The gains from trade in intermediate goods: A Ricardo-Sraffa-Samuelson model*

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November 2013

Abstract

This paper develops a model of intermediate and final goods trade based on comparative advantage. It is shown that the gains from trade in intermediate and final goods exceeds that from the gains from trade in final goods alone. Allowing for decreasing trade and coordination costs results in a shift in trade patterns, from autarky, to trade in final goods only, to trade in intermediate and final goods.

JEL Classification: F11.
Keywords: Intermediates trade; Comparative advantage; Structure of production.

* Thanks to seminar participants at Lancaster University for helpful suggestions. The author is responsible for any errors and omissions.
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1 Introduction

That a large proportion of international trade is trade in intermediate goods has been known since the seminal work of Grubel and Lloyd (1975). Such trade may be viewed as the next step in economic globalisation: if the production process can be broken into several stages, then each stage may be produced in the country that has a comparative advantage in producing that stage. Therefore, trade in intermediate goods should lead to additional gains above those associated with trade in final goods alone.

The original motivation for this paper is a paper by Paul Samuelson (2001) in the Journal of Economic Literature, in which he developed a Ricardian (1817) model of international trade in which each of two final goods can also be used as intermediate inputs in the production of the other final good. International trade results in a much larger gain than would otherwise be obtained if goods could not be used as intermediate inputs. Samuelson attributed the insight of using final goods as intermediate goods to Sraffa (1960); Samuelson’s (2001) contribution was to introduce the international dimension to Sraffa’s idea. Since Samuelson’s contribution, Shiozawa (2007, 2009) has extended the Ricardo-Sraffa model to many goods and many countries, while Fujimoto and Shiozawa (2011a, b) consider how the model can be used to analyse both inter- and intra-industry competition and trade.

In this paper we extend and generalise the model developed by Samuelson (2001). Whilst Samuelson specified that the intermediate inputs are the same as final goods, we decouple intermediates from final goods. This enables us to consider more possible configurations of production than Samuelson’s two (trade in final goods only, and trade in both intermediate and final goods). Here, we consider both domestic and international outsourcing of production; for instance, Fort (2013) shows for a sample of US manufacturers that domestic outsourcing is much more prevalent than international outsourcing. Further, we introduce trade costs and the cost of coordinating intermediates into the model, and show how changing these costs can change the configuration of production in the global economy.

Changes in the structure of production are a key feature of the modern economy. Consider for instance the automobile industry. With Henry Ford’s introduction of the moving assembly line in 1913, the time it took to build a car was reduced from over 12 hours to 2 hours and 30
minutes (The History Channel, 2012). A key feature of the Ford assembly line was the integration of the entire production process. Gross (1997) notes:

“…[In 1921] Ford was free to embark on a great new project: the design and construction of the world's largest and most efficient automobile factory at River Rouge, near Detroit. Arrayed over 2,000 acres, it would include 90 miles of railroad track and enough space for 75,000 employees to produce finished cars from raw material in the span of just forty-one hours. River Rouge had its own power plant, iron forges, and fabricating facilities.” (Gross, 1997, p. 85).

Contrast this to the 3rd generation Apple iPod (released in 2003), for which the hard drive was manufactured in China (as was the final assembly), the display in Japan, the video processor in Taiwan or Singapore, the CPU in the US or Taiwan, and the memory in Korea (Linden et al, 2007). Sturgeon (2002) documents this trend in modular production networks, while Brown and Linden (2005) discuss offshoring in the semiconductor industry. Offshoring has been the topic of a US Government Accountability Office Report to Congressional Committees (US Government Accountability Office, 2006). Although a clear distinction needs to be made between outsourcing, in which firms contract out part of their activities to other domestic firms, and offshoring, in which firms shift part of their activities abroad.

Finally, our formulation of the model overcomes the “chicken and egg” problem inherent in Samuelson’s model. This problem arises because Samuelson assumes that good X can be used to enhance the production of good Y, and vice versa, so that the solution to the model results in enhanced output of both goods. However, this cannot be the case, since either X is used to enhance the production of Y, or vice versa, but not both simultaneously. In principle, it is conceivable that an infinitesimal amount of X is first produced using the basic technology, sent abroad to enhance the production of a slightly less infinitesimal amount of Y, which is then sent back to the home country to enhance the production of slightly more X, and so forth. But as a description of international trade, it seems a bit implausible.

International trade in intermediate goods and the international fragmentation of production have been subjects of a large amount of research. An early formulation was provided in a monopolistic competition model by Ethier (1982). More directly related to the international
fragmentation of production are Jones and Sanyal (1982), Jones and Kierzkowski (1990), and
the literature summarised by Jones’s Ohlin lectures (Jones, 2000). More similar to the present
paper is Yi (2003), who develops a perfectly competitive model of vertical specialisation.
Feenstra and Hanson (1996, 1997) develop a model of offshoring based on the many-good
Heckscher-Ohlin model, while Grossman and Rossi-Hansberg (2008) develop a model of
international trade in tasks, and Rodriguez-Clare’s (2010) model extends the Eaton and
Kortum (2002) model to allow for offshoring. Compared to this work, the present paper does
not assume that the production process must be divided into many steps, instead allowing it to
be a choice made by firms. In this sense the paper is similar to Antras (2003), who analyses
the situations in which firms will choose to engage in arms-length international outsourcing
as opposed to producing abroad as a multinational firm. Unlike Antras (2003), where contract
incompleteness and intra-firm trade take centre stage, in the present paper the equilibrium
structure of production is determined solely by cost considerations, and all transactions are
assumed to take place between rather than within firms. The existing literature has been ably
summarised in Feenstra’s Ohlin lectures (Feenstra, 2009).

A key result of the model developed in this paper is that both domestic and foreign
outsourcing lead to productivity gains. This is distinct from some of the literature such as
Antras and Helpman (2004) and Helpman et al (2004), in which firms have innate differences
in their productivity, and these differences are what drives the structure of production
(although see Grossman and Helpman (2002) for a model of offshoring without heterogeneity
across firms). The empirical evidence has shown strong support for the idea that both
domestic and foreign outsourcing have positive effects on productivity, controlling for the
endogeneity of outsourcing. Recent work in this area includes Amiti and Wei (2006), Gorg et
literature, while Houseman (2007) warns of measurement problems in productivity in the
presence of outsourcing and offshoring.

