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Louis Dupuy

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International trade and structural change: a dynamic model of weak sustainability

Louis Dupuy

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Abstract

We present a dynamic Heckscher-Ohlin model to study structural change in a sustainability context. We show how resource rich economies maximising steady-state consumption should adopt different development strategies depending on the distribution of domestic wealth instruments (assets). Owing to the diversity of development strategies available to both natural resource rich and produced capital rich countries, trade liberalisation is not necessarily the best outcome for sustainability in both types of countries. We offer to amend Adjusted Net Savings (ANS) to include in the indicator trade-induced specialisation gains from trade to fund structural change and diversification, against economic incentives for specialisation.

Keywords – Sustainability, International Trade, Heckscher-Ohlin models, Structural Change

JEL-Classification – F11, F18, F17, Q01, Q32, Q37

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Introduction

The first empirical estimates by [Repetto et al. \(1989\)](#) stressed the importance of wealth for sustainability. Fast depletion of natural capital could lead to the loss of resources critical for future development. Early theoretical sustainability models established how constant consumption over time was a precondition for sustainability ([Dasgupta 1974](#), [Solow 1974](#), [Stiglitz 1974](#)). In the absence of technical change, the income derived from the combination of production factors has to be maintained to fulfil this goal. To this end, the [Hartwick \(1977\)](#) rule promotes sustainable reinvestment of the rent into produced capital to maintain income and consumption as exhaustible resources are depleted. Following developments in natural capital accounting ([Hamilton 1994](#)), the emphasis shifted from constant income to wealth ([Solow 1986](#), [Pearce and Atkinson 1993](#)). So-called "weak sustainability" models establish that the maximum sustainable level of consumption is related to the maintenance of total wealth at constant levels ([Pezzey 2004](#), [Dasgupta 2009](#), [Hanley et al. 2014](#)).

Sourced in wealth, the sustainability of consumption rests on different types of instruments of wealth¹. There are persistent concerns about the actual degree of substitutability between instruments of wealth ([Neu-mayer 2010](#)). Which wealth instruments should be used as the basis for sustainable development? This is especially topical for resource rich economies, which development is currently based on the depletion of exhaustible resources. This objection is formulated by the strong sustainability paradigm ([Ekins et al. 2003](#)).

Recent studies of wealth over the very long run ([Greasley et al. 2014](#)) show that in the course of development, countries adopted a great variety of investment strategies in the components of wealth. Outside of environmental/sustainability economics the decline of the share of land in total wealth is a well documented phenomenon (see the latest wealth estimates in [Piketty \(2014\)](#) for the 19th and 20th centuries). Evolutions in the composition of wealth over time should be guided by the comparison of rates of return on different assets ([Hotelling 1931](#)). There are several potential combinations of wealth instruments supporting an early period level of consumption. Conversely, there are many potential combinations sustaining consumption in later periods and many more development paths linking the two states.

These choices of initial and end conditions and development paths are traditionally studied in the literature on structural change. Structural change is usually defined as the shift of labour across different sectors of the economy, first from agriculture to the industry and then from industry to services. This usually happens following productivity improvements in formerly labour intensive sectors ([Sauvy 1980](#)). Beyond this standard macroeconomic context, the notion of structural change has been used to stress the role of labour movement in explaining the resource curse ([Kuralbayeva and Stefanski 2013](#)) or conversely how labour movement could result from resource scarcity ([López et al. 2007](#)).

Structural change is deemed necessary as some instruments of wealth do not constitute a sound basis for development ([Yi-fu Lin 2012](#)). Some wealth instruments can be associated with increasing returns to scale (human capital) or greater innovation and productivity gains (produced capital) that are clear accelerators of growth. Substitution may increase the sustainable level of consumption over time ([Mccaig et al. 2015](#), [Mcmillan and Rodrick 2011](#)).

The development of natural capital accounting and enquires in the role of natural resources rents in development ([Faber and Proops 1993](#), [Van Der Ploeg 2011](#)) should lead to a broadening of the definition of structural change to fit the sustainability context. In a larger definition, structural change is not only characterised by the mobility of labour, but also by a change in the "factor intensity" of the economy. Structural change is best described by the evolution of the composition of wealth, the evolution of the relative use of instruments of wealth in the economy.

¹ This expression comes from [Fisher \(1906\)](#). It is more telling in a sustainability context than *assets*, although these are synonymous if assets are defined in a very large sense (natural, social, institutional assets).

From this extended definition, it is clear that the Hartwick rule for sustainability is a rule for structural change. As stressed by López et al. (2007) sustainability concerns will inevitably lead to structural change via resource scarcity.

This does not mean that scarcity in a given instrument of wealth is the *only* driver of structural change. As a consequence, the Hartwick rule cannot give a *complete* mapping for a path for structural change, which would not be *unique*. There are several potential paths for structural change when many instruments of wealth are used in the economy. We already hinted at one traditional trigger, productivity gains and one potential brake, limited substitutability between (at least some) instruments of wealth (Neumayer 2010). If some instruments are irreplaceable, or using them is incompatible with other social goals (such as fighting against climate change), structural change is prevented.

The driver we are interested in in this contribution is international trade. The positive role of international trade in development has been stressed by the very first contributions to trade theory (Smith 1776, Ricardo 1817), and since confirmed by countless empirical studies (Bernhofen and Brown 2005). Gains from trade rest on specialisation along the lines of the comparative advantage (Haberler 1930) and ever increasing division of labour. There is therefore, in the "trade channel", a logical chain from specialisation and comparative advantages to sustainability, via structural change.

There is so far no unified literature on the links between sustainability and international trade (Dupuy and Agarwala 2014). As a result, this causal chain has received little direct attention in the literature. The composition effect of trade on environmental services (Copeland and Taylor 2003), the role of exogenous world prices for resource depletion (Hartwick 1995, Vincent et al. 1997) and the natural resources content of trade flows (Proops et al. 1999, Atkinson and Hamilton 2002, Atkinson et al. 2012) have all been studied. A synthesis with the ambition to assess the *overall* impact of trade on sustainability is still missing.

This contribution offers a first step in this direction. We investigate the evolution of sustainable steady-state consumption in open economies undertaking different forms of structural change. We aim to compare different initial and endpoint conditions for structural change following autarky or free-trade paths. We use the level of steady-state consumption as our sustainability indicator, in line with the weak sustainability model.

Doing so, we hope to shed some light on the role of international trade in sustainable development strategies. What would be a sound wealth instruments (assets) management strategy in an open economy context? Is free trade the all-time dominant strategy to maximise steady-state consumption levels? Should sustainability indicators be further amended in the perspective of trade liberalisation?

Our modelling strategy unites three fields: weak sustainability studies, Heckscher-Ohlin theory of trade and neoclassical growth theory. We propose to study the investment/consumption behaviour of a representative agent in a 2 countries, 5 goods, 4 factors dynamic Heckscher-Ohlin (HO) model. This model is based on the work by Cuñat and Maffezzoli (2004), adapting the seminal Ventura (1997) model. The originality of our work comes from the notion of *constrained steady-states*.

Development paths are defined by the exogenous constraints weighing on the representative consumer completing his optimisation program. In this framework we compare the two basic structural change strategies of persisting in your start-of-the period sources of comparative advantages and trying to diversify by investing in assets that are the basis of your partner's comparative advantage.

Using simulations, we define a series of constraint steady states mapping structural change in both countries. Constrained steady-states are ordered using the steady-state level of consumption. Movement from one constraint steady state to another is done changing the structure of the economy, guided by trade-defined factor prices.

This is a dynamic version of the composition effect in the trade and the environment literature (Copeland and Taylor 2003), which we call the *dynamic trade-induced composition effect*. The conditions for factor price equalisation (FPE) and its consequences on domestic re-composition are also examined.

Such a comprehensive study comes at a price, paid under the form of quite restrictive assumptions. Some of these assumptions are made to maintain reasonable tractability. Others reflect our methodological choice of testing several scenarios for structural change and the constraints imposed by sustainability requirements on the economy. We will naturally mention which assumptions are critical to our results and which can be relaxed.

We define 2 scenarios that reflect the essential choices of countries opening up to trade in a dynamic setting. In the first scenario, both countries accumulate endogenously one particular instrument of wealth, produced capital, which is assumed to be qualitatively different and essential to development.² This is the *structural change* (SC) scenario as it implies structural change for the country that is otherwise relatively less endowed in produced capital. The other option is to persist in investing relatively more in exhaustible resources, the basis for the current comparative advantage: this is the *comparative advantage* (CA) scenario.

Scenarios are tested in different trade settings. In *autarky*, no trade means that factor prices are determined solely by domestic instruments of wealth stocks. The conventional opposite is free trade under world prices, which we define following Samuelson (1949) and Cuñat and Maffezzoli (2004) as the *integrated equilibrium* (IE). Finally, if assets distribution is strongly uneven across countries³, factor prices are determined solely by domestic instruments of wealth stocks: this is the *complete specialisation* case (CS).⁴ Our model does not allow for factor intensity reversal, but the level of asymmetry in the distribution of instruments of wealth in both countries will play an important role.

Based on this setting, we develop three propositions, summarising our results:

1. Resource rich economies should consider the distribution of domestic wealth instruments before choosing between produced capital accumulation (structural change) or continued reliance on exhaustible resources as a development strategy.
2. Under the assumptions of our model, resource rich countries should undergo structural change in autarky, or least revert to autarky after the early stages of development.
3. Adjusted Net Savings, the sustainability indicator in the weak sustainability model, should be amended to reflect the reinvestment of some of the gains from trade, because of the *dynamic trade-induced composition effect*.

In section 1 we review the literature on dynamic models of trade and justify our modelling strategy. In section 2 we present the model, notably the important assumptions on the production system. In section 3 we present the simulations under all the scenarios and cases. In section 4 we discuss the results and propose some robustness checks before concluding remarks.

² In doing so, we consider that a majority share of produced capital is a necessary condition for the social organisation desired across all countries.

³ Unevenness is here defined as in the lens condition from Deardorff (1994a).

⁴ As countries completely specialise in the production of some of the goods (Dornbusch et al. 1977), i.e one cone of diversification.

1 Literature review

There is very little work that delves on both “trade and the environment” and “sustainable development” literatures to try and answer a research question similar to ours. We draw from four different fields to build our framework: the weak sustainability literature, the open economy sustainability, the trade and the environment literature and the dynamic Heckscher-Ohlin (HO) macroeconomic literature. Some concepts are easily matched across literatures⁵, while others are harder to integrate. We will therefore present our sources in the literature before justifying the assumptions we pick for our model.

1.1 Sustainability and structural change

The weak sustainability (WS) model is first formulated in Dasgupta (1974), Solow (1974), Stiglitz (1974) and completed by further contributions (Dasgupta 2001, 2009). It is reviewed by Hanley et al. (2014). Different versions of the WS model⁶ present the link between wealth instruments and well-being, through income and steady-state consumption.

The WS model yields the simple insight that dynamic welfare⁷ is determined by price and quantity evolutions of *all* the instruments of wealth available in the economy. This result creates a responsibility for sound domestic wealth management in a sustainability context. A rule to address this responsibility is derived from the WS model, the generalised Hartwick rule (Hartwick 1977, Asheim et al. 2003). It states that rents from exhaustible resources should be reinvested in renewable wealth instrument to maintain the productive base of the economy.

Dasgupta (2001) shows how most countries grew by substituting produced capital for natural capital. Hence, most countries acted knowingly or not in the spirit of the Hartwick rule. Still, this fact is less documented than the complementary phenomenon of structural change (Sauvy 1980). There are many contributions documenting the movement of labour through sectors and its consequences on productivity, growth and income per capita (McMillan and Rodrick 2011).

The most recent developments in this literature focused on the case of resource rich countries. Some forms of structural change are a potential explanation for the resource curse (Kuralbayeva and Stefanski 2013), as exhaustible resources scarcity could trigger labour migration away from the resource intensive sector (López et al. 2007). Botswana, usually painted as a success story against the curse (Heal 2011), might soon be struggling with the movements of labour as natural resources dwindle (Mccaig et al. 2015),

From a sustainability perspective, the Hartwick rule and structural changes are two sides of the same coin. On the one hand, structural change will happen as countries follow (knowingly or not) the Hartwick rule. On the other hand, countries witnessing structural change will substitute produced capital for natural capital as the complementary factor for labour. Nevertheless, the two are not synonyms. Any amount of substitution for natural capital is structural change, but only the reinvestment of all the depleted natural capital can qualify as following the Hartwick rule.

There is therefore an important challenge for sustainability in structural change. Productivity is the main driver of structural change as it changes the technical mix of factors in sectors across the economy. Changing factor intensities will lead to changes in investment/maintenance strategies in comprehensive wealth (investment in both produced capital and human capital). This change happens through modifications of the relative price system, changing the sustainability outlook.

⁵ The instruments of wealth or capital stocks of sustainability theory are readily assimilated as the factor endowments of trade theory. The Factor Price Equalisation (FPE) condition in HO literature mirrors the domestic versus international price debate in open economy sustainability literature.

⁶ Often referred to as the DHSS (for Dasgupta-Heal-Solow-Stiglitz) model.

⁷ Also referred to as "intergenerational well-being".

The impact of productivity and population changes on prices and composition is quite well-documented in the sustainability literature (Asheim et al. 2007, Cheviakov and Hartwick 2009). What is less clear is how international trade will affect the composition of the economy, from a sustainability perspective. There are open versions of the WS model, but the literature on trade and sustainability is not yet unified in a comprehensive setting with both price shocks and dynamic changes in the composition of wealth (Dupuy and Agarwala 2014).

1.2 Sustainability and trade: prices and composition

When assessing the impact of trade on the environment, attention is usually drawn to the works of Copeland and Taylor (Copeland and Taylor 1995, Antweiler et al. 2001). The decomposition of the impact of trade into scale, technique and composition effects is a potent way to discriminate between the contradictory impacts of international trade on the environment.

Models of trade and the environment focused on the evolution of pollution concentration and/or emissions (Copeland and Taylor 1994). The total impact of trade depends on which effect dominates, between the pro-pollution scale effect, the anti-pollution technique effect and the ambiguous composition effect. Composition holds the key to the global impact as scale and technique roughly cancel each other out (Antweiler et al. 2001). At the global scale, the total trade impact (the summation of the 3 effects), is positive (Neumayer 2000) as the composition effect and the technique effect overrun the scale effect.

The evolution of the composition of domestic economies is therefore key to predict and implement sustainability. Empirical exercises based on input/output table show that the amount of natural resources embodied in trade flows is quite large Atkinson and Hamilton (2002), Proops et al. (1999). This is evidence that composition is adapting to natural resource scarcity, making the task of resource rich economies harder. These countries need to deplete their resources to satisfy world demand, at an increasing rate (Atkinson et al. 2012).

International trade creates an incentive to specialise and change the composition of economies, composition that is essential for sustainability. This incentive is propagating through the world price system, which theoretically create a global optimal path. But international trade also creates the possibility of different price regimes (exogenous or endogenous) and with them multiple development paths.

In an open economy setting, the consequences of trade for sustainability vary depending on whether prices are assumed to be endogenous (determined by domestic conditions in trading partners) or exogenous (taken as given by all). The exogenous setting is studied in Dasgupta and Heal (1979), Dixit et al. (1980) and Hamilton et al. (1998), then completed for the Hartwick rule by Asheim (1986). Asheim (1986) shows that exogenous world prices generate "income gains from trade": countries form expectations regarding future world prices, leading to different development paths.

The endogenous prices setting is presented by Hartwick (1995) and Vincent et al. (1997). In Hartwick (1995) the resource poor country has to save less than optimal to pay for imports of natural resources and maintain constant consumption over time. As capital gains generate windfalls for the domestic economy, resources rich countries are expected to use the extra income in a sustainable manner (Pezzey 2004). Over-estimating the gains from trade is credited for un-sustainability in many resource rich countries (Rubio 2004).

The capital gains illustrate the many questions associated with international trade from a sustainability angle: Is it equivalent in the long run to invest windfalls domestically or oversees (Van der Ploeg 2010)? How to maintain domestic responsibility for depletion (Atkinson and Hamilton 2002) when exogenous world prices have the final say on sustainability? When opening-up to free trade, countries effectively pool their resources and accept that other countries' preferences and choices will co-determine their own development path.

Faced with this dilemma, we argue that lacking a global coordination mechanism, development should be harmonious and balanced at the national level as well as the international level. Conditions for sustainability

and sustainable paths should be assessed at the national and the global level, and two sets of prices (domestic and global) should be considered.

How to compare results based on exogenous prices and endogenous prices? There is in trade theory a setting that makes the joint consideration instruments of wealth and consumption possible. This is the Hecksher-Ohlin (HO) model, where patterns of trade are sourced in the asymmetric distribution of endowments (easily assimilated to the instruments of wealth of sustainability theory).

The HO model also happens to be robust to the violation of its core assumption, the Factor Price Equalisation (FPE) condition (Deardorff 1980, 1982, 1994b). Deardorff (1979) shows that the chain ranking of comparative advantage established by Vanek (1968) holds when FPE is not verified if either impediments to free trade or intermediate goods are introduced. HO models can therefore be used when factor prices are equalised (so that factor prices are global, i.e. *exogenous*) and when they are not (so that factor prices are domestically determined, i.e. *endogenous*). The only condition is to assume away tariffs and transaction costs.

Deardorff (1994a) proposes the famous "lens condition" to show how FPE will break down if the asymmetry in the distribution of factor endowments across countries becomes "excessive". An empirical test based on this prediction conducted by Debaere and Demiroglu (2003) shows that the dissimilarity of endowments is too high for FPE to occur at the global scale, but can occur between OECD countries. The breakdown of factor price equalisation creates multiple cones in a Lerner-Pearce diagram, and the possibility that the "integrated world economy" (Dixit and Norman 1980) turns into a place of separate cones of complete specialisation based on relative world endowments.

This result may be extended using comprehensive wealth data from the World Bank (2011). We define a "developed country" specialisation as being relatively more endowed than the world average in labour and produced capital. Conversely, the "developing country" specialisation rests on being relatively more endowed than the world average in natural capital (renewable plus non renewable resources). We break down intangible capital following the World Bank (2006) estimate that labour accounts for 36% of the total.

This gives figure 1, where countries on the left have 100% of total wealth as produced capital and labour, and countries on the right 100% as exhaustible resources. The vertical black lines mark the limit of the FPE zone (see section 2) and the horizontal ones the 50% limit. We can confirm that FPE is not possible at the global level, when all assets are considered.

