdue0 + cr\ qmdpe0 + ku\ bmu\ Pu^{etau+betau}\ Pmu^{sigmamu-betau}\ pmdu^{-sigmamu} + cr\ bmp\ kp\ Pp^{etap+betap}\ Pmp^{sigmamp-betap}\ pmdp^{-sigmamp};$$

Supply of imported unprocessed product = Demand for imported unprocessed product

In[ ]:= $$E5 = qslu0 + repls\ qsiu0 == ku\ bstu\ Pu^{etau+betau}\ Psu^{sigmasu-betau}\ pstu^{-sigmasu};$$

In[ ]:= $$E6 = qhlu0 + replh\ qhiu0 == ku\ bhtu\ bhu\ Pu^{etau+betau}\ Phu^{sigmahu-betau}\ phtu^{-sigmahu};$$

In[ ]:= $$E7 = qalu0 + repla\ qaiu0 == ku\ batu\ bau\ Pu^{etau+betau}\ Pau^{sigmaau-betau}\ patu^{-sigmaau};$$

In[ ]:= $$E8 = qmlu0 + replm\ qmiu0 == ku\ bmtu\ bmu\ Pu^{etau+betau}\ Pmu^{sigmamu-betau}\ pmtu^{-sigmamu};$$

Supply of imported processed product = Demand for imported processed product

In[ ]:= $$E9 = qslp0 + repls\ qsip0 == kp\ bstp\ Pp^{etap+betap}\ Psp^{sigmasp-betap}\ pstp^{-sigmasp};$$

In[ ]:= $$E10 = qhlp0 + replh\ qhip0 == kp\ bhtp\ bhp\ Pp^{etap+betap}\ Php^{sigmahp-betap}\ phtp^{-sigmahp};$$

In[ ]:= $$E11 = qalp0 + repla\ qaip0 == kp\ batp\ bap\ Pp^{etap+betap}\ Pap^{sigmaap-betap}\ patp^{-sigmaap};$$

In[ ]:= $$E12 = qmlp0 + replm\ qmip0 == kp\ bmtp\ bmp\ Pp^{etap+betap}\ Pmp^{sigmamp-betap}\ pmtp^{-sigmamp};$$

```
In[]:= FindRoot[{E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12}, {psdu, psdu0}, {pstu, pstu0},
  {phdu, phdu0}, {phtu, phtu0}, {padu, padu0}, {patu, patu0}, {pmdu, pmdu0},
  {pmtu, pmtu0}, {pstp, pstp0}, {phtp, phtp0}, {patp, patp0}, {pmtp, pmtp0}]

Out[]= {psdu → 0.469825, pstu → 0.693184, phdu → 0.502316, phtu → 1.54259,
  padu → 0.116306, patu → 2.51206, pmdu → 0.915281, pmtu → 2.9239,
  pstp → 4.54554, phtp → 3.91521, patp → 8.52724, pmtp → 3.79292}

In[]:= psdu1 = psdu /. %;

In[]:= pstu1 = pstu /. %%;

In[]:= pstp1 = pstp /. %%%;

In[]:= phdu1 = phdu /. %%%%;

In[]:= phtu1 = phtu /. %%%%%;

In[]:= phtp1 = phtp /. %%%%%%;

In[]:= padu1 = padu /. %%%%%%%;

In[]:= patu1 = patu /. %%%%%%%%;

In[]:= patp1 = patp /. %%%%%%%%%;

In[]:= pmdu1 = pmdu /. %%%%%%%%%%;

In[]:= pmtu1 = pmtu /. %%%%%%%%%%%;

In[]:= pmtp1 = pmtp /. %%%%%%%%%%%%;
```

In[]:= $psdp1 = \frac{psdu1\ psdp0}{psdu0};$

In[]:= $phdp1 = \frac{phdu1\ phdp0}{phdu0};$

In[]:= $padp1 = \frac{padu1\ padp0}{padu0};$

In[]:= $pmdp1 = \frac{pmdu1\ pmdp0}{pmdu0};$

In[]:= $Psu1 = \left(psdu1^{1-sigmasu} + bstu\ pstu1^{1-sigmasu}\right)^{\frac{1}{1-sigmasu}};$