The next section develops the model and the possible outcomes under autarky. Section 3
shows what happens when international trade is allowed. Section 4 provides some concluding
comments.
2 The model: Autarky

2.1 Direct production

First consider the model with no international trade, for the case where there are no intermediate goods. There are two final goods, \( X_1 \) and \( X_2 \). Utility takes the following Cobb-Douglas form:

\[
U = C_{X_1}^\alpha C_{X_2}^{1-\alpha} \quad 0 < \alpha < 1
\]

(1)

All markets are perfectly competitive. Labour is the only factor of production, and is inelastically supplied. The labour endowment is \( \bar{L} \). The production functions exhibit constant returns to scale and take the following form:

\[
Q_{X_1} = A_{X_1} L_{X_1} \\
Q_{X_2} = A_{X_2} L_{X_2}
\]

(2)

Where \( A_{X_1} \) and \( A_{X_2} \) are the productivity parameters. Call these the direct production functions, since they employ labour to produce final goods directly. From the consumer’s first order conditions and the firm’s zero profit conditions we have:

\[
\frac{p_{X_1}}{p_{X_2}} = \frac{A_{X_2}}{A_{X_1}} = \frac{\alpha}{1-\alpha} \frac{C_{X_2}}{C_{X_1}}
\]

(3)

From the properties of the Cobb-Douglas utility function, the labour used in each good is given by:

\[
L_{X_1} = \alpha \bar{L} \\
L_{X_2} = (1-\alpha) \bar{L}
\]

(4)

Hence, output of each good is:

\[
Q_{X_1} = A_{X_1} \alpha \bar{L} \\
Q_{X_2} = A_{X_2} (1-\alpha) \bar{L}
\]

(5)

So national utility under direct production is:

\[
U_D = [A_{X_1} \alpha]^{\alpha}[A_{X_2} (1-\alpha)]^{1-\alpha} \bar{L}
\]

(6)

This provides us with a benchmark with which to compare the results for different organisational forms below.

2.2 Indirect production

Now suppose that in addition to the production functions above, there is another way of producing the two final goods \( X_1 \) and \( X_2 \) involving the use of intermediate inputs \( Y_1 \) and \( Y_2 \). Let \( Y_1 \) be used only in the production of \( X_1 \), and \( Y_2 \) be used only in the production of \( X_2 \). Suppose these indirect production functions take the following fixed-proportions form:
Where, as before, the \( A \) terms represent productivity parameters. That is, under indirect production, production of \( X_1 \) requires the use of both labour and \( Y_1 \), and production of \( X_2 \) requires both labour and \( Y_2 \). This is the main point of departure between our model and that of Samuelson (2001), where \( X_1 \) is used in the production of \( X_2 \), and vice versa. Let the production functions of the intermediate inputs take the following form:

\[
\begin{align*}
Q_{Y_1} &= A_{Y_1}L_{Y_1} \\
Q_{Y_2} &= A_{Y_2}L_{Y_2}
\end{align*}
\]

(8)

The cost functions for \( X_1 \) and \( X_2 \) under indirect production are:

\[
\begin{align*}
p_{X_1} &= \frac{w}{A_{X_{01}}} + \frac{p_{Y_1}}{A_{X_{11}}} \\
p_{X_2} &= \frac{w}{A_{X_{02}}} + \frac{p_{Y_2}}{A_{X_{22}}}
\end{align*}
\]

(9)

Since the cost functions of \( Y_1 \) and \( Y_2 \) are \( p_{Y_1} = \frac{w}{A_{Y_1}} \) and \( p_{Y_2} = \frac{w}{A_{Y_2}} \), substituting into the cost functions above and solving gives:

\[
\frac{p_{X_1}}{p_{X_2}} = \left[ \frac{A_{X_{02}}A_{Y_2}A_{X_{22}}}{A_{X_{01}}A_{Y_1}A_{X_{11}}} \right] \left[ \frac{A_{Y_1}A_{X_{11}} + A_{X_{01}}}{A_{Y_2}A_{X_{22}} + A_{X_{02}}} \right] = \frac{\alpha}{1-\alpha} \left( \frac{c_{X_2}}{c_{X_1}} \right)
\]

(10)

Since consumption equals output, substituting from the production functions (7a), (7b) and (8) above gives the ratio of the consumption of the two final goods:

\[
\frac{c_{X_2}}{c_{X_1}} = \left[ \frac{A_{X_{02}}A_{Y_2}A_{X_{22}}}{A_{X_{01}}A_{Y_1}A_{X_{11}}} \right] \left[ \frac{A_{Y_1}A_{X_{11}} + A_{X_{01}}}{A_{Y_2}A_{X_{22}} + A_{X_{02}}} \right] = \frac{\alpha}{1-\alpha} \left( \frac{c_{X_2}}{c_{X_1}} \right)
\]

(11)

Substituting this into the price ratio (10) and solving for relative labour use in each sector gives:

\[
\begin{align*}
\frac{L_{X_{02}}}{L_{X_{01}}} &= \left( \frac{1-\alpha}{\alpha} \right) \left[ \frac{A_{Y_2}A_{X_{22}}}{A_{Y_1}A_{X_{11}}} \right] \left[ \frac{A_{Y_1}A_{X_{11}} + A_{X_{01}}}{A_{Y_2}A_{X_{22}} + A_{X_{02}}} \right] \\
\frac{L_{Y_2}}{L_{Y_1}} &= \left( \frac{1-\alpha}{\alpha} \right) \left[ \frac{A_{X_{02}}A_{Y_2}}{A_{X_{01}}} \right] \left[ \frac{A_{Y_1}A_{X_{11}} + A_{X_{01}}}{A_{Y_2}A_{X_{22}} + A_{X_{02}}} \right]
\end{align*}
\]

(12a, 12b)

In addition, from the production functions (7a) and (7b), since labour and intermediate inputs are used in fixed proportions, we have:

\[
\begin{align*}
A_{X_{01}}L_{X_{01}} &= A_{X_{11}}A_{Y_1}L_{Y_1} \quad \leftrightarrow \quad L_{X_{01}} = \frac{A_{X_{11}}A_{Y_1}}{A_{X_{01}}} L_{Y_1} \\
A_{X_{02}}L_{X_{02}} &= A_{X_{22}}A_{Y_2}L_{Y_2} \quad \leftrightarrow \quad L_{X_{02}} = \frac{A_{X_{22}}A_{Y_2}}{A_{X_{02}}} L_{Y_2}
\end{align*}
\]

(13a, 13b)

Full employment implies that \( L_{X_{01}} + L_{X_{02}} + L_{Y_1} + L_{Y_2} = \bar{L} \). Substituting from (12a), (12b), (13a) and (13b) into this expression and simplifying gives the following expressions for the labour used in each of the four sectors:

\[
\begin{align*}
L_{Y_1} &= \frac{\alpha A_{X_{01}} L}{A_{Y_1}A_{X_{11}} + A_{X_{01}}} \\
L_{Y_2} &= \frac{(1-\alpha)A_{X_{02}} L}{A_{Y_2}A_{X_{22}} + A_{X_{02}}}
\end{align*}
\]

(14a)
\[ L_{X_{01}} = \frac{\alpha A_{Y_1} A_{X_{11}} L}{A_{Y_1} A_{X_{11}} + A_{X_{01}}} \quad \quad \quad L_{X_{02}} = \frac{(1-\alpha) A_{Y_2} A_{X_{22}} L}{A_{Y_2} A_{X_{22}} + A_{X_{02}}} \]  

Substituting these into the production functions (7a), (7b) and (8) and the utility function (1) enables us to solve for national utility under indirect production:

\[ U_I = \left( \frac{\alpha A_{Y_1} A_{X_{11}} A_{X_{01}}}{A_{Y_1} A_{X_{11}} + A_{X_{01}}} \right)^{\alpha} \left[ \left( \frac{(1-\alpha) A_{Y_2} A_{X_{22}} A_{X_{02}}}{A_{Y_2} A_{X_{22}} + A_{X_{02}}} \right)^{1-\alpha} \right] L \]

There are gains from indirect production provided \( U_I > U_D \). This will be the case if the technology parameters associated with indirect production are sufficiently large relative to the technology parameters associated with direct production. That is, firms will endogenously choose indirect production instead of direct production if there are productivity gains from indirect production. Note that it is possible for there to be direct production in one sector but not in the other sector; this again depends on the technology parameters.