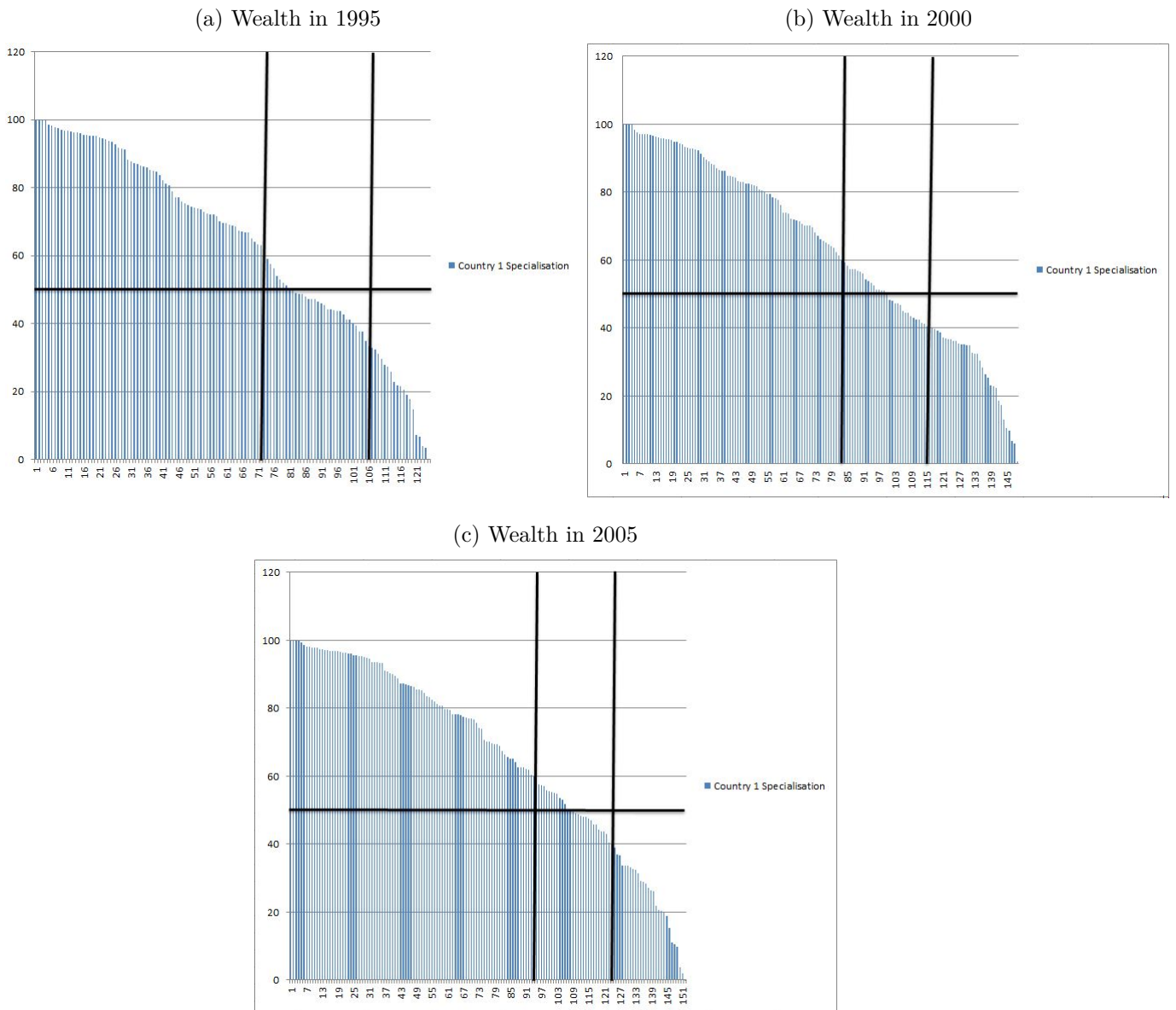
1.3 A dynamic Hecksher-Ohlin model for weak sustainability

To complete the set of assumptions, we need a setting to make this trade model with different price regimes and asymmetric distributions of wealth instrument dynamic. Since Arrow and Debreu (1954) macroeconomic models study growth and factor accumulation. The Lucas critique and the development of rational expectations opened the field to a class of perfect foresight deterministic models (Stokey et al. 1989) used to study economic dynamics.

This literature brings a criterion for international equity: the need for convergence in steady state levels of consumption. Countries should only accept to pool resources under their responsibility at the global scale a) for better management and b) to obtain international equity in steady-state consumption levels.

Ventura (1997) documents the long time failure of income convergence, as developed countries have higher growth rate than developing countries, preventing catch-up. He proposes a dynamic HO model where the composition effect (i.e. the Rybczinsky effect) enables developed countries with non declining return on produced capital, preventing world wide steady-state consumption convergence. (Atkeson and Kehoe 2000) attributes divergence to the different starting point of economies (in terms of produced capital stock). Cuñat and Maffezzoli (2004) finds FPE breakdown to have the same effect, while Bajona and Kehoe (2010) stress the importance of

Figure 1: Distribution of wealth in world countries



Source: The World Bank wealth accounting database (World Bank 2011)

the elasticity of substitution between traded goods in determining the outcome.

The composition effect and differences in price regimes are therefore the most likely explanations for divergence in cross country steady-state levels of consumption. This may be sourced in different levels of productivity, but more permanently in uneven distribution of instruments of wealth worldwide. From this state of the literature, three questions emerge:

1. What would be the best composition for world economies with uneven begin-of-the-period wealth instruments distribution? In other words, what is the best possible path for structural change, and can domestic paths be consistent at the global scale?
2. Of the three main price regimes (autarky, free trade at exogenous prices, free trade at endogenous/domestic prices) which one is best suited for resource-rich countries, currently bearing a high direct responsibility for asset depletion?
3. How to amend sustainability indicators for the trade-induced composition effect in a dynamic setting?

We are not the first to address these questions, although our setting is one of the most general currently available. For example, Redding (1999) investigates how a developing country can diversify away from its comparative advantage, based on endogenous reduction of productivity differences. As our main object is sustainability assessment we focus on endowments differences instead of productivity. In terms of endowments, countries face two broad strategies:

- Early specialisation in line with the comparative advantage(s) paves the way for diversification in order to go upmarket and pursue development beyond the middle income trap. This is the *structural change* (SC) scenario.
- Persistence in an economic structure dominated by early sources of comparative advantage (resource rich economies). This is the *comparative advantage* (CA) scenario.

Our modelling strategy is therefore to compare the two scenarios of SC and CA to provide an answer to question 1. We will then examine different trade/price regimes under both strategies to answer question 2. A detailed studies of the dynamics and the investment behaviours in the model will then enable us to offer trade amendments to Adjusted Net Savings, an answer for question 3.

2 The model

2.1 Modelling strategy and assumptions

Our objective to compare different trade regimes and strategies of wealth instruments management requires an analysis with a large scope. The price associated with this large scope is a large set of restrictive assumptions, which we will list here and detail where relevant:

1. No productivity or preference differences, so that the only driver in the model is the distribution of wealth instruments.
2. One country will be relatively well endowed in produced capital and labour, another in renewable and non-renewable exhaustible resources.

3. Each country accumulates endogenously only one wealth instrument at a time (produced capital or renewable resources depending on the scenario) while the others are exogenously determined. Assumptions regarding the dynamics of accumulations are presented below.
4. We compare the results of our different scenarios under different trade regimes (exogenous and endogenous factor prices), we therefore also assume that the different steady-states are comparable, using to this end the notion of *constrained steady-state*.
5. The production structure of the model rests on one final non-traded good and five intermediate traded goods. This structure, further detailed below, generates the counter-intuitive result that countries are systematically better-off in autarky compared to free trade for the same distribution of wealth instruments.
6. As in standard Heckscher-Ohlin in Ricardian models, we assume that capital is immobile internationally: accumulation and de-cumulation occur through the investment dynamics.

Following [Cuñat and Maffezzoli \(2004\)](#) the model is solved recursively using two sub-models. Every iteration, the distribution of wealth instruments is observed and used to compute factor prices and good prices using the *static component* (general equilibrium prices). These prices are then used in the *dynamic component* to obtain wealth instruments stocks (optimal investment/depletion path) that will be the basis for computation in the next iteration, until equilibrium is reached. See section 2.2.

Our choice of scenarios is based on the observation of different strategies for development, especially in former colonies ([Yi-fu Lin 2012](#)). Our scenarios can be seen as a stylised version of the choice of early *specialisation* in comparative advantages (CA scenario) versus *diversification* (SC scenario) through for example import substitution ([Arezki et al. 2014](#), [Harvey et al. 2010](#)). Our contribution is to frame the choice not in terms of minimal productivity in the manufacturing sector, but in terms of the distribution of wealth instruments.

In our model, it is equivalent to reduce reliance on your abundant wealth instruments by depleting them more than the others, or by investing more in your scarce instruments. In both cases, the abundant wealth instruments are *relatively less* abundant. This is what matters in an HO model, but clearly constitute a limit of our analysis.

Another important concept in our model is the notion of the *constrained steady-state*. We define a series of steady-states that are a function of the distribution of exogenous wealth instruments. For each of these constrained steady-states, the representative agent picks the optimal stock of one endogenous wealth instrument, constrained by the all the others that are exogenously set. Repeating this process gives us a mapping for a development path defined by the unevenness of the distribution of wealth in the country.

We use this strategy instead of the usual unique steady-state with short term shocks procedure as the essence of development (and structural change) is precisely to change the long-run equilibrium point of the economy ([Solow 1956](#)). The exogenous evolution of some instruments of wealth is also consistent with the "price of the time passing" in sustainability theory⁸ ([Arrow et al. 2010](#), [Pemberton and Ulph 2001](#)).

Our production structure choice also requires justification. Wealth instruments enter as unique factors intermediate goods production. There is as a result no substitutability in factor inputs for the production of intermediates. The intuition comes from sustainability theory, which raises doubt about substitutability between instruments of wealth ([Neumayer 2010](#)). This structure encapsulate the idea that specialisation leads to increased reliance on a limited set of wealth instruments, translating into an increased factor content in trade flows ([Atkinson and Hamilton 2002](#), [Proops et al. 1999](#)).

It also reflects the well known theoretical and empirical result that the composition of production changes as countries open-up to free trade (they specialise in their comparative advantage). The development of the

⁸ In this perspective, change in wealth is partly driven by unobservable factors, most of them institutional ([Dasgupta 2009](#)). It is therefore possible to assume exogenous forces constraining an optimal setting.

global supply chain is a contemporary continuation of this old logic to find scarce domestic factors in foreign countries (Costinot et al. 2012). Therefore, we believe a simple Cobb-Douglas function did not fit our aim. This production structure better reflects the *immediate* coordination cost associated with entering the global supply chain and the *long term* risks associated with a relatively scarce, but critical to production wealth instrument⁹.

Finally, we assume that each of the four wealth instruments in the model have a potentially different pattern of accumulation/de-cumulation. This assumption is only binding for produced capital and renewable resources as these are the only 2 being potentially endogenously accumulated:

Labour K_l is accumulated by investment in education. The labour endowment of a given country is equal to the part of the population with adequate training to enter the production process. Therefore, the value of labour is the monetary equivalent of all the training, or education, embedded in the labour force. The reward for labour is the wage w .

Produced Capital K_p is accumulated through investment. It depreciates every period by a constant parameter δ . Produced capital is owned by consumers and rented by firms at a rate p to produce intermediate goods at every period.

Non-Renewable Exhaustible Resources K_e can only be used in the production process, there is no investment. The representative agent does not include exhaustible resources in its budget constraint, as he can not invest to renew them. The reward for exhaustible resources use is the royalties e paid to the representative household by the firms using exhaustible resources in the production process.

Renewable Exhaustible Resources K_r have a rate of natural growth ρ at every period, applied to the current stock. Natural growth is a bonus over investment in renewable resources which takes the form of fish farming or ecosystem services management. The use of the pool is sanctioned by a royalty r .

The formal translation of these dynamics is presented below. Our results are based on numerical simulations, as in Cuñat and Maffezzoli (2004) from which our setting is derived. The different trade regimes prevent the delivery of an analytical solution as goods prices are based on both domestically and globally determined factor prices. We consider two identical countries, country 1 and 2. Those two countries have the same production technologies and preferences. Each economy is composed of a set of identical consumers, who owns all the instruments of wealth/production factors. They only differ in the distribution of their wealth instruments. The economy produces one final good Y which is not traded, consumed or invested. The five intermediate goods can then potentially be traded.

2.2 The dynamic equilibrium

Consider that country 1 and country 2 are populated with a continuum of identical and infinitely lived agents. Countries are indexed using the letter j . We assume perfect information and foresight. Agents being infinitely lived, we also assume *de facto* intergenerational equity. Our continuum assumption allows us to use a single representative agent for all the agents in the economy. This rational agent maximises utility over an infinite horizon. Utility is the sum of discounted consumption flows over an infinite number of periods:

$$U_{j,t} = U_{j,t}(c(t)) = \sum_{s=t}^{\infty} \beta^{s-t} \ln c_{j,t} \quad (1)$$

β is the pure rate of time preference, c is consumption, s indicates the starting period and t the current period. We assume that the representative agent owns all the instruments of wealth available in his country. The use of labour K_l and produced capital K_p generates the usual income flows. Non renewable exhaustible resources are obtained against the payment of a royalty e set at the marginal cost so that extraction is optimal. The same logic applies to renewable exhaustible resources, with the exception that the resource pool regenerates itself via

⁹ And the potential benefits of using trade to mitigate this risk.

natural growth ρ and pays a royalty r . The representative agent optimises future consumption based on wealth, in a permanent-income perspective (Ventura 1997).

We can now define formally our two scenarios of structural change (SC) and increasing comparative advantage (CA). In SC, representative consumers in country 1 and country 2 both set the investment path for produced capital to maximise consumption, constrained by exogenous path for labour, exhaustible resource and renewable resources. In CA, country 1 stick to the SC optimisation plan, but country 2 optimises investment in renewable resources, constrained by exogenous paths for labour, produced capital and exhaustible resources. The different exogenous paths simulated will be presented in section 3.

The dynamics for the endogenous investment paths are:

$$K_{p,t+1} = K_{p,t} - \delta K_{p,t} + IK_{p,t} \quad (2)$$

$$K_{r,t+1} = K_{r,t} + \rho K_{r,t} + IK_{r,t} \quad (3)$$

With $IK_{p,t}$ and $IK_{r,t}$ investment in t . Special attention was devoted to the dynamics of exhaustible resources. We do not have a standard co-state equation of the usual $S \geq \sum_t^T -R_t$ form with S the total stock and R_t depletion in t . Our assumption of an exogenous path prevents the formation of an optimal path, based on a specification of the Hotelling rule. Still, to model increased scarcity we add a variable cost of extraction for exhaustible resources of the form:

$$TC = xK_{e,j} \quad (4)$$

With TC total cost and x an exogenously determined parameter. Under a scenario where quantities extracted are constant, a fixed maintenance cost is paid. This cost turns into a variable cost based on the volume extracted in a scenario of increasing or decreasing extraction.

In SC, both countries face the same budget constraint:

$$\begin{aligned} w_{j,t}K_{l,j,t} + p_{j,t}K_{p,j,t} + e_{j,t}K_{e,j,t} + r_{j,t}K_{r,j,t} \\ = c_{j,t} + K_{p,j,t+1} - K_{p,j,t} + \delta K_{p,j,t} + xK_{e,j,t} - \rho K_{r,j,t} \end{aligned} \quad (5)$$

In CA, country 1 stays under the same constraint while country 2 invests in renewable resources:

$$\begin{aligned} w_{1,t}K_{l,1,t} + p_{1,t}K_{p,1,t} + e_{1,t}K_{e,1,t} + r_{1,t}K_{r,1,t} \\ = c_{1,t} + K_{p,1,t+1} - K_{p,1,t} + \delta K_{p,1,t} + xK_{e,1,t} - \rho K_{r,1,t} \end{aligned} \quad (6)$$

$$\begin{aligned} w_{2,t}K_{l,2,t} + p_{2,t}K_{p,2,t} + e_{2,t}K_{e,2,t} + r_{2,t}K_{r,2,t} \\ = c_{2,t} + K_{r,2,t+1} - K_{r,2,t} - \rho K_{r,2,t} + \delta K_{p,2,t} + xK_{e,2,t} \end{aligned} \quad (7)$$

Every period the representative agent gets income from the factors rented/extracted by the representative firms in the intermediate goods sectors and has to choose between consumption and investment.

Maximising (1) with respect to (5) gives us the following two first order conditions for the SC case:

$$c_{j,t+1} = \beta c_{j,t}(1 - \delta + p_{j,t}) \quad (8)$$

$$K_{p,j,t+1} = w_{j,t}K_{l,j,t} + (1 + p_{j,t} - \delta)K_{p,j,t} + (e_{j,t} - x)K_{e,j,t} + (r_{j,t} + \rho)K_{r,j,t} - c_{j,t} \quad (9)$$

and the transversality condition:

$$\lim_{t \rightarrow \infty} \beta_t \frac{k_{p,j,t+1}}{c_{j,t}} = 0 \quad (10)$$

Maximising (1) with respect to (6) and (1) with respect to (7) gives us the following four first order conditions

for the CA case:

$$c_{1,t+1} = \beta c_{1,t}(1 - \delta + p_{1,t}) \quad (11)$$

$$c_{2,t+1} = \beta c_{2,t}(1 + \rho + r_{2,t}) \quad (12)$$

$$K_{p,1,t+1} = w_{1,t}K_{l,1,t} + (1 + p_{1,t} - \delta)K_{p,1,t} + (e_{1,t} - x)K_{e,1,t} + (r_{1,t} + \rho)K_{r,1,t} - c_{1,t} \quad (13)$$

$$K_{r,2,t+1} = w_{2,t}K_{l,2,t} + (1 + r_{2,t} + \rho)K_{r,2,t} + (e_{2,t} - x)K_{e,2,t} + (p_{2,t} - \delta)K_{p,2,t} - c_{2,t} \quad (14)$$

And the transversality condition:

$$\lim_{t \rightarrow \infty} \beta_t \frac{k_{p,j,t+1}}{c_{j,t}} = 0 \quad (15)$$

Details about the calculations are presented in appendix A.3.