In[]:= $Phu1 = \left(phdu1^{1-sigmahu} + bhtu\ phtu1^{1-sigmahu}\right)^{\frac{1}{1-sigmahu}};$

In[]:= $Pau1 = \left(padu1^{1-sigmaau} + batu\ patu1^{1-sigmaau}\right)^{\frac{1}{1-sigmaau}};$

In[]:= $Pmu1 = \left(pmdu1^{1-sigmamu} + bmtu\ pmtu1^{1-sigmamu}\right)^{\frac{1}{1-sigmamu}};$

In[]:= $Pu1 = \left(Psu1^{1-betau} + bhu\ Phu1^{1-betau} + bau\ Pau1^{1-betau} + bmu\ Pmu1^{1-betau}\right)^{\frac{1}{1-betau}};$

In[]:= $Psp1 = \left(psdp1^{1-sigmasp} + bstp\ pstp1^{1-sigmasp}\right)^{\frac{1}{1-sigmasp}};$

In[•]:= $Php1 = \left(phdp1^{1-sigmahp} + bhtp\ phtp1^{1-sigmahp}\right)^{\frac{1}{1-sigmahp}};$

In[•]:= $Pap1 = \left(padp1^{1-sigmaap} + batp\ patp1^{1-sigmaap}\right)^{\frac{1}{1-sigmaap}};$

In[•]:= $Pmp1 = \left(pmdp1^{1-sigmamp} + bmtp\ pmtp1^{1-sigmamp}\right)^{\frac{1}{1-sigmamp}};$

In[•]:= $Pp1 = \left(Psp1^{1-betap} + bhp\ Php1^{1-betap} + bap\ Pap1^{1-betap} + bmp\ Pmp1^{1-betap}\right)^{\frac{1}{1-betap}};$

In[•]:= $qsdu1 = qsdcap - asdu\ psdu1^{-esdu};$

In[•]:= $qstu1 = qslu0 + repls\ qsiu0;$

In[•]:= $qstp1 = qslp0 + repls\ qsip0;$

In[•]:= $qsdp1 = qsdpe0 + kp\ Pp1^{etap+betap}\ Psp1^{sigmasp-betap}\ psdp1^{-sigmasp};$

In[•]:= $qhdu1 = qhdcap - ahdu\ phdu1^{-ehdu};$

In[•]:= $qhtu1 = qhlu0 + replh\ qhiu0;$

In[•]:= $qhtp1 = qhlp0 + replh\ qhip0;$

In[•]:= $qhdp1 = qhdpe0 + kp\ bhp\ Pp1^{etap+betap}\ Php1^{sigmahp-betap}\ phdp1^{-sigmahp};$

In[•]:= $qadu1 = qadcap - aadu\ padu1^{-eadu};$

In[•]:= $qatu1 = qalu0 + repla\ qaiu0;$

In[•]:= $qatp1 = qalp0 + repla\ qaip0;$

In[•]:= $qadp1 = qadpe0 + kp\ bap\ Pp1^{etap+betap}\ Pap1^{sigmaap-betap}\ padp1^{-sigmaap};$

In[•]:= $qmdu1 = qmdcap - amdu\ pmdu1^{-emdu};$

In[•]:= $qmtu1 = qmlu0 + replm\ qmiu0;$

In[•]:= $qmtp1 = qmlp0 + replm\ qmip0;$

In[•]:= $qmdp1 = qmdpe0 + kp\ bmp\ Pp1^{etap+betap}\ Pmp1^{sigmamp-betap}\ pmdp1^{-sigmamp};$

5. Results

Sardines

Percent change in price of unprocessed domestic sardine production

In[•]:= $$\frac{(psdu1 - psdu0)\ 100}{psdu0}$$

Out[•]= 4.92756

Percent change in quantity of domestic sardine landings

In[ ]:= $\frac{(\text{qsdu1} - \text{qsdu0})\ 100}{\text{qsdu0}}$

Out[ ]= 4.79342

Change in landings (in kg)