### 2.3 Coordination costs

Now suppose that there are coordination costs involved in engaging in indirect production. These may be the costs of contracting with input suppliers, or the transport cost of shipping the intermediate good to the final good producer, or the cost of coordinating specifications of inputs. There are no coordination costs involved with direct production. Suppose that the coordination cost is the same across goods. Let \( \beta < 1 \) be the fraction of a final good that is available for consumption after incurring the coordination cost involved in indirect production; \( 1 - \beta \) is therefore the coordination cost, with lower values of \( \beta \) indicating higher coordination cost. Hence coordination costs are analogous to iceberg-type trade costs, and parallel the use of these costs in Grossman and Rossi-Hansberg (2008). The indirect production functions will become:

\[ Q_{X_1} = \min \{ \beta A_{X_{01}} L_{X_{01}}, \beta A_{X_{11}} Q_{Y_1} \} \] \hspace{1cm} (16a)

\[ Q_{X_2} = \min \{ \beta A_{X_{02}} L_{X_{02}}, \beta A_{X_{22}} Q_{Y_2} \} \] \hspace{1cm} (16b)

Because the coordination cost is assumed to be identical across goods, it has no impact on relative prices and consumption:

\[ \frac{p_{X_1}}{p_{X_2}} = \frac{A_{X_{02}} A_{Y_2} A_{X_{22}}}{A_{X_{01}} A_{Y_1} A_{X_{11}}} \frac{A_{Y_1} A_{X_{11}} + A_{X_{01}}}{A_{Y_2} A_{X_{22}} + A_{X_{02}}} \] \hspace{1cm} (17)

\[ \frac{c_{X_2}}{c_{X_1}} = \frac{A_{X_{02}} L_{X_{02}}}{A_{X_{01}} L_{X_{01}}} = \frac{A_{X_{22}} A_{Y_2} L_{Y_2}}{A_{X_{11}} A_{Y_1} L_{Y_1}} \] \hspace{1cm} (18)
Hence there is also no impact on the labour used in each sector; the expressions in equations (14a) and (14b) continue to hold. Output of $X_1$ and $X_2$ through indirect production are given by:

$$Q_{X_1} = \frac{\alpha \beta A_{X_01} A_{Y_1} A_{X_11}}{A_{Y_1} A_{X_11} + A_{X_01}}$$

$$Q_{X_2} = \frac{(1-\alpha) \beta A_{X_02} A_{Y_2} A_{X_22}}{A_{Y_2} A_{X_22} + A_{X_02}}$$

(19)

As before, indirect production will be used if output via this means exceeds that through direct production. Equation (19) shows that the coordination cost acts as a productivity cost to the firm. Thus it can be seen that high coordination costs will reduce the likelihood that indirect production will be chosen instead of direct production. That is, firms will trade off possible productivity gains from indirect production against the productivity loss from the coordination cost. Comparing the outputs in equation (19) with those in equation (5) allows us to solve for the threshold value of $\beta$ above which firms will decide to engage in indirect as opposed to direct production:

$$\bar{\beta}_1 = \frac{A_{X_1} (A_{Y_1} A_{X_{11}} + A_{X_{01}})}{A_{X_{01}} A_{Y_1} A_{X_{11}}}$$

$$\bar{\beta}_2 = \frac{A_{X_2} (A_{Y_2} A_{X_{22}} + A_{X_{02}})}{A_{X_{02}} A_{Y_2} A_{X_{22}}}$$

(20)

3 The international organisation of production

In this section we extend the model above to allow for international trade. Trade is always assumed to be balanced. In the first two subsections below, we assume no trade or coordination costs; these are introduced in the following sections. Suppose there are two countries, Home and Foreign, with Foreign variables denoted with an asterisk. The utility functions are identical in the two countries. In the previous section we have been flexible with regards to the precise magnitudes of various parameters. In this section, to make progress (and to prevent the paper from degenerating into a taxonomy of possible cases), we make the following assumptions with regard to the parameter values of the model:\(^3\):

\begin{align*}
A_{X_1} & = 4 & A_{X_2} & = 2 & A_{Y_1} & = 4 & A_{Y_2} & = 8 \\
A_{X_{01}} & = A_{X_{11}} = 8 & A_{X_{02}} & = A_{X_{22}} = 4 \\
A_{X_1}^* & = 2 & A_{X_2}^* & = 4 & A_{Y_1}^* & = 8 & A_{Y_2}^* & = 4 \\
A_{X_{01}}^* & = A_{X_{11}}^* = 4 & A_{X_{02}}^* & = A_{X_{22}}^* = 8 \\
\alpha & = 0.5 & \bar{L} & = \bar{L}^* = 2
\end{align*}

\(^3\) These values are different from those in Samuelson (2001), and have been chosen to illustrate the key features of the model. Appendix D shows the outcome of the model using Samuelson’s parameter values.
Hence the two countries are symmetric in terms of their technology. In terms of direct production, Home has a comparative advantage in the production of \( X_1 \). On the other hand, in terms of indirect production, Foreign has a comparative advantage in the production of \( Y_1 \), which is used in the production of \( X_1 \). However, Home still has a comparative advantage in assembling \( X_1 \) from \( Y_1 \). Both countries are assumed to be the same size, and the two goods are symmetric from the consumer’s viewpoint\(^4\).

As a basis for comparison with the results below, note that, given the parameter values above, if there are no coordination or trade costs, then in autarky, under direct production, each country’s utility is 2.83. Under indirect production, each country’s utility is 4.77, an increase of 69 percent over utility under direct production. Hence given the parameter values, there is a productivity gain from indirect production. Also, the threshold values for \( \beta_1 \) and \( \beta_2 \) are 0.63 and 0.56 for Home, and vice versa for Foreign. That is, if \( \beta_1 \) and \( \beta_2 \) are lower than these values, the productivity cost of coordinating inputs from suppliers outweighs the productivity benefits of indirect production, and both countries would produce both goods using direct rather than indirect means.

### 3.1 No trade and coordination costs: International trade in final goods only

There are two sub-cases here. First, parameter values may be such that indirect production will occur in both countries. Second, parameter values may be such that direct production will occur in both countries.