2.3 The static equilibria

2.3.1 production technologies

The two countries have the same production structure. We assume constant returns to scale in production. The final good Y is produced using a Cobb-Douglas function:

$$Y = \Phi y_{1,i}^{\alpha/4} y_{2,i}^{\alpha/4} y_{3,i}^{1-\alpha} y_{4,i}^{\alpha/4} y_{5,i}^{\alpha/4} \quad (16)$$

Goods are indexed using the letter i . y_i and x_i are quantities produced and consumed respectively. Φ represents total factor productivity (assuming Hicks-neutral technology) while α is the usual Cobb-Douglas parameter for input allocation. There are five intermediate goods x_1, x_2, x_3, x_4 and x_5 in both countries. Those five intermediate goods can potentially be traded. They are produced using the following production functions:

$$y_{1,i} = K_{l,i} \quad (17)$$

$$y_{2,i} = K_{p,i} \quad (18)$$

$$y_{3,i} = (K_{l,i}K_{p,i}K_{e,i}K_{r,i})^{\frac{1}{4}} \quad (19)$$

$$y_{4,i} = K_{e,i} \quad (20)$$

$$y_{5,i} = K_{r,i} \quad (21)$$

Goods x_1, x_2, x_4 and x_5 are intensive in one of the four wealth instruments relative to x_3 . The production equilibrium is obtained maximising (16) subject to intermediate production functions (17) to (21):

$$y_{1,i} = \lambda K_{l,i} \quad (22)$$

$$y_{2,i} = \gamma K_{p,i} \quad (23)$$

$$y_{3,i} = ((1 - \lambda)K_{l,i})^{\frac{1}{4}} ((1 - \gamma)K_{p,i})^{\frac{1}{4}} ((1 - \omega)K_{e,i})^{\frac{1}{4}} ((1 - \beta)K_{r,i})^{\frac{1}{4}} \quad (24)$$

$$y_{4,i} = \omega K_{e,i} \quad (25)$$

$$y_{5,i} = \iota K_{r,i} \quad (26)$$

$$\sum_{i=1}^3 p_i x_{i,j} = \sum_{i=1}^3 p_i y_{i,j} \quad (27)$$

With β, γ, ω and λ the shares used in the production of the intermediates and (27) the market clearing conditions.¹⁰ Let us assume for the moment that factor endowments are the same across countries. This allows us

¹⁰ Which are non binding in autarky.

to ignore the market clearing conditions. As shown in appendix A.1, this yields $\gamma = \iota = \omega = \lambda = \alpha$.

The coefficient α determines the allocation of factors across intermediates and at the same time the relative use of intermediates y_1, y_2, y_4 and y_5 against the use of y_3 in the production of the final good. If $\alpha = 0$, good y_3 is the only one entering in the final good production. Allocation shares are meaningless and endowments are allocated entirely to the production of good y_3 . This is the basis for the autarky equilibrium.

2.3.2 The autarky equilibrium

In an HO model, trade is motivated by differences in endowments and our production structure reflects this with the intermediate goods. The development of the global supply chain (Berger 2006) is a case in point that international trade translates into a more complex production structure. When there is no trade, all resources go straight to the production of the final good, without the need to develop comparative advantages. Intermediate goods production makes sense in a trade perspective *only*.

The autarky equilibrium is a special case of our production setting with $\alpha = 0$. This is the single final good case. The dynamic equilibrium is the same in autarky or free trade. Maximisation of output yields first order conditions (28) to (31) for factor prices:

$$w_{j,t} = \frac{\Phi K e_{j,t}^{\frac{1}{4}} K p_{j,t}^{\frac{1}{4}} K r_{j,t}^{\frac{1}{4}}}{4 K l_{j,t}^{\frac{3}{4}}} \quad (28)$$

$$p_{j,t} = \frac{\Phi K e_{j,t}^{\frac{1}{4}} K l_{j,t}^{\frac{1}{4}} K r_{j,t}^{\frac{1}{4}}}{4 K p_{j,t}^{\frac{3}{4}}} \quad (29)$$

$$e_{j,t} = \frac{\Phi K e_{j,t}^{\frac{1}{4}} K p_{j,t}^{\frac{1}{4}} K r_{j,t}^{\frac{1}{4}}}{4 K e_{j,t}^{\frac{3}{4}}} \quad (30)$$

$$r_{j,t} = \frac{\Phi K e_{j,t}^{\frac{1}{4}} K l_{j,t}^{\frac{1}{4}} K p_{j,t}^{\frac{1}{4}}}{4 K r_{j,t}^{\frac{3}{4}}} \quad (31)$$

2.3.3 The factor price equalisation condition: Integrated (IE) versus Complete Specialisation (CS) equilibria

Factor Price Equalisation (FPE) is determined by the world distribution of endowments, technological discrepancies and transaction costs. As presented in Ohlin (1933), FPE depends on the distribution of endowments. When factor prices are equalised, trading patterns behave as a single integrated economy. This is the "integrated equilibrium" (IE) in Dixit and Norman (1980). As in Cuñat and Maffezzoli (2004), we have more goods than factors, hence under FPE we only know that country 1 will export labour and produced capital intensive goods, while country 2 exports exhaustible resources intensive ones.¹¹

We assumed away transactions costs and cross-country technological differences, FPE depends solely on the distribution of endowments. If the distribution is "too diverse", FPE will not occur. Countries then stop producing the two goods in which they have no comparative advantage. They produce good y_3 and the two in which they have a comparative advantage. The trade pattern is then conform to the "complete specialisation" (CS) case in Cuñat and Maffezzoli (2004). Instead of facing world factor prices, firms now face domestic prices.

¹¹ This does not prevent the equilibrium to be unique as any distribution of factor endowments yields a single set of prices for goods and factors.

The breakdown of FPE ends the "separability" property of Heckscher-Ohlin model, under which an evolution of domestic factor output had no impact on factor prices.

As in Deardorff (1994a), FPE breakdown confines countries into overlapping cones of diversification based on comparative advantage. Both have a specific part of the cone where goods y_1 , y_2 , y_4 and y_5 are produced, and an overlapping part with the other for good y_3 . Starting from the theoretical case when endowments are equally distributed between countries (and the incentive to trade is null in an HO model), FPE will break down at some point when the distribution becomes too asymmetric. If $\alpha = 0$, both countries produce good y_3 with equal factor intensities. There is no incentive to trade and both countries are effectively in autarky.

Conversely, if $\alpha = 1$, both countries have an incentive to specialise according to their comparative advantage, and import the bulk of the other intermediates from the other country. In this setting, country 1 specialises into goods y_1 and y_2 and country 2 in goods y_4 and y_5 respectively. Factors K_e and K_r in country 1 and K_l and K_p in country 2 are residually used to produce the disadvantaged intermediates, so that specialisation is not complete. Between those two polar cases lie the area in which all intermediates are produced between the two countries. Depending on the value of α , the production takes place either in CS under IE.

To obtain a more tractable form for the FPE condition, we assume $\alpha \in]0; 0.5[$ as in Cuñat and Maffezzoli (2004).¹² The condition is formulated as Lemma 2.1.

Lemma 2.1 (The Factor Price Equalisation condition). *Factor Price Equalisation (FPE) holds if in both countries, the domestic stock of any instrument of wealth (noted K^{FPE}) satisfies the following condition regarding the global stock K :*

$$K^{FPE} \leq \frac{1}{2}K + \alpha K \leq \left(\frac{1}{2} + \alpha\right)K$$

See appendix A.2 for proof. The violation of the FPE condition for *one* wealth instrument is enough to prevent FPE for *all* of them. Conversely, for FPE to hold the condition must be verified for *every* wealth instrument.

Lemma 2.1 sets the limit between the two free-trade regimes, Integrated Equilibrium (IE) and Complete Specialisation (CS). Sections 2.3.4 and 2.3.5 present them formally.

2.3.4 The Integrated Equilibrium (IE)

Going from autarky to free-trade, we assume country 1 is relatively well-endowed in labour and produced capital and country 2 is relatively well-endowed in renewable and non-renewable exhaustible resources.¹³ Countries will engage in trade of intermediates as asymmetric factor endowments give each country a comparative advantage in the production of two intermediates.

We drop the country subscripts and solve for the global wealth instrument stocks as global factor prices rest on global stocks. To solve the integrated equilibrium for factor prices, we use equations (16) and (17) to (21). We first minimize the budget constraint:

$$P_y = P_1x_1 + P_2x_2 + P_3x_3 + P_4x_4 + P_5x_5 \tag{32}$$

Subject to (16). See appendix A.2 for more details. This gives us an expression for factor prices depending on

¹² The impact of the values taken by α on our results is discussed in section 4.2.

¹³ We assume also that trade is always balanced between the two countries.

factor endowments:

$$P_1 = w = E(K_l^{-\frac{3}{4}} K_p^{\frac{1}{4}} K_e^{\frac{1}{4}} K_r^{\frac{1}{4}}) \quad (33)$$

$$P_2 = p = E(K_p^{-\frac{3}{4}} K_l^{\frac{1}{4}} K_e^{\frac{1}{4}} K_r^{\frac{1}{4}}) \quad (34)$$

$$P_4 = e = E(K_e^{-\frac{3}{4}} K_l^{\frac{1}{4}} K_p^{\frac{1}{4}} K_r^{\frac{1}{4}}) \quad (35)$$

$$P_5 = r = E(K_r^{-\frac{3}{4}} K_l^{\frac{1}{4}} K_p^{\frac{1}{4}} K_e^{\frac{1}{4}}) \quad (36)$$

$$P_3 = 4E \quad (37)$$

$$(38)$$

With $E = X^{-1}4^{\alpha-1}$. P_3 is invariant because of the symmetry in the model. Due to the shape of the production functions in intermediates, factor prices are equalised to the relevant intermediate price.

2.3.5 The Complete Specialisation equilibrium (CS)

As FPE breaks down, countries will face different domestic factor prices. Country 1 becomes the sole producer of goods y_1 and y_2 , while country 2 becomes the sole producer of goods y_4 and y_5 . Good y_3 is still produced in both countries, as it requires the four factors as inputs. We have $y_{1,4} = 0$, $y_{1,5} = 0$, $y_{2,1} = 0$ and $y_{2,2} = 0$. The set of equilibrium equations is extended to take into account different factor prices in the two countries. P_1 and P_2 are determined solely by country 1 factor prices and P_4 and P_5 solely by country 2 factor prices.

We solve the CS equilibrium under those assumptions. We have more unknowns than equations, the system cannot be solved in an explicit form. We first define factor price ratios as a function of factor endowments:

$$K_{l,1} + \frac{K_{e,1}}{\tau(\alpha-1)} = \frac{(\alpha\sigma^{\frac{1}{2}} K_{e,1}^{\frac{1}{4}} K_{l,1}^{\frac{1}{4}} K_{l,2}^{\frac{3}{4}} K_{p,2}^{\frac{1}{4}} K_{r,2}^{\frac{1}{4}})}{((1-\alpha)\tau^{\frac{1}{2}} K_{e,2}^{\frac{1}{4}} K_{p,1}^{\frac{1}{4}} K_{r,1}^{\frac{1}{4}})} \quad (39)$$

$$K_{p,1} + \frac{K_{r,1}}{\nu(\alpha-1)} = \frac{(\alpha\kappa^{\frac{1}{2}} K_{e,2}^{\frac{1}{4}} K_{l,2}^{\frac{1}{4}} K_{p,1}^{\frac{1}{4}} K_{p,2}^{\frac{3}{4}})}{((1-\alpha)\nu^{\frac{1}{2}} K_{l,1}^{\frac{1}{4}} K_{r,2}^{\frac{1}{4}})} \quad (40)$$

$$K_{e,2} + \frac{K_{l,2}\sigma}{(\alpha-1)} = \frac{(\alpha(\frac{\sigma}{\nu})^{\frac{1}{2}} K_{e,2}^{\frac{1}{4}} K_{l,1}^{\frac{1}{4}} K_{l,2}^{\frac{1}{4}})}{((1-\alpha)K_{p,1}^{\frac{1}{4}} K_{p,2}^{\frac{1}{4}} K_{r,2}^{\frac{1}{4}})} \quad (41)$$

$$K_{r,2} + \frac{K_{p,2}\sigma}{(\alpha-1)} = \frac{(\alpha\kappa^{\frac{1}{2}} K_{e,1}^{\frac{3}{4}} K_{p,1}^{\frac{1}{4}} K_{p,2}^{\frac{1}{4}} K_{r,1}^{\frac{1}{4}} K_{r,2}^{\frac{1}{4}})}{((1-\alpha)\tau^{\frac{1}{2}} K_{e,2}^{\frac{1}{4}} K_{l,1}^{\frac{1}{4}} K_{l,2}^{\frac{1}{4}})} \quad (42)$$

With $\sigma = \frac{w_2}{e_2}$, $\tau = (\frac{e_1}{w_1})^{-1}$, $\kappa = \frac{p_2}{r_2}$ and $\nu = (\frac{r_1}{p_1})^{-1}$. Substitution gives us the expression of factor prices as a

function of both factor price ratios and factor endowments:

$$w_1 = E\left(\frac{K_{p,1}}{K_{l,1}}\right)^{\frac{1}{2}} (\kappa\sigma)^{\frac{\alpha}{8}} (\nu\tau)^{\frac{1}{4} - \frac{\alpha}{8}} \quad (43)$$

$$p_1 = E\left(\frac{K_{l,1}}{K_{p,1}}\right)^{\frac{1}{2}} (\kappa\sigma)^{\frac{\alpha}{8}} (\nu\tau)^{\frac{1}{4} - \frac{\alpha}{8}} \quad (44)$$

$$e_1 = E\left(\frac{K_{r,1}}{K_{e,1}}\right)^{\frac{1}{2}} (\kappa\sigma)^{\frac{\alpha}{8}} (\nu\tau)^{-\frac{1}{4} - \frac{\alpha}{8}} \quad (45)$$

$$r_1 = E\left(\frac{K_{e,1}}{K_{r,1}}\right)^{\frac{1}{2}} (\kappa\sigma)^{\frac{\alpha}{8}} (\nu\tau)^{-\frac{1}{4} - \frac{\alpha}{8}} \quad (46)$$

$$w_2 = E\left(\frac{K_{p,2}}{K_{l,2}}\right)^{\frac{1}{2}} (\kappa\sigma)^{\frac{\alpha}{8} + \frac{1}{4}} (\nu\tau)^{-\frac{\alpha}{8}} \quad (47)$$

$$p_2 = E\left(\frac{K_{l,2}}{K_{p,2}}\right)^{\frac{1}{2}} (\kappa\sigma)^{\frac{\alpha}{8} + \frac{1}{4}} (\nu\tau)^{-\frac{\alpha}{8}} \quad (48)$$

$$e_2 = E\left(\frac{K_{r,2}}{K_{e,2}}\right)^{\frac{1}{2}} (\kappa\sigma)^{\frac{\alpha}{8} - \frac{1}{4}} (\nu\tau)^{-\frac{\alpha}{8}} \quad (49)$$

$$r_2 = E\left(\frac{K_{e,2}}{K_{r,2}}\right)^{\frac{1}{2}} (\kappa\sigma)^{\frac{\alpha}{8} - \frac{1}{4}} (\nu\tau)^{-\frac{\alpha}{8}} \quad (50)$$

See appendix A.2 for details.

3 Simulations and results

3.1 The simulation strategy

Our strategy is based on constrained steady-states. We have two scenarios, Comparative Advantage (CA) and Structural Change (SC) representing rival scenarios for development. Within these two scenarios, we have 3 different regimes: Autarky, Complete Specialisation (CS) and Integrated Equilibrium (IE). This gives 6 different types of steady-state, one for each combination of a scenario and a trade regime.

Constrained steady-states are defined by the more or less important asymmetry in the distribution of exogenous wealth instruments associated with the steady-state. We use one number k to define this asymmetry. For example, $k = 1.20$ means that the distribution of exogenous variables is $K_{l,1} = 1.2, K_{e,1} = 0.80, K_{r,1} = 0.8, K_{l,2} = 0.8, K_{e,2} = 1.2$ and either $K_{p,2} = 0.8$ in CA or $K_{r,2} = 1.2$ in SC for country 2. We define the distribution of wealth instruments in *relative terms*, as more or less compatible with FPE and the IE.

This is convenient for our simulations but is also the underlying methodological choice in previous studies on FPE violation (Debaere and Demiroglu 2003) and natural resources content of trade (Atkinson and Hamilton 2002). Under the important reservation of an added production pattern¹⁴, the distribution of wealth instruments (stocks) gives an indication of the nature of the flows (endowments) in the economy and so of the likelihood of FPE. Comprehensive wealth is an indicator of specialisation through endowments derived from it, in line with the Heckscher-Ohlin theorem.

It makes theoretical sense to extend traditional HO tests to the sustainability context. Still, do we observe the same dispersion in factor endowments, and the resulting FPE violation? To test the validity of our approach and obtain estimates for the highest observed dispersion we use comprehensive wealth data from the World Bank

¹⁴ A production structure is implicit in wealth accounting as production functions are used to construct wealth estimates (World Bank 2011).

Table 1: Capital stock shares in comprehensive wealth

Country	Country 1 Specialisation			Country 2 Specialisation			FPE		
	1995	2000	2005	1995	2000	2005	1995	2000	2005
Australia	87.29	84.26	86.24	12.70	15.73	13.75	No	No	No
Canada	86.30	84.70	86.62	13.69	15.29	13.37	FPE	FPE	FPE
							No	No	No
Cameroon	54.07	51.34	53.50	45.92	48.65	46.49	FPE	FPE	FPE
							FPE	FPE	FPE
France	96.20	94.81	96.87	3.79	5.18	3.12	No	No	No
							FPE	FPE	FPE
Germany	97.63	96.61	97.81	2.36	3.38	2.187	No	No	No
							FPE	FPE	FPE
Gabon	51.30	36.15	33.19	48.69	63.84	66.80	FPE	No	No
							FPE	FPE	FPE
Iran	47.31	36.93	40.04	52.68	63.06	59.95	FPE	No	FPE
							FPE	FPE	FPE
Russia	N/A	41.48	45.81	N/A	58.51	54.18	N/A	FPE	FPE
Saudi Arabia	37.77	40.46	26.38	62.22	59.53	73.61	No	FPE	No
							FPE	FPE	FPE
United Kingdom	97.06	97.17	97.90	2.93	2.82	2.09	No	No	No
							FPE	FPE	FPE
United States	95.22	95.35	95.93	4.77	4.64	4.06	No	No	No
							FPE	FPE	FPE

Source: The World Bank wealth accounting database, Author's Calculations

Wealth Accounting database. All data are in constant 2000 US dollars and available in three waves: 1995, 2000 and 2005.

We divide total wealth in four components. Produced capital K_p is obtained directly from the produced capital column. Exhaustible resources K_e is the sum of subsoil assets and renewable resources K_r is the sum of crop, pasture land, forestry and pasture lands. Intangible capital is decomposed using the 2000 estimate of the average share of human capital (skilled and unskilled labour) in intangible capital by the [World Bank \(2006\)](#). Labour (human capital for the World Bank) K_l is assumed to be 36% of intangible capital for all countries by their own estimates.

A selection of values is displayed in table 1. In line with the results in [Debaere and Demiroglu \(2003\)](#), wealth shows a distribution that is strongly asymmetric at this aggregated, four wealth instruments level. Global FPE is no more likely in a sustainability context.

3.2 Parametrisation

Our benchmark parametrisation is given in table 2.¹⁵

α balances wealth instruments between goods x_1, x_2, x_4, x_5 and x_3 . In CS, the higher the value of α the larger the amount of intermediates constituting the country's comparative advantage produced. [Cuñat and Maffezzoli \(2004\)](#) take α to be the average ratio of total trade to GDP for the US between 1947 and 2001. This gives a value of 0.15 for α , which we will also retain for the benchmark parametrisation, submitting it to sensitivity tests in section 4.2.