In[ ]:= qsdu1 - qsdu0

Out[ ]= 48,173.8

Percent change in price of processed domestic production

In[ ]:= $\frac{(\text{psdp1} - \text{psdp0})\ 100}{\text{psdp0}}$

Out[ ]= 4.92756

Percent change in quantity of processed domestic production

In[ ]:= $\frac{(\text{qsdp1} - \text{qsdp0})\ 100}{\text{qsdp0}}$

Out[ ]= 8.93605

Change ($) in operating income, unprocessed product

In[ ]:= (1 / sigmasu) (psdu1 (qsdu1 - qsdue0 - cr qsdp1) - psdu0 (qsdu0 - qsdue0 - cr qsdp0))

Out[ ]= 6398.65

Change ($) in operating income, processed product

In[ ]:= (1 / sigmasp) (psdp1 (qsdp1 - qsdpe0) - psdp0 (qsdp0 - qsdpe0))

Out[ ]= 1093.55

Percent change in price of unprocessed imports

In[ ]:= $\frac{(\text{pstu1} - \text{pstu0})\ 100}{\text{pstu0}}$

Out[ ]= 8.0527

Percent change in quantity of unprocessed imports

In[ ]:= $\frac{(\text{qstu1} - \text{qstu0})\ 100}{\text{qstu0}}$

Out[ ]= -13.7442

Percent change in price of processed imports

In[ ]:= $$\frac{(\text{pstp1} - \text{pstp0})\ 100}{\text{pstp0}}$$

Out[ ]= 8.90347

Percent change in quantity of processed imports

In[ ]:= $$\frac{(\text{qstp1} - \text{qstp0})\ 100}{\text{qstp0}}$$

Out[ ]= -14.6891

Herring

Percent change in price of unprocessed domestic herring production

In[ ]:= $$\frac{(\text{phdu1} - \text{phdu0})\ 100}{\text{phdu0}}$$

Out[ ]= 1.74255

Percent change in quantity of domestic herring landings

In[ ]:= $$\frac{(\text{qhdu1} - \text{qhdu0})\ 100}{\text{qhdu0}}$$

Out[ ]= 3.42537

Change in landings (in kg)

In[ ]:= **qhdu1 - qhdu0**

Out[ ]= 2.28537×10^{6}

Percent change in price of processed domestic production

In[ ]:= $$\frac{(\text{phdp1} - \text{phdp0})\ 100}{\text{phdp0}}$$

Out[ ]= 1.74255

Percent change in quantity of processed domestic product

In[ ]:= $$\frac{(\text{qhdp1} - \text{qhdp0})\ 100}{\text{qhdp0}}$$

Out[ ]= 15.9444

Change ($) in operating income, unprocessed product

In[ ]:= (1 / sigmahu) (phdu1 (qhdu1 - qhdue0 - cr qhdp1) - phdu0 (qhdu0 - qhdue0 - cr qhdp0))

Out[ ]= 161 472.

Change ($) in operating income, processed product

In[ ]:= (1 / sigmahp) (phdp1 (qhdp1 - qhdpe0) - phdp0 (qhdp0 - qhdpe0))

Out[ ]= 76 908.5

Percent change in price of unprocessed imports

In[ ]:= $\frac{(phtu1 - phtu0)\ 100}{phtu0}$

Out[ ]= 2.8174

Percent change in quantity of unprocessed imports

In[ ]:= $\frac{(qhtu1 - qhtu0)\ 100}{qhtu0}$

Out[ ]= -3.59375

Percent change in price of processed imports

In[ ]:= $\frac{(phtp1 - phtp0)\ 100}{phtp0}$

Out[ ]= 4.20946

Percent change in quantity of processed imports

In[ ]:= $\frac{(qhtp1 - qhtp0)\ 100}{qhtp0}$

Out[ ]= -3.47235

Anchovy

Percent change in price of unprocessed domestic anchovy production

In[ ]:= $\frac{(padu1 - padu0)\ 100}{padu0}$

Out[ ]= 2.12819

Percent change in quantity of domestic anchovy landings

In[ ]:= $\frac{(\text{qadu1} - \text{qadu0})\ 100}{\text{qadu0}}$

Out[ ]= 9.99482

Change in landings (in kg)