Consider first the case of indirect production. In this case, since Home has a comparative advantage in the production of \( X_1 \), Home will specialise in the production of \( X_1 \) and will export \( X_1 \) in exchange for imports of \( X_2 \) from Foreign. The equilibrium conditions are shown in Appendix A. Solving for labour in each sector, we have:

\[
L_{Y_1} = \frac{A_{X_{01}L}}{A_{Y_1}A_{X_{11}} + A_{X_{01}}} \quad L_{X_{01}} = \frac{A_{Y_1}A_{X_{11}L}}{A_{Y_1}A_{X_{11}} + A_{X_{01}}} \quad (22a)
\]

\[
L^*_{Y_2} = \frac{A_{X_{02}L^*}}{A_{Y_2}A_{X_{22}} + A_{X_{02}}} \quad L^*_{X_{02}} = \frac{A_{Y_2}A_{X_{22}L^*}}{A_{Y_2}A_{X_{22}} + A_{X_{02}}} \quad (22b)
\]

\(^4\) The symmetry of the model makes it much easier to solve, although where possible, to obtain more general results we will not rely on symmetry.
While, because of the Cobb-Douglas utility function, each country’s share of world income is equal to the share of its comparative advantage final good in expenditure, the expression for utility in the two countries is:

\[
U_H = \alpha \left[ \frac{\frac{A_Y Y_1 A_X 1}{A_Y 1}}{A_X 1 + A_Y 01} \right]^a \left( \frac{A_Y 02 A_X 22 + A_X 22}{A_Y 02 A_X 22 + A_Y 22} \right)^{1-a} \tag{23a}
\]

\[
U_F = (1 - \alpha) \left[ \frac{\frac{A_Y Y_1 A_X 1}{A_Y 1}}{A_X 1 + A_Y 01} \right]^a \left( \frac{A_Y 02 A_X 22 + A_X 22}{A_Y 02 A_X 22 + A_Y 22} \right)^{1-a} \tag{23b}
\]

Assuming no trade or coordination costs, substituting the parameter values into this expression and solving yields utility of 6.4 in both countries. This is higher than under autarky with indirect production, so there are gains from trade in final goods.

The other case is when parameter values are such that direct production occurs in each country, and then each final good is exported to the other country. In that case, all Home labour is used in producing \( X_1 \), while all Foreign labour is used in producing \( X_2 \), so in the absence of trade costs, we have:

\[
U_H = \alpha \left[ \frac{A_X X_1 L}{A_X 1} \right]^a \left( \frac{A_X X_2 L}{A_X 2} \right)^{1-a} \quad U_F = (1 - \alpha) \left[ \frac{A_X X_1 L}{A_X 1} \right]^a \left( \frac{A_X X_2 L}{A_X 2} \right)^{1-a} \tag{24}
\]

Given the parameter values assumed above, utility in both countries is equal to 4.0. What this tells us is that there are productivity gains from specialisation and trade, but that given the parameter values, the gain from indirect domestic production under autarky is larger than the gain from direct production combined with international trade. Clearly the combination of domestic indirect production and international trade in final goods yields the greatest gain.

### 3.2 No trade and coordination costs: International trade in both intermediate and final goods

If international trade is allowed in both intermediate and final goods, then Home will specialise in production of \( Y_2 \), which it will export to Foreign in exchange for \( Y_1 \), which Home will then use in production of \( X_1 \), exporting it to Foreign in exchange for \( X_2 \). Since the two countries are symmetric in every way, wages are equalised in the two countries. The equilibrium conditions are shown in Appendix B. Using these conditions gives the following expressions for the labour used in each of the four sectors:

\[
L_{X_{01}} = \left[ 1 + \left( \frac{1-a}{a} \right) \left( \frac{A_X X_2}{A_X 1 A_Y 1} \right) \left( \frac{A_X X_1 + A_Y 01}{A_X 22 A_Y 22 + A_Y 22} \right) \right]^{-1} \hat{L} = \left[ B \right]^{-1} \hat{L} \tag{25a}
\]

\[
L_{Y_2} = (1 - \left[ B \right]^{-1}) \hat{L} \tag{25b}
\]
\[ L'_{X0} = \left[ 1 + \left( \frac{\alpha}{1-\alpha} \right) \left( \frac{A_{X01}}{A_{X22}Y_2} \right) \left( \frac{A_{X22}Y_2 + A_{X02}}{A_{X11}Y_1 + A_{X01}} \right) \right]^{-1} L' = [D]^{-1}L' \quad (26a) \]

\[ L'_{Y1} = (1 - [D]^{-1})L' \quad (26b) \]

Substituting into the production functions (7a), (7b) and (8) yields the output of each of the two final goods \( X_1 \) and \( X_2 \). Consumption of each final good in each country depends on national income; however, national income (defined as the value of final good output) now depends on the value of both countries’ final good, since each country also produces the intermediate good which is used in the other country. The symmetry of the model allows us to normalise wages in both countries to 1. From Appendix B, the price of \( X_1 \) is:

\[ p_{X1} = \frac{A_{X11}Y_1 + A_{X01}}{A_{X01}A_{X11}Y_1} \quad (27) \]

Hence, substituting from equations (7a) and (25a), the value of Home’s output of \( X_1 \) is:

\[ p_{X1}Q_{X1} = \frac{A_{X11}Y_1 + A_{X01}}{A_{X11}Y_1 [B]} L \quad (28) \]

This is also Home’s GDP. Foreign’s GDP is, analogously:

\[ p_{X2}Q_{X2} = \frac{A_{X22}Y_2 + A_{X02}}{A_{X22}Y_2 [D]} L' \quad (29) \]

Home’s share of world income is therefore:

\[ S_H = \frac{p_{X1}Q_{X1}}{p_{X1}Q_{X1} + p_{X2}Q_{X2}} = \frac{A_{X11}Y_1 + A_{X01}L}{A_{X11}Y_1 [B] + A_{X22}Y_2 [D]} \quad (30) \]

Since preferences are Cobb-Douglas, we can then make use of this to obtain the equilibrium consumption levels in each country:

\[ C_{X1} = S_H A_{X01} [B]^{-1} L \quad C_{X1} = (1 - S_H) A_{X01} [B]^{-1} L \quad (31a) \]

\[ C_{X2} = S_H A_{X02} [D]^{-1} L' \quad C_{X2} = (1 - S_H) A_{X02} [D]^{-1} L' \quad (31b) \]

Substituting these consumption levels into the utility function (1) yields utility equal to 7.11 in both countries. These values are higher than when only trade in final goods is allowed. Therefore, there are additional productivity gains from trading in intermediate as well as final goods, as it enables countries to specialise in the intermediate and final goods in which they have a comparative advantage. This is what Samuelson (2001) refers to as the “Sraffian bonus”: a gain from international trade which goes beyond the gains from the Ricardian model.
Given the parameter values we have chosen, Home produces $Y_2$ and $X_1$, and exports its entire production of $Y_2$, and a fraction of its production of $X_1$. Since $p_{Y_2} = w/\bar{A}_{Y_2} = 1/\bar{A}_{Y_2}$, the value of Home’s output and exports of $Y_2$ is, from equations (8) and (25b):

$$p_{Y_2}Q_{Y_2} = (1 - [B]^{-1})\bar{L}$$

(32)