[Cuñat and Maffezzoli \(2004\)](#) choose the initial values for the capital stock arbitrarily, and follow [Cooley and Prescott \(1995\)](#) for the parameters $\beta = 0.949$ and $\delta = 0.044$. We will use the same value for β . [Cheviakov](#)

¹⁵ Values for X and E are deduced from Φ and α with $X = [(\Phi(\frac{\alpha}{4})^\alpha(1-\alpha)^{1-\alpha})]^{-1}$ and $E = X^{-1}4^{\alpha-1}$.

Table 2: Parameter Values

α	0.15
β	0.949
δ	0.044
Φ	0.607
ρ	0.015
x	0.03

Source: Cuñat and Maffezzoli (2004), Author's calculations

and Hartwick (2009) examine at length the relation between technical progress and capital depreciation. Their scenarios imply a range of 0.0015 to 0.0444 for δ and a Solow neutral productivity term of 0.00384, based on a Cobb-Douglas function with three factors. The value for δ in Cuñat and Maffezzoli (2004) is slightly above the value tested by Cheviakov and Hartwick (2009) so we will use a value of 0.044.

Variations in the value of Φ result in less than proportional variations in the value of E . We will therefore set a value $\Phi = 0.607$ in CS in the SC scenario that yields a world steady-state level for produced capital equal to 2.

Finding an estimate for the parameter x boils down to estimating an aggregate cost function for the production sector intensive in exhaustible resources. Cost functions are notoriously hard to estimate, especially in sectors using exhaustible resources as they have an obvious impact on the negotiations regarding royalties. Back-of-the-envelope estimates of marginal extraction costs¹⁶ oscillate between 20% and 40% of the marginal product. In the IE model where we have a world price, this gives a value for x of 0.03 as 30% of total cost.

In our modelling strategy, ρ diminishes the maintenance cost of renewable resources. ρ is a bonus, equivalent to a marginal benefit of time. The best proxy for this parameter would be the biological rates of growth for a range of renewable resources. However, those rates differ widely across species. Price responses are as a result non homogeneous within and between exhaustible resources. Faced with this uncertainty we approximate the rate of growth using production data, assuming that an increase in production is based on the rate of biological renewal. The OECD and the FAO, cited in Lee et al., forecast an average annual growth in net agriculture and fish production of 1.5% in the coming decades. We take this number for the value of ρ .

This threshold is fixed for exogenous endowments, but a more stringent one can be imposed by the evolution of the endogenous instruments of wealth.

3.3 Results

3.3.1 Definition of shocks: low and high asymmetry

We simulate constrained steady state in both scenarios (SC and CA) and estimate a discrete path of constraint steady-states linking the 3 trade regimes together. Lower asymmetry makes IE more likely than CS, following Lemma 2.1.

Our strategy is based on the use of two different types of shocks: transitional dynamics from one constrained

¹⁶ Commonly approximated with the average cost.

Table 3: Possible outcomes of low and high asymmetry in CA and SC

	Low Asymmetry ($k = 1.19$)	High Asymmetry ($k = 1.75$)
CA	Autarky or Complete Specialisation	Autarky or Complete Specialisation
SC	Autarky or Integrated Equilibrium	Autarky or Complete Specialisation

steady-state to another, and temporary (short run) shocks, where after the shock economies return to the same constrained steady-state.

Transitional dynamics are sweeping movements between two constrained steady-states far apart. We have in our setting six different categories of constrained steady-states, some only available in relatively *low asymmetry* and some only under *high asymmetry* (see table 3).¹⁷ The difference between low and high asymmetry is set by the $k = 1.19$ level of asymmetry, which yields IE under SC.¹⁸ The high asymmetry equilibrium is arbitrarily set at $k = 1.75$.

Temporary shocks are an operational way to introduce exogenous accumulation and depletion constraints on the endogenous accumulation process in both countries. Temporary shocks are used to model the evolution of one exogenous wealth instrument *ceteris paribus*. We test 4 types of temporary shocks:

- Type 1** Country 1 experiences an increase in population size : temporary increase in its comparative advantage.
- Type 2** Country 2 experiences an increase in population size: temporary increase in a wealth instrument stock not part of its comparative advantage.
- Type 3** Country 1 experiences a increase in exhaustible resource stock size: temporary increase in a wealth instrument stock not part of its comparative advantage.
- Type 4** Country 2 experiences a decrease in exhaustible resource stock size: temporary depletion of a source of comparative advantage.

See appendix A.4 for calibration. As a trial run, we test our four scenarios in the autarky model. Those temporary shocks yield predictable results. Increases in available wealth translate into higher consumption (1.4% in scenario 1 and 1.44% in scenario 3 for country 1, 0.55% for country 2 in scenario 2). Wealth decreases lead to lower consumption (5.55% shrinkage for country 2). Increases in exogenous factors also lead to increases in the endogenous factor stock (2.19% increase in produced capital stock for country 1 in scenario 1) and vice-versa (7.8% reduction in the size of renewable resources stock for country 2 in scenario 1).

To run the simulations, we use the Dynare software (Adjemian et al. 2011). Dynare is a powerful solution to provide numerical solutions for both deterministic and stochastic general equilibrium models. We run the model under our benchmark parametrisation.

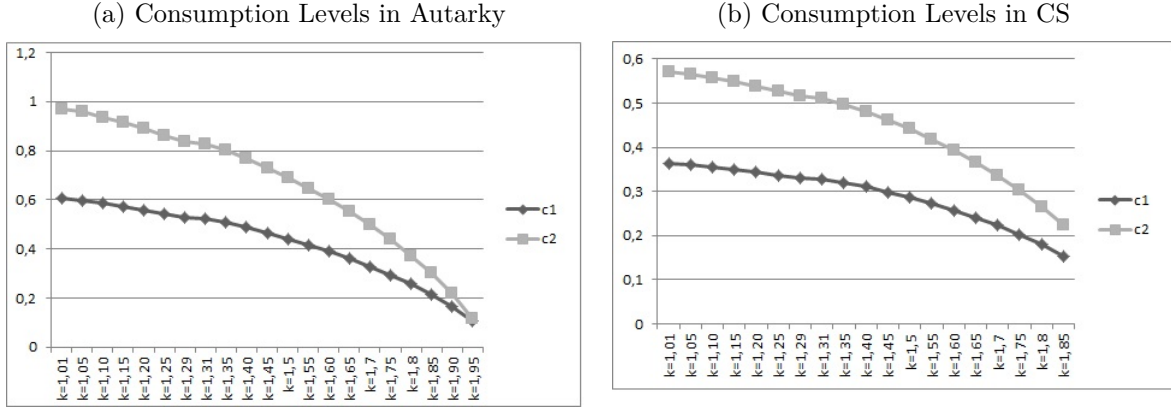
3.3.2 Results

Figure 2 shows the levels of steady state consumption for each constrained steady-state in the CA scenario, for country 1 and country 2. Figure 3 shows the same levels in the SC scenario.

¹⁷ Remember the definition of asymmetry in section 3.1: the value 1.19 means that the stock of any wealth instrument in the country relatively less endowed cannot be less than 68% of the stock in the relatively more endowed country.

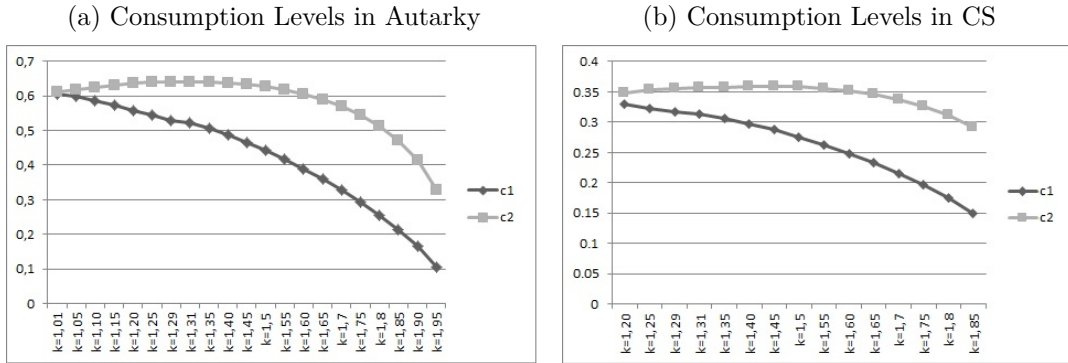
¹⁸ As illustrated below, FPE never occurs in CA.

Figure 2: Constrained steady-state consumption in CA



Source: Author's calculation

Figure 3: Constrained steady-state values under SC



Source: Author's calculation

As factor prices are equal in IE but not in CS or autarky, we take the constraint steady-state values for $k = 1.19$ in the CS model and impose an exogenous shock of factor price equalisation on those values¹⁹. We then use those shocked values as the initial values for the transitional dynamics in the IE model, to obtain a transition path from CS to IE.

The transition from the CS equilibrium to the IE equilibrium is a small permanent shock, as values are quite similar. The CS equilibrium for low asymmetry values already yielded close values for steady-state consumption. In IE, we finally observe convergence in consumption as consumption rises by 2.77% in country 1 and falls by 2.30% in country 2. Although the adjustment is asymmetric with country 2 losing out, the world as a whole witness an increase of 0.16% in consumption and wealth, and 0.65% in produced capital so that the overall effect of integration is slightly positive.

The Integrated Equilibrium (IE) completes figure 3b. It occurs for asymmetry values between $k = 1.01$ and $k = 1.19$ excluded. We choose an arbitrary level of asymmetry, $k = 1.1$ as the “low asymmetry” equilibrium for the transitional dynamics with IE. Comparison of the temporary shocks between IE and Autarky or CS should only be tentative as although the shocks are of the same size, they are implied on transitions of different

¹⁹ As countries are of equal size, we take the average of the steady-states factor prices in both countries as the shock values.

magnitudes.

An important difference between IE, CS and autarky is the nature of the adjustment to the shock. In IE, consumption is always equal between country 1 and country 2. The variable of adjustment to the shocks are prices and the composition of wealth. Movements in wealth and consumptions can be explained by domestic factor prices. Note that the price of the endogenous capital stocks is constant across specifications.

Steady-State consumption levels for low and high asymmetry are summarised in table 4. Form this values for consumption we can derive theorem 3.1:

Table 4: Comparison of Steady-State Consumption Levels

		Autarky		IE	CS	
		LA	HA	LA	LA	HA
SC	c1	0.5592	0.2946	0.340015	NA	0.1963
	c2	0.6359	0.5444	0.340015	NA	0.3267
CA	c1	0.5592	0.2946	NA	0.3444	0.2024
	c2	0.8898	0.4384	NA	0.538	0.3034

Source: Author's calculation

Theorem 3.1 (Asymmetry and Steady-State Consumption levels). *Under all scenarios and trade regimes a higher level of asymmetry (as represented in the k value) will systematically yield a lower level of global steady-state consumption ($c1 + c2$).*

This theorem presents our main result, an inverse relationship between the asymmetry of the distribution of wealth instruments and steady-state consumption. Countries that have a high level of asymmetry today are advanced economies (country 1) relying on natural resources and developing countries (country 2) with a small base of produced capital (see table 1).

For country 2 types the reduction in asymmetry is mostly about a sound application of the Hartwick rule. Country 1 countries, have been through the early industrial revolution with its large labour/produced capital substitution. According to our results, this process may have gone too far *relative to* the development of the rest of the world. Our model suggests that the highest possible global steady-state consumption can only be obtained via a "balanced growth", based on an even distribution of wealth instruments.

Countries characterised by a high level of asymmetry today are advanced economies relying on natural resources in and developing countries with a small base of produced capital (see table 1). We can therefore frame the problem as the need for *structural change towards an even distribution of wealth instruments*. In figures 2 and 3 this means going from the right to the left.

What do the paths look like? As country 1 always accumulates the source of its comparative advantage, it can compensate the shrinkage in labour with an increase in produced capital.²⁰ It should then build up renewable resource via an adequate policy of ecosystem services and exhaustible resources management.²¹

²⁰ Between the high asymmetry and the low asymmetry equilibrium, the abundant exogenous factors are reduced by 32%

²¹ This option is obviously unavailable for exhaustible resources. Still, many developed countries have reserves of exhaustible resources (the US, the UK, France and Poland in shale gas) currently unexploited for economic and environmental reasons. The problem is therefore less the complete lack of resources, more the adequate management and pricing policy.

Country 2 has different challenges. It faces an increase in labour so that its ability to invest in produced capital yields less gains. At the same time, its advantage in exhaustible resources shrinks. The overall result is reduction in wealth, less gains from the substitution of produced capital for exhaustible resources and a relatively lower increase in consumption. The world as a whole is still better-off, but country 2 faces a higher price for asymmetry reduction than country 1.

Based on assumption 3 in the list of section 2.1 produced capital accumulation puts country 1 at a disadvantage, as more needs to be invested to maintain the stock. This is the rationale for consistently lower steady-state consumption in country 1. It has no consequence on the general message of reduced steady-state consumption with asymmetry, only on the relative position of countries.

Theorem 3.1 also holds for consumption in country 1 alone, but not for consumption in country 2. In country 2, the theorem holds in CA, but in SC the distribution of steady-state consumption levels with asymmetry is bell-shaped. In country 2 in SC, asymmetry reduction first leads to increased steady-state consumption (in the range $k = [1.30; 1.75]$) before decreasing it (in the range $k = [1.01; 1.30]$). As noted above, entering the Integrated Equilibrium further reduces steady-state consumption.

Note finally that theorem 3.1 depends on the production setting, assumption 5 in our list in section 2.1. A more usual production setting with final goods traded would be characterised by higher substitutability between instruments of wealth and may lead to different shock responses. We are nonetheless confident that the general message regarding the impact of asymmetry would hold. We can now complete theorem 3.1 with a series of lemmas, presenting secondary results of the simulations.

Lemma 3.2 (Convergence in steady-state consumption). *Stable convergence in steady state consumption only happens in IE under SC (i.e. when the distribution of wealth instruments is similar enough in both countries).*

Lemma 3.2 confirms the results of numerous previous contributions (Ventura 1997, Cuñat and Maffezzoli 2004, Bajona and Kehoe 2010, Umanskaya and Barbier 2008). We only add to the literature the possibility of asymptotic convergence in the CA scenario (autarky and SC). As endowments grow more asymmetric, the exogenous factors become relatively abundant (scarce) with respect to the endogenous ones when they are (not) the source of the comparative advantage. This convergence would happen at a much lower steady-state consumption for both countries (compared to the stable convergence), which makes it in any case a dominated outcome. Lemma 3.2 is completed by corollary 3.2.1:

Corollary 3.2.1. *Factor Price Equalisation is a prerequisite for stable convergence in steady-state consumption levels.*

Based on comprehensive wealth data, only 28 countries in 2005 meet the condition in Lemma 2.1. FPE is therefore the exception and not the rule in world trade, and very little countries will have a distribution compatible with the Integrated Equilibrium (IE).

If low asymmetry is desirable from a steady state consumption perspective, and IE constrained steady-states stable, what are the adjustments required to get there? Going from high to low asymmetry can be undertaken either in autarky or in free trade. Choosing free trade under the SC hypothesis will ultimately yield the IE equilibrium, when in the other cases it systematically yields CS. Here, our model produces an interesting insight. Autarky equilibria under any hypothesis systematically yields higher values for wealth consumption and endogenous factor endowments in both countries for a given hypothesis (CA or SC). This last comparison gives us lemma 3.3.

Lemma 3.3 (The cost of free-trade). *Under our production structure, countries are systematically worse-off entering, free-trade, for any asymmetry in the distribution of wealth instruments and any scenario.*

Lemma 3.3 is derived from assumption 5 on the production structure. The need to allocate factor endowments through a cost minimisation process results in lower overall productive efficiency. To be more accurate,

free trade does rise the direct factor contribution to production, but this is more than compensated by the lower total factor productivity term.²² As discussed in section 4.2, this is not a consequence of the value of α , no value in the range $]0;1[$ changes this result.

These conclusions makes intuitive sense when one considers the complexities and coordination costs implied by setting-up the global supply chain. Those costs are usually modelled as transaction costs, but we believe that organisational costs are fundamentally different in nature from other costs, such a customs duties or shipping. Those costs can exist even in a frictionless, a-spatial model such as ours.

Coordination costs are the main costs in a the world of the global supply chain described by Berger (2006). The production structure and its consequences for total factor productivity are therefore the explanation behind the counter-intuitive result that both countries are better-off in autarky. Still, the study of our scenarios allows us to offer some reasons for opening-up to trade despite the adverse effects on consumption and wealth.

Lemma 3.4 (Dynamic gains from trade). *When countries transition jointly from a high asymmetry constrained steady-state to a low asymmetry constrained steady-state, the transition is made at lower factor prices in free-trade compared to autarky.*

Lemma 3.4 synthesises the ability of free trade to reduce production costs. It can be demonstrated by comparing the transitional dynamics in both CA and SC in autarky and free trade (see table 5). The price of factors constituting the comparative advantage rise by a lesser amount in free trade compared to autarky in the transitional dynamics. Then, the price of the remaining factors decrease by a larger amount.

Table 5: Comparison of factor prices in transitional dynamics (Autarky/Free Trade)

		Autarky	CS
		Variation from LA to HA	Variation from LA to HA
SC	w1	167%	130%
	p1	0%	0%
	e1	-39%	-42%
	r1	-39%	-42%
	w2	-62.00%	-64%
	p2	0%	0%
	e2	63.00%	46%
	r2	63.00%	46%
CA	w1	183%	143%
	p1	0%	0%
	e1	-40%	-44%
	r1	-40%	-44%
	w2	-41%	-42%
	p2	-41%	-42%
	e2	183%	122%
	r2	0%	0%

Source: Author's calculation

This "cost reduction" property of international trade is appealing for the production sector eyeing a long transition. International trade allows both countries to access, via the goods traded, a wider pool of resources,

²² Factors contribution is put to the power $\frac{1}{4}$ in autarky and $\frac{1+\alpha}{4}$ under free trade, but the productivity term is Φ in autarky and $\Phi\alpha^\alpha(1-\alpha)^{\frac{1}{4}}$ under free trade.

wealth instruments scarcer in autarky. While trade magnifies the effect of the shock on prices, it lowers its impact on consumption and investment. The same exogenous increase in asymmetry leads to a lower reduction in world consumption, wealth and endogenous factor endowments. As absolute numbers are higher in country 2, country 1 benefits relatively more from this milder reduction in world consumption, wealth and endogenous endowments. Transition is hence cheaper in free-trade, even though levels of steady-state consumption are lower by lemma 3.3.

There is another caveat associated with trade, presented in corollary 3.4.1 to lemma 3.4.