In[ ]:= qadu1 - qadu0

Out[ ]= 1.7351×10^{6}

Percent change in price of processed domestic production

In[ ]:= $\frac{(\text{padp1} - \text{padp0})\ 100}{\text{padp0}}$

Out[ ]= 2.12819

Percent change in quantity of processed domestic product

In[ ]:= $\frac{(\text{qadp1} - \text{qadp0})\ 100}{\text{qadp0}}$

Out[ ]= 12.2311

Change ($) in operating income, unprocessed product

In[ ]:= (1 / sigmaau) (padu1 (qadu1 - qadue0 - cr qadp1) - padu0 (qadu0 - qadue0 - cr qadp0))

Out[ ]= 20,661.2

Change ($) in operating income, processed product

In[ ]:= (1 / sigmaap) (padp1 (qadp1 - qadpe0) - padp0 (qadp0 - qadpe0))

Out[ ]= 86,128.4

Percent change in price of unprocessed imports

In[ ]:= $\frac{(\text{patu1} - \text{patu0})\ 100}{\text{patu0}}$

Out[ ]= 4.99597

Percent change in quantity of unprocessed imports

In[ ]:= $\frac{(\text{qatu1} - \text{qatu0})\ 100}{\text{qatu0}}$

Out[ ]= -7.08585

Percent change in price of processed imports

In[ ]:= $\frac{(patp1 - patp0)\ 100}{patp0}$

Out[ ]= 5.96468

Percent change in quantity of processed imports

In[ ]:= $\frac{(qatp1 - qatp0)\ 100}{qatp0}$

Out[ ]= -8.1546

Mackerel

Percent change in price of unprocessed domestic mackerel production

In[ ]:= $\frac{(pmdu1 - pmdu0)\ 100}{pmdu0}$

Out[ ]= 1.25841

Percent change in quantity of domestic mackerel landings

In[ ]:= $\frac{(qmdu1 - qmdu0)\ 100}{qmdu0}$

Out[ ]= 6.07327

Change in landings (in kg)

In[ ]:= qmdu1 - qmdu0

Out[ ]= 5.30398×10^{6}

Percent change in price of processed domestic production

In[ ]:= $\frac{(pmdp1 - pmdp0)\ 100}{pmdp0}$

Out[ ]= 1.25841

Percent change in quantity of processed domestic product

In[ ]:= $\frac{(qmdp1 - qmdp0)\ 100}{qmdp0}$

Out[ ]= 11.6784

Change ($) in operating income, unprocessed product

In[ ]:=
```
N[(1/sigmamu) (pmdu1 (qmdu1 - qmdue0 - cr qmdp1) - pmdu0 (qmdu0 - qmdue0 - cr qmdp0))]
```

Out[ ]=
```
72,830.8
```

Change ($) in operating income, processed product

In[ ]:=
```
N[(1/sigmamp) (pmdp1 (qmdp1 - qmdpe0) - pmdp0 (qmdp0 - qmdpe0))]
```

Out[ ]= 2.03946×10^{6}

Percent change in price of unprocessed imports

In[ ]:= $\frac{(\mathrm{pmtu1} - \mathrm{pmtu0})\ 100}{\mathrm{pmtu0}}$

Out[ ]=
```
5.74218
```

Percent change in quantity of unprocessed imports

In[ ]:= $\frac{(\mathrm{qmtu1} - \mathrm{qmtu0})\ 100}{\mathrm{qmtu0}}$

Out[ ]=
```
-8.64995
```

Percent change in price of processed imports

In[ ]:= $\frac{(\mathrm{pmtp1} - \mathrm{pmtp0})\ 100}{\mathrm{pmtp0}}$

Out[ ]=
```
4.31067
```

Percent change in quantity of processed imports

In[ ]:= $\frac{(\mathrm{qmtp1} - \mathrm{qmtp0})\ 100}{\mathrm{qmtp0}}$

Out[ ]=
```
-11.3958
```

Price Indexes

Percent change in unprocessed price index

In[ ]:= $\frac{(\mathrm{Pu1} - \mathrm{Pu0})\ 100}{\mathrm{Pu0}}$

Out[ ]=
```
4.56925
```

Percent change in processed price index

In[ ]:=
$$\frac{(Pp1 - Pp0)\ 100}{Pp0}$$

Out[ ]=
4.9725