The share of intermediate goods in Home’s exports is:

$$\frac{p_{Y_2}Q_{Y_2}}{p_{Y_2}Q_{Y_2} + p_{X_1}C_{X_1}} = \frac{(1-[B]^{-1})\bar{A}_{X_{11}}\bar{A}_{Y_{11}}}{(1-[B]^{-1})\bar{A}_{X_{11}}\bar{A}_{Y_{11}} + ([1-S_H][B]^{-1}(\bar{A}_{X_{11}}\bar{A}_{Y_{11}} + \bar{A}_{X_{01}}))}$$

(33)

For the parameter values we have chosen, the share of intermediate goods trade in total trade is 0.1818. This is less than what is observed empirically; Miroudot et al (2009) and Sturgeon and Memedovic (2010) find values of over 0.5. Nevertheless, trade in intermediates is a significant fraction of total trade, and of course choosing different parameter values may result in a larger share of intermediate goods trade.

### 3.3 Trade and coordination costs: Trade in final goods only

So far the welfare calculations have been performed assuming no coordination or trade costs. In this section and the next, we introduce these costs. Coordination costs have been defined in Section 2.3 above. For trade costs, suppose that international trade occurs with an iceberg trade cost so that for every unit shipped abroad, only $\tau < 1$ units arrive; $1 - \tau$ is therefore the trade cost. Trade costs are the same for all goods.

Our focus in this section will be on obtaining expressions for the threshold values of trade costs such that if trade costs are lower than the threshold values, international trade occurs, but otherwise there will be no trade. As noted above in Section 2.3, the introduction of coordination costs which are identical across sectors has no impact on the share of labour used in each sector. Similarly, when there is only trade in final goods, trade costs which are identical across sectors can be shown to have no impact on the share of labour used in each sector. Consider first the case when firms engage in indirect production. The consumer’s maximisation problem yields the same solution as in equation (3), in terms of domestic prices. On the production side, the relative price of $X_1$ to $X_2$ in the Home country is a function of $\tau$:

$$\frac{p_{X_1}}{p_{X_2}} = \tau \left[ \frac{\bar{A}_{X_{02}}\bar{A}_{Y_{22}}\bar{A}_{X_{22}}}{\bar{A}_{X_{01}}\bar{A}_{Y_{11}}\bar{A}_{X_{11}}} \right] \left[ \frac{\bar{A}_{Y_{11}}\bar{A}_{X_{11}} + \bar{A}_{X_{01}}}{\bar{A}_{Y_{22}}\bar{A}_{X_{22}} + \bar{A}_{X_{02}}} \right]$$

(34)

On the other hand, the consumption ratio is now:
\[
\frac{C_{X_2}}{C_{X_1}} = \frac{\tau A_{x_{02}} A_{y_{02}}}{A_{x_{01}} A_{y_{01}}} = \frac{\tau A_{x_{22}} A_{y_{2}}}{A_{x_{11}} A_{y_{1}}}
\] (35)

Hence the solution to the labour shares remains as in equations (22a) and (22b). The only difference is that consumption of \( X_2 \) in Home is reduced by the trade cost, to \( \tau \) times the consumption without trade costs. Consumption of \( X_1 \) and \( X_2 \) in the two countries is therefore:

\[
C_{X_1} = \frac{\alpha \beta A_{Y_1} A_{X_11} A_{X_{01}} L}{A_{Y_1} A_{X_{11}} + A_{X_{01}}}
\]

\[
C_{X_1}^* = \frac{\tau (1-\alpha) A_{Y_1} A_{X_11} A_{X_{01}} L}{A_{Y_1} A_{X_{11}} + A_{X_{01}}}
\] (36a)

\[
C_{X_2} = \frac{\alpha \beta A_{Y_2} A_{X_22} A_{X_{02}} L}{A_{Y_2} A_{X_{22}} + A_{X_{02}}}
\]

\[
C_{X_2}^* = \frac{(1-\alpha) A_{Y_2} A_{X_22} A_{X_{02}} L}{A_{Y_2} A_{X_{22}} + A_{X_{02}}}
\] (36b)

Since trade is assumed to be balanced, comparing the outputs (consumption) in equation (19) under indirect production in autarky to those in equations (36a) and (36b) under international trade in final goods yields the threshold values of \( \tau_{X_1} \) and \( \tau_{X_2} \) above which the two countries will benefit from and hence engage in international trade:

\[
\tau_{X_1} = \left(\frac{\alpha}{1-\alpha}\right) \left(\frac{A_{X_{01}} A_{Y_1} A_{X_{11}}}{A_{X_{01}} A_{Y_1} A_{X_{11}} + A_{X_{01}}}ight) \left(\frac{A_{Y_1} A_{X_{11}} + A_{X_{01}}}{A_{Y_1} A_{X_{11}} + A_{X_{01}} + A_{Y_1} A_{X_{11}} + A_{X_{01}}}ight) L^* L
\] (37a)

\[
\tau_{X_2} = \left(\frac{1-\alpha}{\alpha}\right) \left(\frac{A_{X_{02}} A_{Y_2} A_{X_{22}}}{A_{X_{02}} A_{Y_2} A_{X_{22}} + A_{X_{02}}}ight) \left(\frac{A_{Y_2} A_{X_{22}} + A_{X_{02}}}{A_{Y_2} A_{X_{22}} + A_{X_{02}} + A_{Y_2} A_{X_{22}} + A_{X_{02}}}ight) L^* L
\] (37b)

Given the parameter values defined above, the threshold values of \( \tau_{X_1} \) and \( \tau_{X_2} \) are 0.56.

On the other hand, suppose that coordination costs are sufficiently high so that direct production occurs in both goods. Then once again there is no effect on labour shares, so equilibrium consumption levels are:

\[
C_{X_1} = \alpha A_{X_1} L
\]

\[
C_{X_1}^* = (1-\alpha) \tau A_{X_1} L
\] (38a)

\[
C_{X_2} = \alpha \tau A_{X_2} L
\]

\[
C_{X_2}^* = (1-\alpha) A_{X_2} L
\] (38b)

Comparing the consumption under international trade with the consumption/output under autarky in equation (5), the threshold values of \( \tau_{X_1} \) and \( \tau_{X_2} \) are given by:

\[
\tau_{X_1} = \left(\frac{\alpha}{1-\alpha}\right) \left(\frac{A_{X_{11}}}{A_{X_1}}\right) L^* L
\]

\[
\tau_{X_2} = \left(\frac{1-\alpha}{\alpha}\right) \left(\frac{A_{X_{22}}}{A_{X_2}}\right) L^* L
\] (39)

Substituting from the assumed values of the parameters above yields \( \tau_{X_1} = \tau_{X_2} = 0.5 \). This shows us that comparing direct and indirect production, trade costs can be higher under direct production and still allow countries to gain from international trade in final goods.
3.4 Trade and coordination costs: Trade in intermediate and final goods

In this section, we consider the case of international trade in both intermediate and final goods. It may seem reasonable from Antras (2003) to assume that the coordination costs in international trade exceed those in domestic trade. Let the coordination cost be the same across goods. Hence define \((1 - \beta_T) > (1 - \beta)\) as the coordination costs of indirect production when the inputs are imported. In this section we seek to obtain the threshold values of \(\beta_T\) such that for values greater than the threshold value, trade in both intermediate and final goods will occur, but if not, only trade in final goods (with domestic indirect production) will occur as in Section 3.3 above.