Corollary 3.4.1 (Asymmetric shocks in free-trade). *When countries engage in free trade the burden of adjustment to asymmetric shocks on the distribution of wealth instruments is mostly supported by:*

- *The country affected in the first place in CS.*
- *The country not affected in the first place in the IE.*

In both CS and IE, adjustment to short run shocks depends on the factor hit by the shock. If the factor is a source of comparative advantage for the country, then the shock is positive and both countries win in consumption, wealth and produced capital. But if the factor is not a source of comparative advantage, then the country hit by the shock benefit from it while the partner loses out.

Take as an example of corollary 3.4.1 the short term shocks, the CA scenario. In type 1 shocks, consumption increases by 1.48% in country 1 and 0.13% in country 2. Conversely, in type 4 shocks, consumption decreases by 5.43% in country 2 and 1.11% in country 1. More interestingly, with type 3 shocks, consumption increases by 1.22% in country 1 and shrinks by 0.04% in country 2. Hence, a positive shock on a capital stock not constituting the comparative advantage has a positive impact on the country experiencing the shock, but a negative impact on the trading partner.

In CS, type 4 shocks result in larger steady state consumption loss for country 2 than for country 1. One can think of the oil shocks of the 70's as the perfect illustration of this situation. But in IE, although wealth is reduced by more in country 2 because of the exogenous shock, the endogenous response is stronger in country 1 (-6.86% for produced capital) than in country 2 (-4.76%) for produced capital. The "Integrated Economy" balances the equilibrium at the world level, which in the context of depleting exhaustible resources, means transferring the burden of adjustment to countries not directly subject to the new exogenous constraint.

Finally, corollary 3.4.2 summarises the magnitude of the gains from trade:

Corollary 3.4.2 (Size of the gains from trade). *The higher the asymmetry in wealth instruments when opening up to free trade the larger the dynamic gains from trade in the transitional dynamics.*

If countries intend to enter free trade as a mean of reducing asymmetry more cheaply, the sooner the better. Gains from trade are derived from the asymmetry of the distribution of wealth instruments, so larger reduction in factor prices can be expected for the constrained steady-states associated with a very asymmetric distribution. From the perspective of transitional dynamics, more gains from trade are therefore obtained in transitions starting from a situation of relatively high asymmetry.²³

Together, lemma 3.4 and its two corollaries characterise the *trade-induced dynamic composition effect*, the way international trade changes the composition of economies in transition from high to low asymmetry. We will use this notion in the three propositions answering our research questions.

²³ This result is a dynamic version of the well-known static Heckscher-Ohlin result that higher gains from trade can be expected when endowments are less evenly distributed across countries.

4 Discussion and Robustness checks

4.1 Propositions for trade and sustainable development

We offer 3 propositions based on our results. Proposition 1 summarises our conclusions regarding the choice of the SC scenario against the CA scenario. Proposition 2 presents our conclusions regarding free trade. Proposition 3 suggests amendments to sustainability indicators.

Proposition 1 (Scenarios for development). *Countries should consider a) the asymmetry in the distribution of domestic instruments of wealth and b) the situation of potential trading partners when choosing a scenario for sustainable development/structural change.*

Proposition 1 is based on theorem 3.1, lemma 3.3 and 3.4. Table 4 shows how in line with theorem 1 autarky systematically yields higher steady-state consumption. But this maximum corresponds to the smallest possible asymmetry for country 1, when it corresponds to the tipping point of the bell for country 2. If both countries are from the start at the relevant level of asymmetry, they should therefore stay in autarky and country 2 chooses the CA scenario.

Any other situation is subject to the behaviour of the potential trading partner. Remember that for country 1, CA and SC are the same, only the trade regime matters. Therefore, our focus here will be on country 2. If country 2 has a low asymmetry distribution of wealth instruments (left of the tipping point in SC), it will choose CA and try to reduce asymmetry further. Increasing asymmetry or choosing SC are both clearly dominated.

If country 2 has a highly asymmetric distribution of wealth instruments (right of the tipping point in SC), it will reduce asymmetry. In CA, this will bring it closer to the low asymmetry constrained steady-states. In SC, this will bring it closer to the tipping point. The choice between SC and CA depends on the countries' pure rate of time preference. Choosing SC and autarky leads to a closer maximum in steady state consumption, hence a shorter transition. But choosing CA promises both a longer transition and higher steady-state consumption once asymmetry is really low.

The argument on free trade then depends on the domestic arbitrage between consumers and producers. Producers will suggest to open-up to free trade as it makes the transition cheaper in terms of prices. Following this logic, lemma 3.4 makes SC more appealing as cost reduction is more pronounced in SC than in CA. So producers would vote for SC and free trade. Consumers will want a path with the highest constrained steady-state consumption levels. For asymmetry higher than $k = 1.55$ SC dominates CA. It then reverses. Therefore rational consumers will side with producers in the short run and choose SC, before asking for CA after $k = 1.55$ and follow this scenario until perfect symmetry is reached. The decision regarding free trade is discussed further with proposition 2.

Proposition 2 (Autarky versus Free Trade). *Under the assumptions of our model, resource rich countries should undergo structural change in autarky, or at least revert to autarky after early stages of development.*

We will use here lemmas 3.2 and 3.4. We need to differentiate between the reason to enter free trade and the motives to stay in free trade. Using lemma 3.2, we know that free trade is always a dominated strategy compared to autarky. If both countries have a diversified set of wealth instruments (low asymmetry) they will be worse-off entering free-trade and will choose autarky. Opening-up to trade systematically reduces consumption, it should first be noted that the reduction is not uniform with asymmetry. In both CA and SC, consumption losses are lower for high asymmetry steady-states than for low asymmetry ones. For both countries, the incentive to open-up to trade will be mostly felt under high asymmetry.

For the same reason that SC makes more sense than CA in high asymmetry, making the transition from a high to a low asymmetry constrained steady-state is less costly with international trade. w_1 , e_2 and r_2 increase

by less while w_1 , e_1 and r_1 decrease by more. Reduced overall production efficiency means that consumption increases by less in the transition (lemma 3.4 again). Should consumer and producers opinion be considered separately, opinions on trade liberalisation would diverge.

Once the initial negative shock is suffered, transition between constrained steady-states is made at a lesser cost under free trade and under positive short run shocks reducing asymmetry. Country 2 is therefore in an awkward situation. It is (in high asymmetry) better-off in SC, and once it chooses SC, it will face incentives to open-up to trade to obtain cost control gains from trade as it reduces asymmetry through investment. As the country reduces asymmetry its incentives to stay under (CS) free trade fades since reduced asymmetry makes the CA scenario more competitive.

Therefore, for country 2, the best strategy starting in high asymmetry is to turn to SC, open-up to trade to reduce asymmetry at a lower cost and turn back to CA and autarky when "enough" reduction in asymmetry took place. We would estimate that moment as the moment where consumption is higher in CA than SC, that is at $k = 1.55$.

It is however unlikely that country 1 will accept this. Country 1 is not affected by the decision between CA and SC in autarky but should it decide to open-up to trade the decision of country 2 between those two possibilities becomes critical. As is the case for country 2, country 1 should decide to open-up to trade to exploit the "cost control" property when in high asymmetry. Contrary to country 2, once under (SC) free trade, country 1 has an incentive to stay under free trade until the two countries reach factor price equalisation (FPE).

Should both countries consider the long run and all the possible constrained steady-states, country 2 would revert to autarky and CA as asymmetry is reduced. Country 1 would do the same as it would also be *absolutely* better-off even if it loses out in *relative* terms.²⁴ Alternatively, when considering only the most immediate constrained steady-states (as in the scenarios), country 1 has every incentive to keep the free trade agreement. In a scenario where unilateral break away is impossible, country 2 is then stuck in a scenario that is not adapted to the distribution of its wealth instruments.

Finally, theorem 3.1, lemma 3.2 and corollary 3.2.1 together provide a tentative explanation for the "middle income trap", related to the FPE condition. In table 1, the majority of countries in the middle income trap satisfy the FPE condition. In our model, they could obtain higher steady state consumption in SC by increasing asymmetry (if they are of the country 2 kind), but would reduce consumption after the tipping point is reached. As a result, countries in FPE could only increase *absolute* steady-state consumption by returning to autarky or increase *relative* steady state consumption as other countries reduce the asymmetry of their distribution. Failing to do either leads to stagnation.

We will finally use lemma 3.4 and its corollaries to propose the inclusion of the trade-induced dynamic composition effect into Adjusted Net Savings (ANS) in proposition 3. (Pearce and Atkinson 1993, World Bank 2011). In our model, capital gains are endogenous as in Hartwick (1995), exclusively generated only as a *composition effect*.

Proposition 3 (Adjusted Net Savings and the gains from trade). *The trade-induced composition effect generates gains from trade. These gains should be saved and reinvested just like rents in the Hartwick (1977) rule. As a result, They should also be accounted for in Adjusted Net Savings (ANS).*

These gains are equal to the amount saved in free trade compared to autarky in the transitional dynamics. They are equal to the amount saved under the "cost control" of lemma 3.4. Would the considered country still be in autarky, it would encounter neither the efficiency losses from going to trade, neither the cost control gains.

With ANS, rents are subtracted from Net Savings, as it is assumed that the economic value brought by rents is already represented by Net Savings. The same logic applies for the gains from the composition effect.

²⁴ Under the lowest possible asymmetry ($k = 1.01$) in CA, consumption in country 1 is 61% of consumption in country 2 in autarky, when it would be 64% of consumption in country 2 in CS.

Their benefits for the economy are wide-spread via production. Their cost should then be subtracted in the final accounting stage in ANS. This cost comes from the fact that the *composition under free trade* is in fact a *second best* compared to the composition in autarky, because of the coordination and specialisation costs induced by opening up to free trade. As gains from trade are notoriously hard to estimate, it is worth considering how to estimate those gains from trade related to structural change.

An estimate of the extra savings can be provided using the figures from the transitional dynamics. Let us consider the SC case, in transition from low to high asymmetry. We estimate that w_1 increases by 41% less and e_1 and r_1 decrease by 4% more in free trade compared to autarky. Multiplying those percentage by the low asymmetry equilibrium quantities leads to gains from trade equivalent to 8.02% of steady-state income for country 1. The same calculation yields a value of 5.48% of steady-state income in country 2. These figures would represent a significant addition to ANS as ANS for most countries are in a range of 3 to 10% of income. It should also be noted that this magnitude would help reconcile ANS with more pessimistic indicators of sustainability such as the ecological footprint. It also suggests that neither country 1 and country 2 types are saving enough today.

Saving these gains from trade would also provide a first solution to the debate about responsibility for depletion (Atkinson et al. 2012). It should be stressed that this solution rests upon the assumption of perfect substitutability, as it implies that capital not accumulated (or depleted) in country 2 and imported in country 1 is reinvested in domestic capital there and vice versa. This solution involves international compensation between countries and therefore shared responsibility. It makes sense even in terms of patterns of trade, as reduced asymmetry will diminish the volume of trade as it diminishes the rationale for trade (as in any HO model). As countries use trade to slowly level their endowments, trade becomes unnecessary and die out. The ironic but expectable result is that sustainable trade is working for its own extinction.

4.2 Robustness and sensitivity checks

We focus on the impact of the values taken by the parameters on the stability of the model. We do not perform any additional test on the values for the asymmetry on endowments. The values presented in section 3.3.1 already cover the widest range of values for which all the models (autarky, complete specialisation and integrated equilibrium) are stable. Stability tends to break down for the CS model in the CA scenario if the parameters are unchanged compared to lower asymmetry. Still, as our model is not calibrated on real world data, this does not represent a challenge to the validity of our conclusions. If anything, it suggests that the main functional relations (utility, production, etc.) are not stable across different phases of structural change.

We focused our tests on the values of the parameters. The parameters ρ and δ have been calibrated as to be realistic, but their impact on our results is unambiguous. Higher δ values increase produced capital depreciation so that the steady-state values for produced capital, consumption and wealth are lowered for both countries and any level of asymmetry. Conversely, higher ρ values increase the “bonus” associated with renewable resources. As a consequence, steady-state values for renewable resources, consumption and wealth are higher in both countries. As country 1 (resp. 2) is relatively more intensive in produced capital (resp. renewable resources) it is more sensitive to variations of δ (resp. ρ).

The two parameters we tested more thoroughly are α and Φ . We use the CS model to conduct our robustness tests as it is the most comprehensive one. α determines the allocation of factors between intermediate goods (see section 2.3.1). Higher α values make for a bigger share of endowments allocated to the intermediate goods forming the comparative advantage in both countries (goods y_1 , y_2 , y_4 and y_5). As a consequence, the volume of trade is likely to be bigger. To test the impact of the value of α on steady-states values we computed the steady-states corresponding to asymmetries $k = 1.19$ (for both IE and CS equilibria) and $k = 1.75$ (in CS only). We run the test for two alternative values for α . Results are displayed in tables in annex A.5.

We observe that higher α values systematically reduce consumption, wealth and income in both countries.

Interestingly, the overall reduction (at the global level) is the same in both CS and IE, but in CS countries are not affected the same way. Country 2 (resp. 1) benefits (resp. suffers) the most from lower (resp. higher) α values. The fact that the global impact is the same in CS and IE is proof that the model is consistent. The fact that country 2 is more impacted by variations in α is also consistent with our interpretation of the results. As country 2 has higher steady-states consumption values, it is more impacted by evolutions in the volume of trade and world prices.

We follow the same strategy for the parameter Φ . Φ is a measure of total factor productivity in the final good production function. We observe that lower Φ values reduce consumption, income and wealth in all three settings (autarky, IE and CS). Conversely, higher Φ values lead to higher consumption income and wealth. As with α , the global impacts are similar under the CS and IE models, showing the robustness and consistency of the model. As expected, autarky variations are higher. This value reflects the direct impact of Φ in that model, when in CS and IE settings the impact of Φ is reduced by coordination costs.

A final comment should be made on the autarky model. For lower values of Φ we observe that steady-state consumption falls in country 1. However, in country 2 we see an increase in steady-state consumption for the low asymmetry steady-state. This seemingly odd result comes from the CS equilibrium. As productivity is reduced, all endowments becomes *de facto* scarcer. As a result country 2 has to invest more into produced capital to obtain the same contribution from the factor. Therefore, in high asymmetry consumption falls while steady-state wealth and produced capital are higher.

When asymmetry is lower, the basic mechanism is the same except that the price reaction to lower productivity is milder from reduced asymmetry. As a consequence, the representative agent increases consumption. This mechanism could be expected from the bell-shaped evolution of consumption with asymmetry in the model (see figure 3). It stresses the importance of considering asymmetry in endowments in a dynamic setting.

Conclusion

We explored in this article the consequences of trade liberalisation for the sustainable development of countries characterised by the distribution of their instruments of wealth (assets). Our main formal result is that steady-state consumption is reduced as the distribution of wealth instruments becomes more and more uneven. Based on this result, we derive a series of lemmas regarding the gains from trade and the different consequences of trade liberalisation in different stages of development.

Our use of the Heckscher-Ohlin structure, put our result in direct affiliation to the composition, scale and technique effects in [Copeland and Taylor \(2003\)](#). Nonetheless, our results go beyond these concepts, mostly through the introduction of dynamic interdependence with four factors. Our results are certainly limited by methodological choices inherent to our production structure and HO modelling. The absence of factor intensity reversal and international capital movements are two obvious limits. Nevertheless, these assumptions reflect the main sustainability issues. As in [Dasgupta and Heal \(1979\)](#), all factors are required in production. We also study the consequences of expected substitution between factors as a consequence of the depletion of natural capital.

We summarise our contribution in three propositions. We first stress how countries should consider the distribution of wealth instruments before committing to a development strategy. Different investment policies in different types of wealth instruments fit different levels of asymmetry in the distribution of domestic assets. The final aim of development in our model is nonetheless clear: a "balanced" development, where consumption is based on an even distribution of wealth instruments, yields the highest possible level of steady-state consumption.

Higher asymmetry in the distribution of wealth provides a greater incentive to trade. The larger the post trade liberalisation productive reorganisation, the larger the gains from trade. Still, proposition 2 reminds us that free trade is a dominated regime in our model. Trade liberalisation brings benefits to the production

sector and makes the transition from high asymmetry in wealth instruments to low asymmetry (and higher consumption) less expensive. The price to pay for this discount is a permanently lower level of steady-state consumption as long as the free-trade regime is maintained.

Here, our trading partners have diverging interests. The resource rich country wants to break away from the free trade agreement, the resource poor country wants to keep it. The strategic and political dimension of free trade agreement should therefore not be ignored. The question is especially acute in the context of asymmetric shocks, when the most extreme form of integration, the Integrated Equilibrium, transfers the largest part of the burden of adjustment to the country unaffected by the shock *ex ante*.

Those results stress how international trade brings interdependence, with important consequences for sustainability. International trade shapes the distribution of instruments of wealth in all trading countries, encouraging specialisation to generate gains from trade. Investment and depletion decisions do not depend solely on domestic factors but also on the situation of the trading partners. As a consequence, sustainability assessment cannot afford to ignore the dynamics of the international environment to assess a given country course. A diagnosis on the rationale for trade liberalisation (or trade restriction) should be applied.

To make this diagnosis more informative a more accurate picture of sustainability on a country-by-country basis can be obtained amending the Adjusted Net Savings (ANS). We show how a reduction in asymmetry in the distribution of endowments is less costly in free trade than in autarky. This property is linked to the trade-induced dynamic composition effect, which generates (capital) gains from trade. These gains constitute the main rationale for opening-up to trade in high asymmetry. We propose to save these gains from trade to finance structural change. Those resources can legitimately be mobilised for structural change, as an alternative autarky path would have been to the benefit of the wider society.

Practically, an estimate of these composition gains from trade should be subtracted from Net Savings, the way natural capital depletion is currently treated (World Bank 2011). Sustainability requires a differentiated treatment for the gains from trade, as productivity gains should not be subtracted but added to ANS. In that sense, our model is the theoretical background behind the measures of “virtual sustainability” (Atkinson et al. 2012). High rates of natural resources embodied in trade flows are not *per se* a problem. But they clearly are a strong message of trade-induced un-sustainability when domestic investment is inadequate.

As international trade creates interdependence, trade liberalisation should always be managed using corrective tools institutions. Some trade flows should be limited or banned if they work against sustainability. Future research should focus on the role of trade management instruments in the context of structural change and large evolutions in the composition of economies.

Other sources of comparative advantage exist, generating different kinds of trade flows. Future contributions should interrogate the status of intra-industry trade. Intra-industry trade generates gains from trade, and their status in the context of sustainability is not clear. It should certainly be interrogated again in the light of our results. This question could be of prime importance in countries where trade liberalisation does not necessarily benefit all the social groups and/or wealth instruments ownership is not evenly distributed.