Since Home specialises in \(X_1\) and Foreign in \(X_2\), the production functions are now:

\[
Q_{X_1} = \min \{ \beta_T A_{X_{01}} L_{X_{01}}, \beta_T \tau A_{X_{11}} Q_{Y_1}^* \} \tag{40a}
\]

\[
Q_{X_2}^* = \min \{ \beta_T A_{X_{02}}^* L_{X_{02}}^*, \beta_T \tau A_{X_{22}}^* Q_{Y_2} \} \tag{40b}
\]

The equilibrium conditions are shown in Appendix C. Solving for labour in each of the four sectors yields:

\[
L_{X_{01}} = \left[ 1 + \left( \frac{1}{\tau} \right) \left( \frac{1}{\alpha} \right) \left( \frac{A_{X_{02}}}{A_{X_{11}} A_{Y_1}^*} \right) \left( \frac{A_{X_{11}} A_{Y_1}^* + A_{X_{01}}}{A_{X_{22}} A_{Y_2}^* + A_{X_{01}}} \right) \right]^{-1} L = \left[ B \right]^{-1} L \tag{41a}
\]

\[
L_{Y_2} = \left( 1 - [B]^{-1} \right) L \tag{41b}
\]

\[
L_{X_{02}}^* = \left[ 1 + \left( \frac{1}{\tau} \right) \left( \frac{\alpha}{1 - \alpha} \right) \left( \frac{A_{X_{01}}}{A_{X_{11}} A_{Y_1}^*} \right) \left( \frac{A_{X_{11}} A_{Y_1}^* + A_{X_{01}}}{A_{X_{22}} A_{Y_2}^* + A_{X_{01}}} \right) \right]^{-1} L^* = \left[ D \right]^{-1} L^* \tag{42a}
\]

\[
L_{Y_1}^* = \left( 1 - [D]^{-1} \right) L^* \tag{42b}
\]

Notice that, just as in autarky, the coordination cost does not enter into the labour allocation across sectors, although the trade cost does. The coordination cost however does enter into the production function, resulting in a productivity cost and reducing the final amount of each good available for consumption. As before, consumption of each good depends on each country’s national income. Following the same steps as in Section 3.2, the value of Home’s national income is:

\[
p_{X_1} Q_{X_1} = \frac{\tau A_{X_{11}} A_{Y_1}^* + A_{X_{01}}}{\tau A_{X_{11}} A_{Y_1}^* [B]} L \tag{43}
\]

And Foreign’s national income is:

\[
p_{X_2} Q_{X_2}^* = \frac{\tau A_{X_{22}} A_{Y_2}^* + A_{X_{02}}}{\tau A_{X_{22}} A_{Y_2}^* [B]} L^* \tag{44}
\]

Home’s share of world income is therefore:
\[
\bar{S}_H = \frac{\tau A_{X_{11}} \beta_1 T}{\tau A_{X_{11}} \beta_1} + \frac{\tau A_{X_{11}} \beta_2 T}{\tau A_{X_{11}} \beta_2} \left[ \frac{\tau A_{X_{01}}}{\tau A_{X_{01}}} \right] + \frac{\tau A_{X_{22}} \beta_2 T}{\tau A_{X_{22}} \beta_2} \left[ \frac{\tau A_{X_{02}}}{\tau A_{X_{02}}} \right] \]

(45)

Hence equilibrium consumption in the two countries is:

\[
C_{X_1} = \bar{S}_H \tau \beta_1 T A_{X_{01}} \left[ \beta \right]^{-1} L \quad C_{X_1}^* = (1 - \bar{S}_H) \tau \beta_1 T A_{X_{01}} \left[ \beta \right]^{-1} L \quad (46a)
\]

\[
C_{X_2} = \bar{S}_H \tau \beta_1 T A_{X_{02}} \left[ \beta \right]^{-1} L \quad C_{X_2}^* = (1 - \bar{S}_H) \tau \beta_1 T A_{X_{02}} \left[ \beta \right]^{-1} L \quad (46b)
\]

The threshold values of \( \beta_T \) are obtained by comparing these consumption levels with consumption under international trade in final goods only (36a) and (36b):

\[
\bar{\beta}_{1T} = \frac{\alpha \beta_1 A_{Y_{1}} A_{X_{11}} \left[ \beta \right]}{\bar{S}_H (A_{Y_{1}} A_{X_{11}} + A_{X_{01}})} \quad \bar{\beta}_{2T} = \frac{\alpha \beta_1 A_{Y_{2}} A_{X_{22}} \left[ \beta \right]}{\bar{S}_H (A_{Y_{2}} A_{X_{22}} + A_{X_{02}})} \quad (47)
\]

Values of \( \beta_T \) greater than the threshold values mean that output with trade in both intermediate and final goods is larger than output with trade in final goods alone. Figure 1 shows that the threshold values depend positively on the domestic coordination cost \( \beta \), while for the parameter values chosen, it is negatively related to the trade cost \( \tau \); the relationship with \( \beta \) is a general result, while the relationship with \( \tau \) depends on other parameter values.

Figure 1: Threshold values of \( \beta_{1T} \) as a function of \( \beta \) and \( \tau \).

3.5 A history of the international organisation of production

The previous subsections have shown how production is organised in the world economy depending on the coordination and trade costs that exist. In this subsection we consider what happens as both trade and coordination costs decrease over time. The outcomes depend in a
relatively complex way on these trade and coordination costs; hence we offer here an example of the parameter values under which different configurations exist.

Suppose initially that both types of costs are very high; for example, $\beta = \tau = 0.4$ and $\beta_T = 0.3$. Whilst these may appear to be very large trade costs (equivalent to a trade friction of 150%), this is not out of line with the figures quoted in Anderson and van Wincoop (2004), who suggest a total trade barrier of 170% in developed countries. With such high costs, it is not beneficial to engage in international trade, or indeed to engage in domestic indirect production. This is the situation with Henry Ford’s monolithic factory: firms produce final goods directly from raw materials, and there is no international trade.