References

- S. Adjemian, H. Bastani, M. Juillard, F. Mihoubi, G. Perendia, M. Ratto, and S. Villemot. Dynare: Reference Manual, Version 4. 2011. [24](#)
- W. Antweiler, B. R. Copeland, and S. M. Taylor. Is Free Trade Good for the Environment? *The American Economic Review*, 91(4):877–908, 2001. [10](#)
- R. Arezki, K. Hadri, P. Loungani, and Y. Rao. Testing the Prebisch-Singer hypothesis since 1650: Evidence from panel techniques that allow for multiple breaks. *Journal of International Money and Finance*, 42:208–223, 2014. ISSN 02615606. [14](#)
- K. J. Arrow and G. Debreu. Existence of an equilibrium for a competitive economy. *Econometrica*, 22:265–290, 1954. [11](#)
- K. J. Arrow, P. Dasgupta, L. H. Goulder, K. J. Mumford, and K. Oleson. Sustainability and the Measurement of Wealth. 2010. [14](#)
- G. B. Asheim. Hartwick’s Rule in Open Economies. *The Canadian Journal of Economics*, 19(3):395–402, 1986. [10](#)
- G. B. Asheim, W. Buchholz, and C. A. Withagen. The Hartwick Rule: Myths and Facts. *Environmental and Resource Economics*, 25(2):129–150, 2003. [9](#)
- G. B. Asheim, W. Buchholz, J. M. Hartwick, T. Mitra, and C. Withagen. Constant savings rates and quasi-arithmetic population growth under exhaustible resource constraints. *Journal of Environmental Economics and Management*, 53(2):213–229, 2007. [10](#)
- A. Atkeson and P. J. Kehoe. Paths of Development for Early- and Late-Bloomers in a Dynamic Heckscher-Ohlin Model. 2000. [11](#)
- G. Atkinson and K. Hamilton. International trade and the ‘ecological balance of payments’. *Resources Policy*, 28(1-2):27–37, 2002. [7](#), [10](#), [14](#), [21](#)
- G. D. Atkinson, M. Agarwala, and P. Muñoz. Are national economies (virtually) sustainable?: an empirical analysis of natural assets in international trade. In *Inclusive Wealth Report 2012 Measuring progress toward sustainability*, chapter 5, pages 87–117. Cambridge University Press, Cambridge, UK, 2012. ISBN 9781107683396. [7](#), [10](#), [32](#), [34](#)
- C. Bajona and T. J. Kehoe. Trade, growth, and convergence in a dynamic Heckscher-Ohlin model. *Review of Economic Dynamics*, 13(3):487–513, 2010. [11](#), [27](#)
- S. Berger. *Made in monde. Les nouvelles frontières de l’économie mondiale*. Le Seuil, 2006. [18](#), [28](#)
- D. M. Bernhofen and J. C. Brown. An Empirical Assessment of the Comparative Advantage Gains from Trade: Evidence from Japan. *The American Economic Review*, 95(1):208–225, 2005. [7](#)
- A. F. Cheviakov and J. Hartwick. Constant per capita consumption paths with exhaustible resources and decaying produced capital. *Ecological Economics*, 68(12):2969–2973, 2009. [10](#), [22](#), [23](#)
- T. F. Cooley and E. C. Prescott. *Frontiers of Business Cycle Research*. Princeton University Press, Princeton, NJ., 1995. [22](#)
- B. R. Copeland and S. M. Taylor. North-South Trade and the Environment. *The Quarterly Journal of Economics*, 109(3):755–787, 1994. [10](#)
- B. R. Copeland and S. M. Taylor. Trade and the Environment: A Partial Synthesis. *American Journal of Agricultural Economics*, 77(3):765–771, 1995. [10](#)

- B. R. Copeland and S. M. Taylor. *Trade and the Environment: Theory and Evidence*. Princeton University Press, 2003. 7, 8, 33
- A. Costinot, J. Vogel, and S. Wang. An Elementary Theory of Global Supply Chains. *The Review of Economic Studies*, 80(1):109–144, May 2012. ISSN 0034-6527. 15
- A. Cuñat and M. Maffezzoli. Neoclassical growth and commodity trade. *Review of Economic Dynamics*, 7(3): 707–736, 2004. 7, 8, 11, 14, 15, 18, 19, 22, 23, 27, 45
- P. Dasgupta. On some problems arising from Professor Rawls’ conception of distributive justice. *Theory and Decision*, 4(3):325–344, 1974. 6, 9
- P. Dasgupta. *Human well-being and the natural environment*. Oxford University Press, 2001. 9
- P. Dasgupta. The Welfare Economic Theory of Green National Accounts. *Environmental & Resource Economics*, 42(1):3–38, 2009. 6, 9, 14
- P. Dasgupta and G. Heal. *Economic Theory and Exhaustible Resources*. Cambridge University Press, London, 1979. 10, 33
- A. V. Deardorff. Weak links in the chain of comparative advantage. *Journal of International Economics*, 9(2): 197–209, May 1979. ISSN 00221996. 11
- A. V. Deardorff. The General Validity of the Law of Comparative Advantage. *The Journal of Political Economy*, 88(5):941–957, 1980. 11
- A. V. Deardorff. The General Validity of the Heckscher-Ohlin Theorem. *The American Economic Review*, 72 (4):683–694, 1982. 11
- A. V. Deardorff. The possibility of factor price equalization, revisited. *Journal of International Economics*, 36 (1-2):167–175, Feb. 1994a. ISSN 00221996. 8, 11, 19
- A. V. Deardorff. Exploring the limits of comparative advantage. *Review of World Economics*, 130(1):1–19, 1994b. 11
- P. Debaere and U. Demiroglu. On the similarity of country endowments. *Journal of International Economics*, 59(1):101–136, Jan. 2003. ISSN 00221996. 11, 21, 22
- A. K. Dixit and V. Norman. *Theory of International Trade*. Cambridge University Press, 1980. 11, 18
- A. K. Dixit, P. Hammond, and M. Hoel. On Hartwick’s Rule for Regular Maximin Paths of Capital Accumulation and Resource Depletion. *The Review of Economic Studies*, 47(3):551–556, 1980. 10
- R. Dornbusch, S. Fischer, and P. A. Samuelson. Comparative Advantage, Trade, and Payments in a Ricardian Model with a Continuum of Goods. *The American Economic Review*, 67(5):823–839, 1977. 8
- L. Dupuy and M. Agarwala. International trade and sustainable development. In G. Atkinson, S. Dietz, E. Neumayer, and M. Agarwala, editors, *Handbook of Sustainable Development*, chapter 25, page 23. Edward Elgar Ltd., Cheltenham, second edition, 2014. 7, 10
- P. Ekins, S. Simon, L. Deutsch, C. Folke, and R. De Groot. A framework for the practical application of the concepts of critical natural capital and strong sustainability. *Ecological Economics*, 44(2-3):165–185, 2003. 6
- M. Faber and J. L. R. Proops. Natural resource rents, economic dynamics and structural change: a capital theoretic approach. *Ecological Economics*, 8(1):17–44, 1993. 6
- I. Fisher. *The Nature of Capital and Income*. Macmillan and Company Limited, London, 1906. 6

- D. Greasley, N. Hanley, J. Kunnas, E. McLaughlin, L. Oxley, and P. Warde. Testing genuine savings as a forward-looking indicator of future well-being over the (very) long-run. *Journal of Environmental Economics and Management*, 67(2):171–188, Mar. 2014. ISSN 00950696. 6
- G. Haberler. Die Theorie der komparativen Kosten und ihre Auswertung für die Begründung des Freihandels. *Weltwirtschaftliches Archiv*, 32:349–70, 1930. 7
- K. Hamilton. Green adjustments to GDP. *Resources Policy*, 20(3):155–168, 1994. 6
- K. Hamilton, G. Atkinson, and D. Pearce. Savings rules and sustainability: selected extensions. 1998. 10
- N. Hanley, L. Dupuy, and E. Mclaughlin. Genuine Savings and Sustainability. 2014. 6, 9
- J. M. Hartwick. Intergenerational Equity and the Investing of Rents from Exhaustible Resources. *The American Economic Review*, 67(5):972–974, 1977. 6, 9, 31
- J. M. Hartwick. Constant Consumption Paths In Open Economies With Exhaustible Resources. *Review of International Economics*, 3(3):275–283, 1995. 7, 10, 31
- D. I. Harvey, N. M. Kellard, J. B. Madsen, and M. E. Wohar. The Prebisch-Singer Hypothesis: Four Centuries of Evidence. *Review of Economics and Statistics*, 92(2):367–377, May 2010. ISSN 0034-6535. 14
- G. Heal. Sustainability and its Measurement. 2011. 9
- H. Hotelling. The economics of exhaustible resources. *The Journal of Political Economy*, 39:137–175, 1931. 6
- K. Kuralbayeva and R. Stefanski. Windfalls , structural transformation and specialization. *Journal of International Economics*, 90(2):273–301, 2013. ISSN 0022-1996. 6, 9
- B. Lee, F. Preston, J. Kooroshy, R. Bailey, G. Lahn, N. Asia, and S. Asia. Resources Futures. 23
- R. E. López, G. Anríquez, and S. Gulati. Structural change and sustainable development. *Journal of Environmental Economics and Management*, 53(3):307–322, 2007. 6, 7, 9
- B. Mccaig, M. S. Mcmillan, K. Jefferis, and B. Mccaig. Stuck In the Middle? Structural Change and Productivity Growth in Botswana. 2015. 6, 9
- M. S. Mcmillan and D. Rodrick. Globalization, Structural Change and Productivity Growth. 2011. 6, 9
- E. Neumayer. Scarce or Abundant? The Economics of Natural Resource Availability. *Journal of Economic Surveys*, 14(3):307–335, Dec. 2000. ISSN 09500804. 10
- E. Neumayer. *Weak Versus Strong Sustainability: Exploring the Limits of Two Opposing Paradigms*. Edward Elgar, 2010. ISBN 978-1-84844-873-5. 6, 7, 14
- B. G. Ohlin. *Interregional and International Trade*. Harvard University Press, Cambridge, MA., 1933. 18
- D. W. Pearce and G. D. Atkinson. Capital theory and the measurement of sustainable development: an indicator of "weak" sustainability. *Ecological Economics*, 8(2):103–108, 1993. 6, 31
- M. Pemberton and D. Ulph. Measuring Income and Measuring Sustainability. *Scandinavian Journal of Economics*, 103(1):25–40, 2001. ISSN 03470520. 14
- J. C. Pezzey. One-sided sustainability tests with amenities, and changes in technology, trade and population. *Journal of Environmental Economics and Management*, 48(1):613–631, 2004. 6, 10
- T. Piketty. *Capital in the Twenty-First Century*. Harvard University Press, Cambridge, MA., 2014. ISBN 978-0674430006. 6

- J. L. R. Proops, G. Atkinson, B. F. v. Schlotheim, and S. Simon. International trade and the sustainability footprint: a practical criterion for its assessment. *Ecological Economics*, 28(1):75–97, 1999. 7, 10, 14
- S. J. Redding. Dynamic comparative advantage and the welfare effects of trade. *Oxford Economic Papers*, 51: 15–39, 1999. 13
- R. Repetto, W. Magrath, M. Wells, B. C., and R. F. Wasting Assets: Natural Resources in the National Accounts, 1989. 6
- D. Ricardo. *On the Principles of Political Economy and Taxation*. John Murray, London, 1817. 7
- M. d. M. Rubio. The capital gains from trade are not enough: evidence from the environmental accounts of Venezuela and Mexico. *Journal of Environmental Economics and Management*, 48(3):1175–1191, 2004. 10
- P. A. Samuelson. International Factor-Price Equalisation Once Again. *The Economic Journal*, 59(234):181–197, 1949. 8
- A. Sauvy. *La Machine et le Chomage*. Dunod, Paris, 1980. 6, 9
- A. Smith. *An Inquiry Into the Nature and Causes of the Wealth of Nations*. W. Strahan and T. Cadell, London, glasgow ed edition, 1776. 7
- R. M. Solow. A Contribution to the Theory of Economic Growth. *The Quarterly Journal of Economics*, 70(1): 65–94, 1956. 14
- R. M. Solow. Intergenerational Equity and Exhaustible Resources. *The Review of Economic Studies*, 41:29–45, 1974. 6, 9
- R. M. Solow. On the Intergenerational Allocation of Natural Resources. *The Scandinavian Journal of Economics*, 88(1):141–149, 1986. 6
- J. E. Stiglitz. Growth with Exhaustible Natural Resources: The Competitive Economy. *The Review of Economic Studies*, 41:139–152, 1974. 6, 9
- N. L. Stokey, R. E. J. Lucas, R. E. Lucas Jr, and E. C. Prescott. *Recursive Methods in Economic Dynamics*. Harvard University Press, 1989. ISBN 0-674-75096-9. 11
- V. I. Umanskaya and E. B. Barbier. Can Rich Countries Become Pollution Havens? *Review of International Economics*, 16(4):627–640, 2008. ISSN 09657576. 27
- F. Van der Ploeg. Why do many resource-rich countries have negative genuine saving?: Anticipation of better times or rapacious rent seeking. *Resource and Energy Economics*, 32(1):28–44, 2010. 10
- F. Van Der Ploeg. Natural Resources: Curse or Blessing? *Journal of Economic Literature*, 49(2):366–420, June 2011. ISSN 0022-0515. 6
- J. Vanek. The Factor Proportions Theory: The N-Factor Case. *Kyklos*, 21(4):749–755, 1968. 11, 39
- J. Ventura. Growth and Interdependence. *The Quarterly Journal of Economics*, 112(1):57–84, 1997. 7, 11, 16, 27
- J. R. Vincent, T. Panayotou, and J. M. Hartwick. Resource depletion and sustainability in small open economies. *Journal of Environmental Economics and Management*, 33(3):274–286, 1997. 7, 10
- World Bank. *Where is the wealth of nations? Measuring Capital for the 21st century*. The World Bank, Washington D.C., 2006. ISBN 0-8213-6354-9. 11, 22
- World Bank. *The Changing Wealth of Nations: Measuring Sustainable Development in the New Millennium*. The World Bank, Washington D.C., 2011. ISBN 9780821384886. 11, 12, 21, 31, 34
- J. Yi-fu Lin. *The Quest for Prosperity: How Developing Economies Can Take Off*. Princeton University Press, Princeton, NJ., 2012. ISBN 9780691155890. 6, 14

A Appendixes

A.1 Resource allocation and comparative advantages

In section 2.3, the allocation of instruments of wealth between the five sectors is obtained from the aggregate production function:

$$Y = \Phi y_{1,i}^{\alpha/4} y_{2,i}^{\alpha/4} y_{3,i}^{1-\alpha} y_{4,i}^{\alpha/4} y_{5,i}^{\alpha/4}$$

And the intermediate goods functions:

$$\begin{aligned} y_{1,i} &= \lambda K_{l,i} \\ y_{2,i} &= \gamma K_{p,i} \\ y_{3,i} &= (K_{l,i} K_{p,i} K_{e,i} K_{r,i})^{\frac{1}{4}} \\ y_{4,i} &= \omega K_{e,i} \\ y_{5,i} &= \iota K_{r,i} \end{aligned}$$

Substituting those intermediate goods production functions into the aggregate production function yields:

$$Y = \Phi \lambda K_{l,i}^{\alpha/4} \gamma K_{p,i}^{\alpha/4} (K_{l,i} K_{p,i} K_{e,i} K_{r,i})^{\frac{1}{4} (1-\alpha)} \omega K_{e,i}^{\alpha/4} \iota K_{r,i}^{\alpha/4}$$

We derive this expression with respect to λ, γ, ω and ι . Doing so gives us:

$$\begin{aligned} \frac{\partial Y}{\partial \lambda} &= 0 \Leftrightarrow \lambda = \alpha \\ \frac{\partial Y}{\partial \gamma} &= 0 \Leftrightarrow \gamma = \alpha \\ \frac{\partial Y}{\partial \omega} &= 0 \Leftrightarrow \omega = \alpha \\ \frac{\partial Y}{\partial \iota} &= 0 \Leftrightarrow \iota = \alpha \end{aligned}$$

The α parameter is equal to the allocation parameters, so that α effectively allocates instruments of wealth across sectors.

To predict the pattern of trade in a world with more than two factors, we use the chain ranking of factor endowments, as defined by Vanek (1968). World capital stocks are the sum of countries' capital stocks:

$$\begin{aligned} K_l &= K_{l,1} + K_{l,2} \\ K_p &= K_{p,1} + K_{p,2} \\ K_e &= K_{e,1} + K_{e,2} \\ K_r &= K_{r,1} + K_{r,2} \end{aligned}$$

The chain ranking prediction states that a country will produce the goods intensive in factors it is relatively well endowed with. With more than two factors, those are all the factors for which the country has a world share superior to its share of world income.

Considering our assumption regarding endowment distribution, we obtain the following chain ranking:

$$\frac{K_{e,1}}{K_e} \leq \frac{K_{r,1}}{K_r} < \frac{W_1}{W} < \frac{K_{l,1}}{K_l} \leq \frac{K_{p,1}}{K_p}$$

$$\frac{K_{l,2}}{K_l} \leq \frac{K_{p,2}}{K_p} < \frac{W_2}{W} < \frac{K_{e,2}}{K_e} \leq \frac{K_{r,2}}{K_r}$$

This is the multi-factor version of the Heckscher-Ohlin Theorem.