What happens next depends on whether trade costs decrease faster than coordination costs or vice versa. In the former case, suppose that $\beta = 0.4$, $\beta_T = 0.3$ as before, and $\tau$ increases to 0.5. This is sufficient to ensure that international trade in final goods with direct production is the most beneficial outcome. In this case Home will specialise in $X_1$ and export it to Foreign in exchange for imports of $X_2$. On the other hand, if coordination costs decrease faster than trade costs, then autarky with indirect production will occur, for instance if $\beta_T = 0.3$, and $\tau = 0.4$ as before, then $\beta = 0.593$ is sufficient to obtain this outcome. Therefore, industries in which trade costs are relatively low compared to coordination costs will be engaged in international trade, whereas industries in which trade costs are relatively high will engage in domestic indirect production.

As both trade and coordination costs continue to fall, production begins to take place indirectly, although only international trade in final goods continues to occur. For example, this occurs if $\beta_T = 0.3$ as before, and $\beta = \tau = 0.625$. Therefore, as trade and coordination costs fall, countries may actually become less specialised as they move from international trade with direct production to international trade with indirect production. And finally, when the cost of coordinating imported intermediate products is sufficiently small relative to the cost of coordinating domestically produced intermediate products ($\beta_T$ is sufficiently close to $\beta$), countries will trade both intermediate and final goods, specialising in the production of intermediates and final goods in which they have a comparative advantage. This is the production structure of the Apple iPod as discussed in the Introduction. Given the parameters assumed above, an example of this occurring is when $\beta = \tau = 0.65$, and $\beta_T = 0.62$. 

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If inputs are defined as being in the same industry as the final good it is used in, then trade will be intra-industry in nature: Home exports $X_1$ and $Y_2$ in exchange for imports of $X_2$ and $Y_1$. Therefore, intra-industry trade can occur only when the cost of transacting internationally is not too large relative to the cost of transacting domestically. In addition, similarly to Yi (2003), once trade and coordination costs fall to this low level, the volume of trade increases, possibly in a nonlinear way, depending on the parameter values. If international standards such as ISO certification help to reduce these international transactions costs, then this may provide a justification for the existence of such standards (see for example Clougherty and Grajek, 2008). A similar role may exist for business networks (see for example Rauch, 2001).

4 Conclusions

This paper develops a simple model of international trade with 2 countries, 2 final goods, 2 intermediate goods, and one factor of production. The objective is to explore the structure of production that emerges. Both domestic and foreign outsourcing lead to productivity gains. Despite the simple setup, the model allows for many possible outcomes, depending on the cost of international trade and the cost of coordinating intermediate inputs. When both trade and coordination costs are very high, not only is there no international trade, but firms engage in direct production of final goods (that is, they do not make use of intermediate inputs produced outside the firm). As coordination costs fall, indirect production of final goods occurs with the use of domestic intermediate inputs, while as trade costs fall, international trade in final goods occurs. Finally, when coordination costs for imported intermediates are not too large relative to the coordination costs of domestically produced intermediates, international trade occurs in both intermediate and final goods, and production occurs indirectly through the use of imported intermediates.

The model in this paper has assumed a single factor of production. Whilst this simplifies the analysis, it also prevents us from analysing the distributional effects of trade in intermediate goods, which has been an important policy issue (see Mankiw and Swagel, 2006). In addition, by assuming only one intermediate good for each final good, the model is unable to address the possibility that decreasing trade and coordination costs may result in an expansion in the range of intermediate inputs being outsourced. The other key omission is
heterogeneity across firms, which would allow for different organisational forms within each sector. Progress along these lines can be made using a model with more than one factor of production, many intermediate goods, and firm heterogeneity of the Melitz (2003) type, and is an important avenue for future research.

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Appendix A: Equilibrium conditions with international trade in final goods only

The equilibrium conditions when international trade is allowed in final goods only are as follows:

\[
p_{X_1} = p_{X_1}^* = \frac{w(A_{X_{11}}A_{Y_1} + A_{X_{01}})}{A_{X_{01}}A_{X_{11}}A_{Y_1}} \quad p_{X_2} = p_{X_2}^* = \frac{w^*(A_{X_{22}}A_{Y_2} + A_{X_{02}})}{A_{X_{02}}A_{X_{22}}A_{Y_2}} \tag{A1}
\]

\[
\frac{p_{X_1}}{p_{X_2}} = \left[ \frac{A_{X_{02}}A_{X_{22}}A_{Y_2}}{A_{X_{01}}A_{X_{11}}A_{Y_1}} \right] \left[ \frac{A_{X_{11}}A_{Y_1} + A_{X_{01}}}{A_{X_{22}}A_{Y_2} + A_{X_{02}}} \right] = \frac{\alpha}{1-\alpha} \left( \frac{C_{X_2}}{C_{X_1}} \right) \tag{A2}
\]

\[
\frac{c_{X_2}}{c_{X_1}} = \frac{A_{X_{02}}L_{X_2}}{A_{X_{01}}L_{X_1}} = \frac{A_{X_{22}}A_{Y_2}L_{Y_2}}{A_{X_{22}}A_{Y_2} + A_{X_{02}}} \tag{A3}
\]

\[
\frac{L_{X_2}}{L_{Y_2}} = \left( \frac{1-\alpha}{\alpha} \right) \left( \frac{A_{X_{02}}}{A_{X_{01}}} \right) \left( \frac{A_{X_{11}}A_{Y_1} + A_{X_{01}}}{A_{X_{22}}A_{Y_2} + A_{X_{02}}} \right) \tag{A4}
\]

\[
A_{X_01}L_{X_01} = A_{X_{11}}A_{Y_1}L_{Y_1} \quad \leftrightarrow \quad L_{X_01} = \frac{A_{X_{11}}A_{Y_1}}{A_{X_{01}}} L_{Y_1} \tag{A6}
\]

\[
A_{X_{02}}^*L_{X_{02}} = A_{X_{22}}^*A_{Y_2}^*L_{Y_2} \quad \leftrightarrow \quad L_{X_{02}}^* = \frac{A_{X_{22}}A_{Y_2}}{A_{X_{02}}^*} L_{Y_2}^* \tag{A7}
\]

\[
L_{X_01} + L_{Y_1} = \bar{L} \quad L_{X_02}^* + L_{Y_2}^* = \bar{L}^* \quad w = w^* \tag{A8}
\]

Appendix B: Equilibrium conditions with international trade in both intermediate and final goods