A.2 The static equilibria and FPE conditions

In section 2.3, the general equilibrium depends on the technical equilibrium between the aggregate production function and the intermediate goods production function. This is true in either autarky, the integrated or the complete specialisation equilibrium. First, the unit cost of production (so that $Y = 1$ while P_y is the *numéraire*) should be minimized:

Minimize:

$$P_y = P_1x_1 + P_2x_2 + P_3x_3 + P_4x_4 + P_5x_5$$

Subject to:

$$1 = \Phi y_1^{\alpha/4} y_2^{\alpha/4} y_3^{1-\alpha} y_4^{\alpha/4} y_5^{\alpha/4}$$

The resulting Lagrangian L yields five first order conditions with respect to the goods quantities:

$$L = P_1x_1 + P_2x_2 + P_3x_3 + P_4x_4 + P_5x_5 - \zeta(\Phi y_1^{\alpha/4} y_2^{\alpha/4} y_3^{1-\alpha} y_4^{\alpha/4} y_5^{\alpha/4} - 1)$$

$$\frac{\partial L}{\partial x_1} = 0 \Leftrightarrow P_1 = \frac{\Phi \alpha \zeta x_1^{\frac{\alpha}{4}-1} x_2^{\frac{\alpha}{4}} x_3^{1-\alpha} x_4^{\frac{\alpha}{4}} x_5^{\frac{\alpha}{4}}}{4}$$

$$\frac{\partial L}{\partial x_2} = 0 \Leftrightarrow P_2 = \frac{\Phi \alpha \zeta x_1^{\frac{\alpha}{4}} x_2^{\frac{\alpha}{4}-1} x_3^{1-\alpha} x_4^{\frac{\alpha}{4}} x_5^{\frac{\alpha}{4}}}{4}$$

$$\frac{\partial L}{\partial x_3} = 0 \Leftrightarrow P_3 = -\frac{\Phi \zeta (\alpha - 1) x_1^{\frac{\alpha}{4}} x_2^{\frac{\alpha}{4}} x_4^{\frac{\alpha}{4}} x_5^{\frac{\alpha}{4}}}{x_3^\alpha}$$

$$\frac{\partial L}{\partial x_4} = 0 \Leftrightarrow P_4 = \frac{\Phi \alpha \zeta x_1^{\frac{\alpha}{4}} x_2^{\frac{\alpha}{4}} x_3^{1-\alpha} x_4^{\frac{\alpha}{4}-1} x_5^{\frac{\alpha}{4}}}{4}$$

$$\frac{\partial L}{\partial x_5} = 0 \Leftrightarrow P_5 = \frac{\Phi \alpha \zeta x_1^{\frac{\alpha}{4}} x_2^{\frac{\alpha}{4}} x_3^{1-\alpha} x_4^{\frac{\alpha}{4}} x_5^{\frac{\alpha}{4}-1}}{4}$$

Substituting those values for the prices into the objective function gives a value for the Lagrangian ζ of 1. Rearranging the first order condition using $\zeta = 1$ and the objective function gives the following equilibrium

conditions:

$$\begin{aligned}x_1 &= \frac{\alpha}{4P_1} \\x_2 &= \frac{\alpha}{4P_2} \\x_3 &= \frac{1-\alpha}{P_1} \\x_4 &= \frac{\alpha}{4P_4} \\x_5 &= \frac{\alpha}{4P_5}\end{aligned}$$

Then, substituting into the unit cost production with $X = [(\Phi(\frac{\alpha}{4})^\alpha(1-\alpha)^{1-\alpha})]^{-1}$ gives:

$$1 = Xp_3^{1-\alpha}(P_1P_2P_4P_5)^{\frac{\alpha}{4}}$$

Which is our general equilibrium condition for the production of the final good. The market share conditions are derived from the rearranged first order conditions. It naturally follows from those that all the p_jx_j are equal to $\frac{\alpha}{4}$ so that $p_ix_i = p_jx_j$ for all i but $i = 3$. The market share for good 3 is obtained by taking the ratio of $p_1x_1 = \frac{\alpha}{4}$ over $p_3x_3 = (1-\alpha)$.

For the intermediate goods, the price equal marginal cost conditions are derived from the equilibrium of the firm in each sector:

$$\begin{aligned}\Pi_1 &= P_1y_1 - wK_l \\ \Pi_2 &= P_2y_2 - pK_p \\ \Pi_3 &= P_3y_3 - wK_l - pK_p - eK_e - rK_r \\ \Pi_4 &= P_4y_4 - eK_e \\ \Pi_5 &= P_5y_5 - rK_r\end{aligned}$$

With Π the profit. As inputs enter one to one in the production of intermediates, it is straightforward that equilibrium requires the price of the intermediate to be set at the price of the corresponding factor. The exception is as usual good y_3 where four factors enter production. Maximising profit for good y_3 requires to substitute for y_3 in the profit function using the production function $y_3 = K_l^{\frac{1}{4}}K_p^{\frac{1}{4}}K_e^{\frac{1}{4}}K_r^{\frac{1}{4}}$. Deriving the profit function with respect to the four factors yields four first order conditions:

$$\begin{aligned}\frac{\partial \Pi}{\partial K_l} = 0 &\Leftrightarrow P_3 = \frac{4w}{K_l^{-\frac{3}{4}}K_p^{\frac{1}{4}}K_e^{\frac{1}{4}}K_r^{\frac{1}{4}}} \\ \frac{\partial \Pi}{\partial K_p} = 0 &\Leftrightarrow P_3 = \frac{4p}{K_l^{\frac{1}{4}}K_p^{-\frac{3}{4}}K_e^{\frac{1}{4}}K_r^{\frac{1}{4}}} \\ \frac{\partial \Pi}{\partial K_e} = 0 &\Leftrightarrow P_3 = \frac{4e}{K_l^{\frac{1}{4}}K_p^{\frac{1}{4}}K_e^{-\frac{3}{4}}K_r^{\frac{1}{4}}} \\ \frac{\partial \Pi}{\partial K_r} = 0 &\Leftrightarrow P_3 = \frac{4r}{K_l^{\frac{1}{4}}K_p^{\frac{1}{4}}K_e^{\frac{1}{4}}K_r^{-\frac{3}{4}}}\end{aligned}$$

Equalising those first order conditions using P_3 gives us two ratios $\frac{w}{p} = \frac{K_p}{K_l}$ and $\frac{e}{r} = \frac{K_r}{K_e}$. Substituting those ratios into the four first order conditions gives the same equilibrium condition:

$$P_3 = 4(eprw)^{\frac{1}{4}}$$

Finally we set the market equilibrium conditions on all markets:

$$\begin{aligned} \sum_{i=1}^5 x_i &= y_i \\ \sum_{i=1}^5 \frac{c_i(w,p,e,r)}{w} &= K_l \\ \sum_{i=1}^5 \frac{c_i(w,p,e,r)}{p} &= K_p \\ \sum_{i=1}^5 \frac{c_i(w,p,e,r)}{e} &= K_e \\ \sum_{i=1}^5 \frac{c_i(w,p,e,r)}{r} &= K_r \end{aligned}$$

With $X > 0$. The system has 19 equations and 19 unknowns. The unknowns are $P_1, P_2, P_3, P_4, P_5, x_1, x_2, x_3, x_4, x_5, y_1, y_2, y_3, y_4, y_5, w, p, e$ and r . We solve the system by substituting marginal costs and market shares equations into the market clearing conditions.

This demonstration holds for the autarky and the integrated equilibrium. For the complete specialisation (CS) equilibrium, differences come in the consumption shares and price equal marginal costs conditions. In CS, both countries specialise so that the entirety of goods y_1 and y_2 is produced in country 1 while the entirety of goods y_4 and y_5 is produced in country 2. As a consequence, price equal marginal cost conditions for the intermediate goods solely depend on one out of two countries endowments and factor prices for the relevant goods.

The market share condition for good y_3 is also amended as not only consumption but also production is made in both countries. The global equilibrium is left unchanged, so that the form of the equation is left unchanged. Still, production needs to be differentiated between countries 1 and 2 so that substitution in the resolution of the general equilibrium only takes place with $x_{3,1}$ and $x_{3,2}$ together.

The price equal unit cost equations for the CS equilibrium are:

$$\begin{aligned} 1 &= X p_3^{1-\alpha} (p_1 p_2 p_4 p_5)^{\frac{\alpha}{4}} \\ P_1 &= w_1 \\ P_2 &= p_1 \\ P_3 &= 4(e_1 p_1 r_1 w_1)^{\frac{1}{4}} \\ P_3 &= 4(e_2 p_2 r_2 w_2)^{\frac{1}{4}} \\ P_4 &= e_2 \\ P_5 &= r_2 \end{aligned}$$

The consumption shares:

$$\begin{aligned} P_1 x_1 &= P_2 x_2 \\ P_1 x_1 &= P_5 x_5 \\ P_1 x_1 &= -\frac{\alpha P_3 (x_{3,1} + x_{3,2})}{4(\alpha - 1)} \\ P_1 x_1 &= P_4 x_4 \end{aligned}$$

Finally, the market clearing conditions for both goods and factors:

$$\begin{aligned}
x_{1,1} + x_{1,2} &= y_{1,1} \\
x_{2,1} + x_{2,2} &= y_{2,1} \\
x_{3,1} + x_{3,2} &= y_{3,1} + y_{3,2} \\
x_{4,1} + x_{4,2} &= y_{4,2} \\
x_{5,1} + x_{5,2} &= y_{5,2} \\
y_1 + (e_1 p_1 r_1)^{\frac{1}{4}} (w_1)^{-\frac{3}{4}} y_{3,1} &= K_{l,1} \\
y_2 + (e_1 w_1 r_1)^{\frac{1}{4}} (p_1)^{-\frac{3}{4}} y_{3,1} &= K_{p,1} \\
(w_1 p_1 r_1)^{\frac{1}{4}} (e_1)^{-\frac{3}{4}} y_{3,1} &= K_{e,1} \\
(e_1 p_1 w_1)^{\frac{1}{4}} (r_1)^{-\frac{3}{4}} y_{3,1} &= K_{r,1} \\
(e_2 p_2 r_2)^{\frac{1}{4}} (w_2)^{-\frac{3}{4}} y_{3,2} &= K_{l,2} \\
(e_2 w_2 r_2)^{\frac{1}{4}} (p_2)^{-\frac{3}{4}} y_{3,2} &= K_{p,2} \\
y_4 + (w_2 p_2 r_2)^{\frac{1}{4}} (e_2)^{-\frac{3}{4}} y_{3,2} &= K_{e,2} \\
y_5 + (e_2 p_2 w_2)^{\frac{1}{4}} (r_2)^{-\frac{3}{4}} y_{3,2} &= K_{r,2}
\end{aligned}$$

With $X = [(\Phi(\alpha/4)^\alpha(1-\alpha)^{1-\alpha})^{-1}] > 0$. Note that in CS market clearing is performed at the global level, as the country level production is traded in the global market. This is a system of 24 equations with 25 unknowns. As P_3 depends on both country 1 and country 2 factor prices, a direct expression for factor prices as a function of capital stocks can not be deduced from the system of equations. The resolution of the system to provide factor prices expressed in terms of factor endowments needs to be done in two steps. This is because of the indeterminacy introduced by unequal factor prices. The first step relates factor endowments to factor price ratios, while the second step relates factor prices to factor price ratios. Substitution and simplification of market clearing conditions gives the equilibrium factor use conditions:

$$\begin{aligned}
\frac{e_1}{r_1} &= \frac{K_{r,1}}{K_{e,1}} \\
\frac{p_1}{w_1} &= \frac{K_{l,1}}{K_{p,1}} \\
\frac{p_2}{w_2} &= \frac{K_{l,2}}{K_{p,2}} \\
\frac{e_2}{r_2} &= \frac{K_{r,2}}{K_{e,2}}
\end{aligned}$$

Those equilibrium conditions are then used to define the relation between factor endowments and factor price ratios. We define the ratios as:

$$\begin{aligned}
\sigma &= \frac{w_2}{e_2} \\
\tau &= \left(\frac{e_1}{w_1}\right)^{-1} \\
\kappa &= \frac{p_2}{r_2} \\
\nu &= \left(\frac{r_1}{p_1}\right)^{-1}
\end{aligned}$$

Rearranging the market clearing conditions of the CS equilibrium using equilibrium conditions to obtain factor

price ratios finally yields to following system of four equations:

$$\begin{aligned}
K_{l,1} + \frac{K_{e,1}}{\tau(\alpha-1)} &= \frac{(\alpha\sigma^{\frac{1}{2}}K_{e,1}^{\frac{1}{4}}K_{l,1}^{\frac{1}{4}}K_{l,2}^{\frac{3}{4}}K_{p,2}^{\frac{1}{4}}K_{r,2}^{\frac{1}{4}})}{((1-\alpha)\tau^{\frac{1}{2}}K_{e,2}^{\frac{1}{4}}K_{p,1}^{\frac{1}{4}}K_{r,1}^{\frac{1}{4}})} \\
K_{p,1} + \frac{K_{r,1}}{\nu(\alpha-1)} &= \frac{(\alpha\kappa^{\frac{1}{2}}K_{e,2}^{\frac{1}{4}}K_{l,2}^{\frac{1}{4}}K_{p,1}^{\frac{1}{4}}K_{p,2}^{\frac{3}{4}})}{((1-\alpha)\nu^{\frac{1}{2}}K_{l,1}^{\frac{1}{4}}K_{r,2}^{\frac{1}{4}})} \\
K_{e,2} + \frac{K_{l,2}\sigma}{(\alpha-1)} &= \frac{(\alpha(\frac{\sigma}{\nu})^{\frac{1}{2}}K_{e,2}^{\frac{1}{4}}K_{l,1}^{\frac{1}{4}}K_{l,2}^{\frac{1}{4}})}{((1-\alpha)K_{p,1}^{\frac{1}{4}}K_{p,2}^{\frac{1}{4}}K_{r,2}^{\frac{1}{4}})} \\
K_{r,2} + \frac{K_{p,2}\sigma}{(\alpha-1)} &= \frac{(\alpha\kappa^{\frac{1}{2}}K_{e,1}^{\frac{3}{4}}K_{p,1}^{\frac{1}{4}}K_{p,2}^{\frac{1}{4}}K_{r,1}^{\frac{1}{4}}K_{r,2}^{\frac{1}{4}})}{((1-\alpha)\tau^{\frac{1}{2}}K_{e,2}^{\frac{1}{4}}K_{l,1}^{\frac{1}{4}}K_{l,2}^{\frac{1}{4}})}
\end{aligned}$$

This is the first step of the definition of factor prices. For the second step we use the unit cost equation for the final good to obtain factor prices are a function of both factor price ratios and factor endowments:

$$\begin{aligned}
w_1 &= E\left(\frac{K_{p,1}}{K_{l,1}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}}(\nu\tau)^{\frac{1}{4}-\frac{\alpha}{8}} \\
p_1 &= E\left(\frac{K_{l,1}}{K_{p,1}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}}(\nu\tau)^{\frac{1}{4}-\frac{\alpha}{8}} \\
e_1 &= E\left(\frac{K_{r,1}}{K_{e,1}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}}(\nu\tau)^{-\frac{1}{4}-\frac{\alpha}{8}} \\
r_1 &= E\left(\frac{K_{e,1}}{K_{r,1}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}}(\nu\tau)^{-\frac{1}{4}-\frac{\alpha}{8}} \\
w_2 &= E\left(\frac{K_{p,2}}{K_{l,2}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}+\frac{1}{4}}(\nu\tau)^{-\frac{\alpha}{8}} \\
p_2 &= E\left(\frac{K_{l,2}}{K_{p,2}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}+\frac{1}{4}}(\nu\tau)^{-\frac{\alpha}{8}} \\
e_2 &= E\left(\frac{K_{r,2}}{K_{e,2}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}-\frac{1}{4}}(\nu\tau)^{-\frac{\alpha}{8}} \\
r_2 &= E\left(\frac{K_{e,2}}{K_{r,2}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}-\frac{1}{4}}(\nu\tau)^{-\frac{\alpha}{8}}
\end{aligned}$$

Goods prices can be deducted from the unit cost conditions:

$$\begin{aligned}
P_1 &= w_1 = E\left(\frac{K_{p,1}}{K_{l,1}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}}(\nu\tau)^{\frac{1}{4}-\frac{\alpha}{8}} \\
P_2 &= p_1 = E\left(\frac{K_{l,1}}{K_{p,1}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}}(\nu\tau)^{\frac{1}{4}-\frac{\alpha}{8}} \\
P_3 &= E\left(\frac{(\kappa\sigma)^{\frac{\alpha}{2}}}{(\nu\tau)^{\frac{\alpha}{2}}}\right)^{\frac{1}{4}} \\
P_4 &= e_2 = E\left(\frac{K_{r,2}}{K_{e,2}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}-\frac{1}{4}}(\nu\tau)^{-\frac{\alpha}{8}} \\
P_5 &= r_2 = E\left(\frac{K_{e,2}}{K_{r,2}}\right)^{\frac{1}{2}}(\kappa\sigma)^{\frac{\alpha}{8}-\frac{1}{4}}(\nu\tau)^{-\frac{\alpha}{8}}
\end{aligned}$$

To choose between the IE and CS equilibrium, a condition for factor price equalisation (FPE) must be used. To determine the FPE condition, it is better to think of the world as a single country and look for conditions that may lead to the breakdown of FPE rather than imagining how to bring FPE in a two states setting. Our

demonstration for the FPE condition is quite similar to the one in Cuñat and Maffezzoli (2004) as we also have only two countries. Consider that factor endowments in one of the two countries, starting from an equal distribution between the two countries differ from a symmetric share ε :

$$\begin{aligned} K_{l,1} &= \left(\frac{1}{2} + \varepsilon\right)K_l \\ K_{l,2} &= \left(\frac{1}{2} - \varepsilon\right)K_l \\ K_{p,1} &= \left(\frac{1}{2} + \varepsilon\right)K_p \\ K_{p,2} &= \left(\frac{1}{2} - \varepsilon\right)K_p \\ K_{e,1} &= \left(\frac{1}{2} - \varepsilon\right)K_e \\ K_{e,2} &= \left(\frac{1}{2} + \varepsilon\right)K_e \\ K_{r,1} &= \left(\frac{1}{2} - \varepsilon\right)K_r \\ K_{r,2} &= \left(\frac{1}{2} + \varepsilon\right)K_r \end{aligned}$$

With $0 < \varepsilon < \frac{1}{2}$. As there are more than two factors, no 2D diagrammatic representation is possible for the FPE set. What we are looking for is a share of capital in country 1 (and the symmetric share in country 2) for which FPE cannot occur. Assume α is the same in both countries. The total demand for factors from the optimal factor allocation is equal to $\alpha K_{l,1}$ and $\alpha K_{p,1}$ for goods y_1 and y_2 in country 1 and $\alpha K_{e,2}$ and $\alpha K_{r,2}$ for goods y_4 and y_5 in country 2. Under the production pattern identified supra, in IE goods y_1 and y_2 are only produced in country 1. Therefore, the share α of $K_{l,1}$ and $K_{p,1}$ used in country 1 are shares of the *world* stock of those factors: $\alpha K_{l,1} = \alpha K_l$ and $\alpha K_{p,1} = \alpha K_p$.

Following the same logic, $\alpha K_{e,2} = \alpha K_e$ and $\alpha K_{r,2} = \alpha K_r$. If we now focus on labour in country 1, the rest of the endowment will be used to produce good y_3 . Assume $0 < \alpha < 0.5$. Assume then that while our hypothetical country 1 is relatively well-endowed in K_l and K_p , both country 1 and country 2 are endowed with one unit of K_e and one unit of K_r ²⁵. We can then write for country 1:

$$\frac{K_{l,3}}{K_{e,3}} \left(\frac{1}{2}K_e\right) = \frac{K_l}{K_e} \left(\frac{1}{2}K_e\right) = \frac{1}{2}K_l$$

With $0 < \alpha < 0.5$, $K_{l,3}$ cannot be less than half of the total world stock. In the integrated equilibrium perspective, the local $K_{l,3}$ to $K_{e,3}$ ratio²⁶ is equal to the world ratio as the two dummy regions behave as a single world.

Adding the two allocations of K_l gives us a limit $K_1^{FPE} = \frac{1}{2}K_l + \alpha K_l = \left(\frac{1}{2} + \alpha\right)K_l$. Hence, ε can take values in the range $(0, \alpha)$, as an asymmetry in factor endowments above α would break FPE. It is straightforward to show that the same limit holds for $K_{p,1}$ and with respect to the same factors K_e and K_r . Similarly, a condition in terms of country 2 comparative advantage could be found based on $K_{e,2}$ or $K_{r,2}$ with respect to K_l and K_p . Therefore, FPE breaks down in our case when *any* of the conditions is broken.

²⁵This would arguably destroy the incentive for trade in a HO setting as country 2 has now no comparative advantage. For the sake of the counterfactual we are presenting here, it is better to think in terms of the breakdown of a country into two regions rather than in terms of convergence by trade.

²⁶The demonstration can be conducted with K_r instead of K_e as the shares are the same by symmetry.

A.3 Recursive equilibrium for the dynamic model

The four wealth instruments dynamics are the basis for the recursive competitive equilibrium of the dynamic model. The model is based on a representative consumer in both countries, maximising utility:

$$U_{j,t} = \sum_{s=t}^{\infty} \beta^{s-t} \ln c_{j,t}$$

Where utility in t $U_{j,t}$ is the sum of discounted consumption flows $c_{j,s}$ over an infinite number of periods, so that t goes to ∞ from the present period s . Utility is maximised subject to the budget constraint:

$$\begin{aligned} & w_{j,t}K_{l,j,t} + p_{j,t}K_{p,j,t} + e_{j,t}K_{e,j,t} + r_{j,t}K_{r,j,t} \\ & = c_{j,t} + K_{p,j,t+1} - K_{p,j,t} + \delta K_{p,j,t} + xK_{e,j,t} - \rho K_{r,j,t} \end{aligned}$$

under the structural change (SC) scenario. The constraint is the same in both countries. To solve this system we consider three endowments to be exogenous (K_l, K_e and K_r) so that our representative agents in both countries only choose a value for $c_{j,t}$ and $K_{p,j,t}$. We rearrange the budget constraint to isolate $c_{j,t}$:

$$\begin{aligned} c_{j,t} & = w_{j,t}K_{l,j,t} + p_{j,t}K_{p,j,t} + e_{j,t}K_{e,j,t} + r_{j,t}K_{r,j,t} \\ & \quad - K_{p,j,t+1} + K_{p,j,t} - \delta K_{p,j,t} - xK_{e,j,t} + \rho K_{r,j,t} \end{aligned}$$

We can then substitute the constraint into the utility function. We can then derive the utility function with respect to produced capital in $t+1$:

$$\frac{\partial U_{j,t}}{\partial K_{p,j,t+1}} = 0 \iff \frac{-1}{c_{j,t}} + \beta \frac{1}{c_{j,t+1}} (1 - \delta + p_{j,t}) = 0$$

Which gives us the first equation of motion:

$$c_{j,t+1} = \beta c_{j,t} (1 - \delta + p_{j,t})$$

This first equation of motion can then be used to obtain the steady-state value. In steady-state, consumption is constant over time, so that $c_{j,t+1} = c_{j,t}$. The first equation of motion becomes:

$$\frac{1}{\beta} = 1 + p_{j,t} - \delta$$

Under the comparative advantage (CA) scenario, the budget constraint changes for country 2 :

$$\begin{aligned} & w_{2,t}K_{l,2,t} + p_{2,t}K_{p,2,t} + e_{2,t}K_{e,2,t} + r_{2,t}K_{r,2,t} \\ & = c_{2,t} + K_{r,2,t+1} - K_{r,2,t} - \rho K_{r,2,t} + \delta K_{p,2,t} + xK_{e,2,t} \end{aligned}$$

So that the same procedure yields a slightly modified equation of motion:

$$c_{2,t+1} = \beta c_{2,t} (1 + \rho + r_{2,t})$$

A.4 Shock calibration

To calibrate shocks, we use the data on comprehensive wealth. We use 2000 as the reference year since we based our decomposition of intangible capital on it. For the shocks on labour, we look at the sample of countries under FPE in 2000 and we take those with a northern specialisation. This is a sample of 16 countries²⁷. We then compute the variation for the same countries in 2005. The data exhibits strong cross country variations,

²⁷It is interesting to note that the same criteria yields the exact same sample size for 2005, but only 4 countries are left from 2000.

for an average increase in labour of 10%. This figure is subject to the strong assumptions we made earlier regarding the decomposition of intangible capital. We use this number as the order of magnitude, increasing or decreasing the exogenous labour endowment by 10% over 30 periods. We take this value of 30 periods since it is the third of the period required for the bulk of the adjustment in the transitional dynamics.

Scenario 3 and 4 require a similar magnitude for the non renewable component of natural capital. We use a similar method taking (as in those scenarios the economy converges towards low asymmetry) the evolution between 2000 and 2005 of exhaustible non renewable resources in countries with a country 2 specialisation without FPE. This yields a sample of 30 countries²⁸, shortened to 13 to remove the zeros and aberrant values. The average variation is this time 23%, which we take as our shock value, spread over 30 periods.

Once calibrated, shocks are applied to the associated transitional dynamics. Scenario 1 translate into an increase in asymmetry for country 1, and a consequences is imposed from the low asymmetry-equilibrium towards the high asymmetry one.

A.5 Robustness checks tables

²⁸The 2005 sample is composed of 28 countries and the two samples have 18 common values, suggesting more stability in country-two specialisation without FPE.

Table 6: Stressed values for α in the CS model

Robustness checks	benchmark $\alpha=0,15$		$\alpha=0,45$		$\alpha=0,1$		variation for $\alpha=0,45$		variation for $\alpha=0,1$	
	k=1,19	k=1,75	k=1,19	k=1,75	k=1,19	k=1,75	k=1,19	k=1,75	k=1,19	k=1,75
c	0,678886	0,523022	0,45081	0,427085	0,775291	0,578217	-33,60%	-18,34%	14,20%	10,55%
W	8,03315	7,52359	7,3624	7,1344	8,31356	7,70168	-8,35%	-5,17%	3,49%	2,37%
Y	0,798345	0,620061	0,540755	0,506999	0,907088	0,683091	-82,27%	-18,23%	13,62%	10,17%
K_p	2,03315	1,52359	1,3624	1,1344	2,31356	1,70168	-32,99%	-25,54%	13,79%	11,69%
K_l	2	2	2	2	2	2	0,00%	0,00%	0,00%	0,00%
K_e	2	2	2	2	2	2	0,00%	0,00%	0,00%	0,00%
K_r	2	2	2	2	2	2	0,00%	0,00%	0,00%	0,00%
c_1	0,330835	0,196335	0,232055	0,173431	0,373277	0,212587	-29,86%	-11,67%	12,83%	8,28%
c_2	0,348051	0,326688	0,218755	0,253654	0,402014	0,36563	-37,15%	-22,36%	15,50%	11,92%
W_1	3,97036	2,95555	3,85928	3,04965	4,05121	2,96943	-2,80%	3,18%	2,04%	0,47%
W_2	4,06279	4,56804	3,50312	4,08475	4,26235	4,73225	-13,78%	-10,58%	4,91%	3,59%
Y_1	0,394041	0,231129	0,290373	0,212365	0,44004	0,247992	-26,31%	-8,12%	11,67%	7,30%
Y_2	0,404304	0,388932	0,250382	0,294633	0,467048	0,435098	-38,07%	-24,25%	15,52%	11,87%
$K_{p,1}$	1,16036	0,705551	1,04928	0,799647	1,24121	0,719432	-9,57%	13,34%	6,97%	1,97%
w_1	0,0953063	0,0394064	0,0861823	0,0446618	0,101947	0,0401816	-9,57%	13,34%	6,97%	1,97%
p_1	0,0977408	0,0977408	0,0977408	0,0977408	0,0977408	0,0977408	0,00%	0,00%	0,00%	0,00%
e_1	0,103217	0,186413	0,052629	0,112098	0,121856	0,214713	-49,01%	-39,87%	18,06%	15,18%
r_1	0,103217	0,186413	0,052629	0,112098	0,121856	0,214713	-49,01%	-39,87%	18,06%	15,18%
$K_{p,2}$	0,872793	0,818043	0,313122	0,33475	1,07235	0,982247	-64,12%	-59,08%	22,86%	20,07%
w_2	0,105318	0,319825	0,0377837	0,130875	0,129398	0,384022	-64,12%	-59,08%	22,86%	20,07%
p_2	0,0977408	0,0977408	0,0977408	0,0977408	0,0977408	0,0977408	0,00%	0,00%	0,00%	0,00%
e_2	0,0981887	0,0654341	0,0794844	0,0654845	0,108161	0,0694535	-19,05%	0,08%	10,16%	6,14%
r_2	0,0981887	0,0654341	0,0794844	0,0654845	0,108161	0,0694535	-19,05%	0,08%	10,16%	6,14%

Table 7: Stressed values for α in the IE model

Robustness checks	benchmark $\alpha=0,15$	$\alpha=0,45$	$\alpha=0,1$	variation for $\alpha=0,45$	variation for $\alpha=0,1$
c	0,68	0,4684	0,7787	-31,12%	14,52%
W	8,0464	7,4365	8,3309	-7,58%	3,54%
Y	0,8001	0,5616	0,9113	-29,81%	13,90%
K_p	2,0464	1,4365	2,3309	-29,81%	13,90%
K_l	2	2	2	0,00%	0,00%
K_e	2	2	2	0,00%	0,00%
K_r	2	2	2	0,00%	0,00%
c_1	0,34	0,2342	0,3894	-31,12%	14,52%
c_2	0,34	0,2342	0,3894	-31,12%	14,52%
W_1	4,1338	3,7234	4,3252	-9,93%	4,63%
W_2	3,9126	3,7131	4,0058	-5,10%	2,38%
Y_1	0,4104	0,2865	0,4682	-30,18%	14,08%
Y_2	0,3897	0,2751	0,4431	-29,41%	13,72%
$K_{p,1}$	1,3238	0,9134	1,5152	-31,00%	14,46%
w	0,1	0,0702	0,1139	-29,81%	13,90%
p	0,0977	0,0977	0,0977	0,00%	0,00%
e	0,1	0,0702	0,1139	-29,81%	13,90%
r	0,1	0,0702	0,1139	-29,81%	13,90%
$K_{p,2}$	0,7226	0,5231	0,8158	-27,62%	12,88%

Table 8: Stressed values for Φ in the CS model

Robustness checks	benchmark $\Phi=0,607$		$\Phi=0,7$		$\Phi=0,4$		variation for $\Phi=0,7$		variation for $\Phi=0,4$	
	k=1,19	k=1,75	k=1,19	k=1,75	k=1,19	k=1,75	k=1,19	k=1,75	k=1,19	k=1,75
c	0,678886	0,523022	0,827279	0,638788	0,37651	0,28713	21,86%	22,13%	-44,54%	-45,10%
W	8,03315	7,52359	8,45876	7,84253	7,16591	6,8737	5,30%	4,24%	-10,80%	-8,64%
Y	0,798345	0,620061	0,965465	0,749859	0,45781	0,355573	20,93%	20,93%	-42,66%	-42,66%
K_p	2,03315	1,52359	2,45876	1,84253	1,16591	0,873704	20,93%	20,93%	-42,65%	-42,65%
K_l	2	2	2	2	2	2	0,00%	0,00%	0,00%	0,00%
K_e	2	2	2	2	2	2	0,00%	0,00%	0,00%	0,00%
K_r	2	2	2	2	2	2	0,00%	0,00%	0,00%	0,00%
c_1	0,330835	0,196335	0,402633	0,238219	0,184534	0,110988	21,70%	21,33%	-44,22%	-43,47%
c_2	0,348051	0,326688	0,424646	0,400569	0,191976	0,176142	22,01%	22,62%	-44,84%	-46,08%
W_1	3,97036	2,95555	4,21326	3,10325	3,47541	2,6546	6,12%	5,00%	-12,47%	-10,18%
W_2	4,06279	4,56804	4,2455	4,73928	3,6905	4,21911	4,50%	3,75%	-9,16%	-7,64%
Y_1	0,394041	0,231129	0,476526	0,279512	0,225962	0,132541	20,93%	20,93%	-42,66%	-42,65%
Y_2	0,404304	0,388932	0,488938	0,470347	0,231848	0,223033	20,93%	20,93%	-42,66%	-42,66%
$K_{p,1}$	1,16036	0,705551	1,40326	0,853246	0,665408	0,404598	20,93%	20,93%	-42,66%	-42,66%
w_1	0,0953063	0,0394064	0,115257	0,0476554	0,0546534	0,0225976	20,93%	20,93%	-42,65%	-42,66%
p_1	0,0977408	0,0977408	0,0977408	0,0977408	0,0977408	0,0977408	0,00%	0,00%	0,00%	0,00%
e_1	0,103217	0,186413	0,124824	0,225436	0,0591898	0,106899	20,93%	20,93%	-42,65%	-42,65%
τ_1	0,103217	0,186413	0,124824	0,225436	0,0591898	0,106899	20,93%	20,93%	-42,65%	-42,65%
$K_{p,2}$	0,872793	0,818043	1,0555	0,989284	0,500502	0,469106	20,93%	20,93%	-42,66%	-42,66%
w_2	0,105318	0,319825	0,127364	0,386774	0,0603944	0,183403	20,93%	20,93%	-42,66%	-42,66%
p_2	0,0977408	0,0977408	0,0977408	0,0977408	0,0977408	0,0977408	0,00%	0,00%	0,00%	0,00%
e_2	0,0981887	0,0654341	0,118743	0,0791315	0,0563063	0,0375231	20,93%	20,93%	-42,66%	-42,66%
τ_2	0,0981887	0,0654341	0,118743	0,0791315	0,0563063	0,0375231	20,93%	20,93%	-42,66%	-42,66%

Table 9: Stressed values for Φ in the IE model

Robustness checks	benchmark $\Phi=0,607$	$\Phi=0,7$	$\Phi=0,4$	variation for $\Phi=0,7$	variation for $\Phi=0,4$
	k=1,19	k=1,19	k=1,19	k=1,19	k=1,19
c	0,6789	0,8287	0,3772	22,06%	-44,44%
W	8,0332	8,4748	7,1735	5,50%	-10,70%
Y	0,7983	0,9676	0,4588	21,19%	-42,53%
K_p	2,0332	2,4748	1,1735	21,72%	-42,28%
K_l	2	2	2	0,00%	0,00%
K_e	2	2	2	0,00%	0,00%
K_r	2	2	2	0,00%	0,00%
c_1	0,3308	0,4143	0,1886	25,24%	-43,00%
c_2	0,3481	0,4143	0,1886	19,04%	-45,82%
W_1	3,9704	4,422	3,5466	11,37%	-10,67%
W_2	4,0628	4,0528	3,627	-0,24%	-10,73%
Y_1	0,394	0,4974	0,2331	26,23%	-40,83%
Y_2	0,4043	0,4701	0,2257	16,29%	-44,19%
$K_{p,1}$	1,1604	1,612	0,7365	38,92%	-36,52%
w	0,0953	0,1209	0,0574	26,90%	-39,83%
p	0,0977	0,0977	0,0977	0,00%	0,00%
e	0,1032	0,1209	0,0574	17,17%	-44,44%
r	0,1032	0,1209	0,0574	17,17%	-44,44%
$K_{p,2}$	0,8728	0,8628	0,437	-1,14%	-49,94%

Table 10: Stressed values for Φ in the autarky model

Robustness checks	benchmark $\Phi=0,607$		$\Phi=0,7$		$\Phi=0,4$		variation for $\Phi=0,7$		variation for $\Phi=0,4$	
	k=1,19	k=1,75	k=1,19	k=1,75	k=1,19	k=1,75	k=1,19	k=1,75	k=1,19	k=1,75
c	0,678886	0,523022	1,45423	1,02084	0,673806	0,468293	114,21%	95,18%	-0,75%	-
										10,46%
W	8,03315	7,52359	10,2777	9,02867	8,02847	7,43615	27,94%	20,00%	-0,06%	-1,16%
Y	0,798345	0,620061	1,67245	1,1841	0,793059	0,561484	109,49%	90,97%	-0,66%	-9,45%
K_p	2,03315	1,52359	4,27771	3,02867	2,02847	1,43615	110,40%	98,79%	-0,23%	-5,74%
K_l	2	2	2	2	2	2	0,00%	0,00%	0,00%	0,00%
K_e	2	2	2	2	2	2	0,00%	0,00%	0,00%	0,00%
K_r	2	2	2	2	2	2	0,00%	0,00%	0,00%	0,00%
c_1	0,330835	0,196335	0,682454	0,357	0,317222	0,167312	106,28%	81,83%	-4,11%	-
										14,78%
c_2	0,348051	0,326688	0,771777	0,663839	0,356584	0,300981	121,74%	103,20%	2,45%	-7,87%
W_1	3,97036	2,95555	4,81194	3,28973	3,7593	2,74303	21,20%	11,31%	-5,32%	-7,19%
W_2	4,06279	4,56804	5,46577	5,73894	4,26918	4,69313	34,53%	25,63%	5,08%	2,74%
Y_1	0,394041	0,231129	0,78269	0,406496	0,371142	0,192756	98,63%	75,87%	-5,81%	-
										16,60%
Y_2	0,404304	0,388932	0,889761	0,777602	0,421918	0,368728	120,07%	99,93%	4,36%	-5,19%
$K_{p,1}$	1,16036	0,705551	2,00194	1,03973	0,949298	0,493027	72,53%	47,36%	-	-
									18,19%	30,12%
w_1	0,0953063	0,0394064	0,164431	0,0580711	0,077971	0,0275365	72,53%	47,36%	-	-
									18,19%	30,12%
p_1	0,0977408	0,0977408	0,0977416	0,0977403	0,0977408	0,0977408	0,00%	0,00%	0,00%	0,00%
e_1	0,103217	0,186413	0,241571	0,406498	0,11455	0,192756	134,04%	118,06%	10,98%	3,40%
r_1	0,103217	0,186413	0,241571	0,406498	0,11455	0,192756	134,04%	118,06%	10,98%	3,40%
$K_{p,2}$	0,872793	0,818043	2,27577	1,98894	1,07918	0,943127	160,75%	143,13%	23,65%	15,29%
w_2	0,105318	0,319825	0,27462	0,777602	0,130221	0,368728	160,75%	143,13%	23,65%	15,29%
p_2	0,0977408	0,0977408	0,0977408	0,0977408	0,0977408	0,0977408	0,00%	0,00%	0,00%	0,00%
e_2	0,0981887	0,0654341	0,186926	0,111086	0,0886382	0,0526755	90,37%	69,77%	-9,73%	-
										19,50%
r_2	0,0981887	0,0654341	0,186926	0,111086	0,0886382	0,0526755	90,37%	69,77%	-9,73%	-
										19,50%