The equilibrium conditions when international trade is allowed in both intermediate and final goods are as follows:

\[
p_{X_1} = p_{X_1}^* = \frac{w(A_{X_{11}}A_{Y_1} + w^*A_{X_{01}})}{A_{X_{01}}A_{X_{11}}A_{Y_1}} \tag{B1}
\]

\[
p_{X_2} = p_{X_2}^* = \frac{w^*A_{X_{22}}A_{Y_2} + wA_{X_{02}}}{A_{X_{02}}A_{X_{22}}A_{Y_2}} \tag{B2}
\]

\[
\frac{p_{X_1}}{p_{X_2}} = \left[ \frac{A_{X_{02}}A_{X_{22}}A_{Y_2}}{A_{X_{01}}A_{X_{11}}A_{Y_1}} \right] \left[ \frac{A_{X_{11}}A_{Y_1} + A_{X_{01}}}{A_{X_{22}}A_{Y_2} + A_{X_{02}}} \right] = \frac{\alpha}{1-\alpha} \left( \frac{C_{X_2}}{C_{X_1}} \right) \tag{B3}
\]

\[
\frac{c_{X_2}}{c_{X_1}} = \frac{A_{X_{02}}L_{X_2}}{A_{X_{01}}L_{X_1}} = \frac{A_{X_{22}}A_{Y_2}L_{Y_2}}{A_{X_{22}}A_{Y_2} + A_{X_{02}}} \tag{B4}
\]

\[
\frac{L_{X_{02}}^*}{L_{X_01}} = \left( \frac{1-\alpha}{\alpha} \right) \left( \frac{A_{Y_2}A_{X_{22}}}{A_{Y_1}A_{X_{11}}} \right) \left( \frac{A_{X_{11}}A_{Y_1} + A_{X_{01}}}{A_{X_{22}}A_{Y_2} + A_{X_{02}}} \right) \tag{B5}
\]
\[ \frac{L_{Y_2}}{L_{Y_1}} = \left( \frac{1-\alpha}{\alpha} \right) \left( \frac{A_{X_{02}}}{A_{X_{01}}} \right) \left( \frac{A_{X_{11}}A_{Y_1}^{*} + A_{X_{01}}^{*}}{A_{X_{12}}A_{Y_2}^{*} + A_{X_{02}}^{*}} \right) \]  
\tag{B6}

\[ A_{X_{01}}L_{X_{01}} = A_{X_{11}}A_{Y_1}^{*}L_{Y_1}^{*} \quad \leftrightarrow \quad L_{X_{01}} = \frac{A_{X_{11}}A_{Y_1}^{*}}{A_{X_{01}}}L_{Y_1}^{*} \]  
\tag{B7}

\[ A_{X_{02}}^{*}L_{X_{02}}^{*} = A_{X_{22}}^{*}A_{Y_2}L_{Y_2} \quad \leftrightarrow \quad L_{X_{02}}^{*} = \frac{A_{X_{22}}A_{Y_2}}{A_{X_{02}}^{*}}L_{Y_2} \]  
\tag{B8}

\[ L_{X_{01}} + L_{Y_2} = \bar{L} \quad L_{X_{02}}^{*} + L_{Y_1}^{*} = \bar{L}^{*} \quad w = w^{*} \]  
\tag{B9}

**Appendix C: Equilibrium conditions with trade and coordination costs**

The equilibrium conditions when trade in both intermediate and final goods is allowed in the presence of trade and coordination costs are (setting \( w = w^{*} \)):

\[ p_{X_1} = \tau p_{X_1}^{*} = \frac{w(A_{X_{11}}A_{Y_1}^{*} + A_{X_{01}}^{*})}{\beta_{T}A_{X_{01}}A_{X_{11}}A_{Y_1}^{*}} \]  
\tag{C1}

\[ p_{X_2} = \frac{p_{X_2}^{*}}{\tau} = \frac{w(A_{X_{22}}A_{Y_2}^{*} + A_{X_{02}}^{*})}{\beta_{T}A_{X_{02}}A_{X_{22}}A_{Y_2}^{*}} \]  
\tag{C2}

\[ \frac{p_{X_1}}{p_{X_2}} = \tau \left( \frac{A_{X_{02}}^{*}A_{Y_2}^{*}A_{X_{22}}}{A_{X_{01}}A_{X_{11}}A_{Y_1}^{*}} \right) \left( \frac{A_{X_{11}}A_{Y_1}^{*} + A_{X_{01}}^{*}}{A_{X_{22}}A_{Y_2}^{*} + A_{X_{02}}^{*}} \right) = \frac{\alpha}{\frac{1}{1-\alpha}} \left( \frac{C_{X_2}}{C_{X_1}} \right) \]  
\tag{C3}

\[ \frac{L_{X_{02}}}{L_{X_{01}}} = \frac{\tau A_{X_{02}}^{*}L_{X_{02}}^{*}}{A_{X_{01}}L_{X_{01}}} = \frac{\tau A_{X_{02}}^{*}A_{Y_2}L_{Y_2}}{A_{X_{11}}A_{Y_1}^{*}L_{Y_1}^{*}} \]  
\tag{C4}

\[ L_{X_{01}}^{*} + L_{Y_2} = \bar{L} \quad L_{X_{02}}^{*} + L_{Y_1}^{*} = \bar{L}^{*} \]  
\tag{C9}

**Appendix D: Comparison with Samuelson’s (2001) results**

The equivalent parameter values used in Samuelson’s (2001) paper are:

\[ A_{X_1} = 2 \quad A_{X_2} = 0.5 \quad A_{Y_1} = 0.5 \quad A_{Y_2} = 2 \]  
\tag{D1}

\[ A_{X_{01}} = 8 \quad A_{X_{11}} = 4 \quad A_{X_{02}} = 2 \quad A_{X_{22}} = 1 \]  
\tag{D2}

\[ A_{X_1}^{*} = 0.5 \quad A_{X_2}^{*} = 2 \quad A_{Y_1}^{*} = 2 \quad A_{Y_2}^{*} = 0.5 \]  
\tag{D3}
\(A_{X_01} = 2\) \(A_{X_{11}} = 1\) \(A_{X_{02}} = 8\) \(A_{X_{22}} = 4\)  
\(\alpha = 0.5\) \(\bar{L} = \bar{L}^* = 1\)

Given these parameter values, the autarkic utility level is 0.5 under direct production, and is 0.411 under indirect production. Hence as Samuelson (2001) suggests, under autarky it does not make sense to engage in indirect production.

Trade in final goods alone yields utility of 1 – a two-fold increase over the autarkic utility level, as Samuelson (2001) finds. Finally, trade in both intermediate and final goods yields utility equal to 2 – a two-fold increase over trade in final goods alone, or a four-fold increase over the autarkic utility level. This is different from what Samuelson obtains; he gets utility equal to 3 when there is trade in both intermediate and final goods. The reason for this difference is what was alluded to in the Introduction as Samuelson’s “chicken and egg” problem. Samuelson’s model sidesteps the fact that intermediate goods need to be produced before final goods, hence enables him to obtain a larger gain from trade in intermediate inputs. In our formulation, by taking into account this timing issue, we find that the gains from trade in intermediate inputs, whilst large, is not as large as that obtained by Samuelson (2001).

In addition, Samuelson (2001) claims that “… all consumptions will become unboundably large” (Samuelson, 2001, p. 1207) when \(A_{X_{01}}\) and \(A_{X_{02}}^*\) become very large. This does not happen in our formulation, again because we have decoupled intermediates from final goods. Instead, given the values above, utility approaches 4 as \(A_{X_{01}}\) and \(A_{X_{02}}^*\) become very large. The reason is that when these parameters become very large, almost all labour is used in producing the intermediate inputs. Unless labour productivity in these intermediate inputs becomes very large as well, simply altering labour productivity in assembling the final product will not yield unbounded levels of consumption and utility.